International Journal of Plant & Soil Science

Volume 37, Issue 1, Page 355-366, 2025; Article no. IJPSS.128234
ISSN: 2320-7035

Bee Forage Tree Resources for Wild Honeybees: A Case Study from Kodagu's Sacred Groves and Coffee Agroecosystems

Akash Sangappa Neelagund [a], R. N. Kencharaddi [a*], Chandrashekar S. Y [b], K. S. Anantha Krishna [b] and Hareesh T.S [a]

[a] *College of Forestry, Ponnampet, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, 571216, India.*
[b] *College of Agricultural Sciences, Iruvakki, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, 577412, India.*

Authors' contributions

This work was carried out in collaboration among all authors. Author ASN conducted the research, collected the data and wrote the manuscript. Authors RNK, KSAK, CSY and HTS contributed to the data analysis and proofread the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i15277

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/128234

Original Research Article

Received: 24/10/2024
Accepted: 27/12/2024
Published: 25/01/2025

**Corresponding author: E-mail: rnkencharaddi@uahs.edu.in;*

Cite as: *Neelagund, Akash Sangappa, R. N. Kencharaddi, Chandrashekar S. Y, K. S. Anantha Krishna, and Hareesh T.S. 2025. "Bee Forage Tree Resources for Wild Honeybees: A Case Study from Kodagu's Sacred Groves and Coffee Agroecosystems". International Journal of Plant & Soil Science 37 (1):355-66. https://doi.org/10.9734/ijpss/2025/v37i15277.*

ABSTRACT

Wild honeybee populations are fundamental to biodiversity conservation and agricultural productivity, particularly as pollinators in tropical regions. This study investigated the diversity and seasonal availability of bee forage trees within sacred groves and coffee agro ecosystems in Kodagu, Karnataka, a biodiversity-rich area in the Western Ghats. Sacred groves, protected for cultural reasons, feature high floral diversity, providing continuous nectar and pollen resources, crucial for wild bee populations throughout the year. In contrast, coffee plantations, particularly in semi-evergreen systems, offer valuable yet seasonally limited forage, supplemented by selective native tree retention. By integrating traditional ecological knowledge associated with sacred groves and modern conservation practices, the research highlights how culturally protected landscapes contribute to year-round floral resources, crucial for sustaining wild bee populations. Sacred groves were found to consistently surpass coffee plantations in floral diversity and forage stability, particularly in semi-evergreen groves, which recorded the highest diversity and richness (H' = 3.75, 52 species). In contrast, coffee plantations, enhanced by selective retention of native trees, offer seasonally valuable but limited forage, with moderate diversity (H' = 3.35, 54 species). The study identifies key forage species unique to sacred groves and underscores their role in maintaining ecological resilience. These findings have practical implications for guiding community-based conservation programs, demonstrating that leveraging sacred groves and ecologically managed coffee agroecosystems can effectively balance biodiversity conservation with agricultural productivity. This integrated approach offers a model for sustaining pollinator populations vital to ecosystem health and crop yields.

Keywords: Bee forage resources; biodiversity conservation; pollinator diversity; floral resources.

1. INTRODUCTION

Bee forage resources are essential for wild honeybee populations, crucial players in pollination and biodiversity conservation. The survival and productivity of wild bees rely heavily on access to diverse floral resources, as the abundance and variety of forage significantly affect both their population size and species diversity in agricultural landscapes (Roulston and Goodell, 2011). Ensuring continuous forage availability across seasons is thus vital, with resources typically shifting from woody vegetation in spring to herbaceous plants later on (Ammann et al., 2024). Increased availability of floral resources correlates with greater bee species richness and abundance, supporting not only common pollinators but also rare species and essential crop pollinators (Maurer et al., 2022; Ammann et al., 2024). Effective conservation must prioritize diverse habitats that provide complementary resources to enhance bee diversity both locally and across landscapes (Casanelles-Abella et al., 2022).

In Kodagu, Karnataka, traditional land-use practices like the careful maintenance of sacred groves and diverse coffee agro ecosystems support honeybee populations and preserve biodiversity (Bhagwat et al., 2005). Sacred groves, held in cultural and spiritual reverence, are biodiversity hotspots that offer year-round nectar and pollen from a wide array of flowering plants, crucial for bee populations. Local communities protect these groves, serving as sanctuaries for countless endemic, rare, and endangered species, and creating a consistent, life-sustaining forage supply for bees (Bhagwat and Rutte, 2006). The untouched vegetation within these groves features a variety of tree species, shrubs, and understory plants, resulting in high species diversity and functioning as refuges for many pollinators (Sharma and Devi, 2014). Compared to managed landscapes, sacred groves provide a stable and diverse floral environment, supporting a broad array of bee species, including resilient wild honeybees that aid in pollinating natural and agricultural landscapes (Mondal and Mondal, 2024).

Kodagu's coffee agro ecosystems are similarly vital to supporting pollinator diversity due to their integration with native tree species. Unlike intensive monocultures, these agro forestry systems maintain a complex structure, fostering a habitat rich in wild bees and other pollinators. This ecological setup not only enhances biodiversity but also improves coffee yield and quality (Parida et al., 2023; Singh et al., 2024). The heterogeneous environment created by native trees within coffee plantations provides varied habitats for pollinators, including essential floral resources during the coffee bloom, which is vital for sustaining bee populations (Depecker et al., 2024). Such structural complexity is particularly valuable for bee forage, supporting robust pollinator communities and thus contributing to the ecological and economic resilience of coffee farming systems (Silva et al., 2024). Wild bee pollination significantly boosts coffee yield and quality, with direct economic benefits for farmers (Machado et al., 2024). The conservation of native vegetation around these plantations is therefore crucial for maintaining pollinator populations and enhancing productivity (Koutouleas et al., 2024). However, agro forestry systems may not fully replicate the pollinator conservation potential found in natural forests, underscoring the importance of selecting optimal species for intercropping to maximize biodiversity (Depecker et al., 2024).

The importance of wild honeybees in Kodagu is essential for encouraging agricultural productivity, especially within coffee plantations. But, wild honeybee populations in Kodagu face threats from habitat loss, climate change and urbanization. Deforestation and agricultural expansion reduce floral diversity, a cornerstone of honeybee nutrition and health, while habitat fragmentation limits their access to diverse forage, affecting colony resilience and pollination efficacy (Dequenne et al., 2022; Krishnan et al., 2017). Climate change further disrupts floral availability by altering bloom periods and durations, causing seasonal gaps in forage. This can result in unsynchronized flowering in coffee plants, reducing pollinator visits and potentially decreasing seed set and yield (Boreux et al., 2013). Integrating honeybees within coffee plantations enhances honey production and yield, supporting farmer income and sustainable practices (Saepudin, 2014). Studies show that pollination can increase coffee yields by over 50%, highlighting the critical role wild honeybees play in both agricultural productivity and ecosystem sustainability (Roubik, 2002).

This study explores the diversity and seasonal availability of bee forage tree resources in Kodagu’s sacred groves and coffee agro ecosystems, identifying key forage species sustaining wild honeybee populations year-round. The findings emphasized the need for balanced conservation strategies that support biodiversity and agricultural resilience in Kodagu’s landscapes.

2. MATERIALS AND METHODS

2.1 Study Sites

This study was conducted in the Kodagu district of Karnataka, situated in the Western Ghats, a globally recognized biodiversity hotspot, covering an area of 4,102 square kilometers between 11°56'–12°15' N latitude and 75°22'–76°14' E longitude, Kodagu is renowned for its rich diversity of flowering plants. Research sites were selected from six locations, encompassing three sacred groves (SG) and three coffee plantations (CP), which represent three distinct forest ecosystems: evergreen (EG), semi-evergreen (SEG), and moist deciduous (MD).

2.2 Bee Forage Plant Resources

At each study site, observations on the diversity, abundance and richness of bee forage trees were recorded. This assessment involved surveying trees within a circular transect of 100 meters in radius. Five subplots, each measuring 20 m × 20 m, were set up within the transect—one at the center and four positioned in different directions—to evaluate tree species. Only trees used as forage sources by bees were included in the calculation of forage plant indices. A tree was classified as a bee forage source if it received at least one bee visit during observations. Bee visitations on tall trees were recorded using Binocular (SUPER ZENITH-7×50, 5x) with each of the flowering plant being observed for 10 minutes (Fig. 1). Samples of certain forage trees that could not be identified in the field were collected for identification and sent to botanists at Jnana Bharathi, Bangalore University, with additional reference from the ‘www.flowersofindia.net’ website. Forest tree species were identified at the College of Forestry, Ponnampet. The diversity, richness, and abundance of forage trees were analyzed using standard vegetation analysis methods for forest ecosystems. Observations of bee forage trees were recorded monthly from November 2023 to May 2024. The floristic diversity and abundance of bee forage plants were evaluated by calculating plant diversity indices, including the Shannon-Wiener Index (H'), Simpson's Diversity Index (D), and species evenness. The Shannon–Wiener index is a measure of diversity that reflects the degree of uncertainty in predicting the species identity of an individual randomly selected from a collection. This uncertainty increases with both the number of species (S) and the evenness of their distribution. The index (H’) is calculated using the formula:

$$\text{Shannon – Wieners' index (H')} = -\sum_{i=1}^{s}\left(\frac{ni}{N}\right)\ln\left(\frac{ni}{N}\right)$$

Where:

ni= Number of pollen grains belonging to the ith species
N=Total number of pollen grains in the sample
S =No. of species

An H’ value of 0 indicates no diversity, where all individuals belong to a single species. Conversely, a higher H’ value reflects greater diversity, particularly when individuals are evenly distributed among species. This index not only captures the number of species but also provides insights into the distribution of abundance among forage species in an ecosystem.

Simpson’s index of diversity, derived from Simpson’s dominance index, provides an alternative measure of biodiversity by emphasizing the likelihood that two randomly chosen individuals represent different species. It is expressed as:

$$\text{Simpson's dominance index (D)} = \sum\frac{\mathrm{n(n-1)}}{\mathrm{N(N-1)}}$$

Species evenness measures the relative abundance and distribution of species within a sample. Evenness values range from 0 to 1, where 1 represents complete evenness in the distribution of species.

$$\text{Species evenness (E)} = \frac{\mathrm{H'}}{\ln\text{(S)}}$$

Where:

H'= Shannon’s diversity index
S = Species richness

3. RESULTS AND DISCUSSION

The assessment of species diversity, richness, and evenness across various ecosystems consistently showed that sacred groves outperform coffee plantations in these ecological metrics. Within the semi-evergreen ecosystem, sacred groves display the highest species diversity (H' = 3.75) and richness (52 species), while sacred groves in the moist deciduous ecosystem exhibit the highest species evenness (E = 0.96), despite having lower diversity and richness (Table 1). In terms of diversity and richness, semi-evergreen sacred groves exhibit values of H' = 3.75 with 52 species, moist deciduous sacred groves have H' = 3.48 with 37 species, and evergreen sacred groves record H' = 3.60 with 43 species. In comparison, coffee plantations demonstrate slightly lower diversity and richness, with semi-evergreen coffee plantations showing H' = 3.35 and 54 species, moist deciduous plantations with H' = 2.95 and 24 species, and evergreen plantations with H' = 3.19 and 30 species. Sacred groves also show high species evenness, particularly in moist deciduous and evergreen ecosystems, both scoring E = 0.96. By contrast, coffee plantations display lower evenness, particularly within the moist deciduous ecosystem (E = 0.92) (Tables 1, 2, 3 and 4).

Sacred groves in semi-evergreen ecosystems exhibited the highest species tree forage diversity (H’=3.75, D=0.02), richness (52 species) and evenness (E=0.95) (Table 2). The stable environmental conditions and cultural protection associated with these groves significantly enhance biodiversity. Sacred groves are tracts of virgin forest protected by local communities for cultural and religious reasons, serving as crucial biodiversity reservoirs (Khan et al., 2008). These groves harbor numerous endemic, rare, and endangered species, often including plants not found in surrounding forests (Prasad et al., 2010). Functioning similarly to formal protected areas, they support diverse communities of trees, birds and macro fungi, with some species being exclusive to these locations (Bhagwat et al., 2005). However, these biodiversity hotspots face increasing threats from anthropogenic activities, emphasizing the urgent need for conservation efforts to protect these unique ecosystems (Kulkarni et al., 2018). Coffee plantations in these ecosystems also displayed relatively high diversity (H’=3.35, D=0.02) and richness (51 species) (Table 3), primarily due to rustic coffee systems that retain native forest canopies (Philpott et al., 2008). However, diversity in coffee plantations was lower than in sacred groves, as selective management practices prioritize economically valuable species.

The findings regarding species diversity and richness in sacred groves and evergreen coffee plantations highlight the significant role of stable environmental conditions in fostering biodiversity (Tables 4 and 5). Sacred groves exhibit moderate species diversity (H'=3.60, D=0.02) and richness (43 species), attributed to stable humidity and temperature, which promote even distribution among species (Rathore, 2024; Ahmed et al., 2023). In contrast, semi-evergreen ecosystems show slightly lower diversity due to the competitive dominance of certain tree species (Rathore, 2024). These findings are in line with Deepanshu and Manju (2021). However, slightly lower diversity compared to semi-evergreen ecosystems may be due to the dominance of certain tree species that effectively compete for resources. Evergreen coffee plantations similarly exhibited moderate levels of diversity and richness (28 species), along with notable species evenness, likely resulting from stable environmental conditions and selective tree retention practices that help preserve biodiversity. Factors such as altitude, soil characteristics, and management practices affect biodiversity patterns in these ecosystems (Tankou et al., 2014). The integration of informal protected areas like sacred groves with formal conservation strategies is crucial for maintaining biodiversity in regions where cultivated landscapes surround formal reserves (Bhagwat et al., 2005).

Fig. 1. (a) Observing foraging bees using binoculars; (b) Recording bee visitation observations

Table 1. Floristic diversity indices for trees under different land uses and ecosystems

Sl. No.	Floristic diversity indices	Evergreen ecosystem		Semi-evergreen ecosystem		Moist deciduous ecosystem	
		SG	CP	SG	CP	SG	CP
1	Shannon – Wieners' index (H')	3.60	3.19	3.75	3.35	3.48	2.95
2	Simpson's dominance index (D)	0.02	0.03	0.02	0.02	0.02	0.04
3	Species richness (S)	43	30	52	54	37	24
4	Species evenness €	0.96	0.94	0.95	0.89	0.96	0.92

SG- Sacred grove; CP-Coffee plantation

Table 2. Details of bee forage trees recorded in sacred groves of semi-evergreen ecosystem

Sl. No.	Scientific name	Family	Flowering period	Source
1	*Acrocarpus fraxinifolius*	Caesalpiniaceae	Feb-March	N
2	*Acronychia pedunculata*	Rutaceae	Feb-April	NP
3	*Actinodaphne hookeri*	Lauraceae	April-May	NP

Sl. No.	Scientific name	Family	Flowering period	Source
4	*Actinodaphne malabarica*	Lauraceae	Dec-Feb	NP
5	*Adina cordifolia*	Rubiaceae	May-Aug	NP
6	*Aglaia barberi*	Meliaceae	Dec-june	P
7	*Ailanthus triphysa*	Simaroubaceae	April-June	N
8	*Alstonia scholaris*	Apocynaceae	Feb-March	NP
9	*Antidesma menasu*	Euphorbiaceae	Dec-Jan	P
10	*Aphananthe cuspidata*	Cannabaceae	Jan-March	P
11	*Apodytes dimidiate*	Icacinaceae	April-Oct	NP
12	*Aporosa lindleyana*	Euphorbiaceae	Dec-June	N
13	*Atalantia racemosa*	Rutaceae	Nov-Dec	N
14	*Atalantia wightii*	Rutaceae	March-May	P
15	*Bischofia javanica*	Euphorbiaceae	Jan – Aug	NP
16	*Bridelia retusa*	Phyllanthaceae	March-May	N
17	*Callicarpa tomentosa*	Verbenaceae	Aug-Nov	NP
18	*Canarium strictum*	Burseraceae	Feb-April	NP
19	*Canthium dicoccum*	Rubiaceae	Nov-Jan	N
20	*Carallia brachiata*	Rhizophoraceae	Feb-Oct	N
21	*Caryota urens*	Arecaceae	Jan-July	NP
22	*Casearia ovata*	Flacourtiaceae	March-May	N
23	*Cassia spectabilis*	Caesalpiniaceae	Oct-Dec	P
24	*Celtis tetrandra*	Cannabaceae	March-May	N
25	*Chukrasiatabularis*	Meliaceae	Feb-July	NP
26	*Cinnamomum malabatrum*	Lauraceae	March-April	NP
27	*Coffea arabica*	Rubiaceae	March-April	N
28	*Dillenia pentagyna*	Dilleniaceae	Jan-May	NP
29	*Dimocarpus longan*	Sapindaceae	March-May	NP
30	*Diospyros ebenum*	Ebenaceae	April-May	N
31	*Eucalyptus sp*	Myrtaceae	Nov-April	NP
32	*Homalium zeylanicum*	Flacourtiaceae	May-June	N
33	*Hydnocarpus pentandra*	Flacourtiaceae	Feb-March	NP
34	*Mallotus philippensis*	Bignoniaceae	Aug-Nov	P
35	*Mesua ferrea*	Calophyllaceae	March-May	NP
36	*Palaquium ellipticum*	Sapotaceae	Feb-July	NP
37	*Persea macrantha*	Lauraceae	Jan-March	N
38	*Phyllanthus emblica*	Phyllanthaceae	Dec-May	NP
39	*Pongamia pinnata*	Fabaceae	March-May	NP
40	*Prunus ceylanica*	Rosaceae	Jan-Dec	P
41	*Sageraea laurifolia*	Annonaceae	Nov-Dec	N
42	*Sapindus emarginatus*	Sapindaceae	Dec-Jan	NP
43	*Syzygium hemisphericum*	Myrtaceae	March-May	NP
44	*Syzygium jambos*	Myrtaceae	March-April	NP
45	*Tamarindus indica*	Caesalpiniaceae	April-May	N
46	*Terminalia bellirica*	Combretaceae	Feb-March	N
47	*Terminalia paniculata*	Combretaceae	Jan-March	NP
48	*Toona ciliata*	Meliaceae	Dec-March	N
49	*Trichilia connaroides*	Meliaceae	Feb-March	NP
50	*Vateria indica*	Dipterocarpaceae	Jan-April	NP
51	*Vitex negundo*	Lamiaceae	Sep-Nov	NP
52	*Ziziphus rugosa*	Cannabaceae	April-Oct	N

Note: N- Nectar, P- Pollen and NP-Both Nectar and Pollen

Table 3. Details of bee forage trees recorded in coffee plantations of semi-evergreen ecosystem

Sl. No.	Scientific name	Family	Flowering period	Source
1	*Acacia auriculiformis*	Mimosoideae	June-July	NP
2	*Acacia mangium*	Mimosoideae	May-June	N
3	*Acrocarpus fraxinifolius*	Caesalpinioideae	Feb-March	N
4	*Acronychia pedunculata*	Rutaceae	Feb-April	NP
5	*Actinodaphne malabarica*	Lauraceae	Dec-Feb	NP
6	*Anacardium occidentale*	Anacardiaceae	Dec-March	NP
7	*Antidesma menasu*	Euphorbiaceae	Dec-Jan	P

Sl. No.	Scientific name	Family	Flowering period	Source
8	*Aphananthe cuspidata*	Ulmaceae	Jan-March	P
9	*Aporosa lindleyana*	Euphorbiaceae	Dec-June	N
10	*Bischofia javanica*	Phyllanthaceae	Sep-Nov	N
11	*Bixa orellana*	Bixaceae	Nov-Jan	P
12	*Callicarpa tomentosa*	Verbenaceae	Aug-Nov	NP
13	*Careya arborea*	Lecythidaceae	Feb-March	NP
14	*Caryota urens*	Arecaceae	Throughout the year	NP
15	*Casearia ovata*	Flacourtiaceae	March-May	N
16	*Canthium dicoccum*	Rubiaceae	Nov-Jan	P
17	*Celtis tetrandra*	Ulmaceae	Feb-April	NP
18	*Chionanthus malabarica*	Oleaceae	Jan-March	NP
19	*Cinnamomum malabatrum*	Lauraceae	Jan-March	NP
20	*Cythroxylon quadrangularis*	Verbenaceae	July-Sep	P
21	*Dalbergia latifolia*	Faboideae	Feb-March	NP
22	*Dimocarpus longan*	Sapindaceae	March-April	NP
23	*Elaeocarpus tuberculatus*	Elaecarpaceae	Jan-Feb	NP
24	*Eucalyptus sp*	Myrtaceae	Nov-April	N
25	*Flacourtia montana*	Flacourtiaceae	Dec-Feb	N
26	*Grewia tiliaefolia*	Tiliaceae	June-July	N
27	*Homalium zeylanicum*	Flacourtiaceae	May-June	P
28	*Lagerstroemia microcarpa*	Lythraceae	March-April	NP
29	*Lannea coromandelica*	Anacardiaceae	Feb-March	NP
30	*Litsea floribunda*	Lauraceae	Sep-Dec	P
31	*Mallotus philippensis*	Euphorbiaceae	Aug-Nov	P
32	*Mangifera indica*	Anacardiaceae	Feb-April	NP
33	*Meliosma simplicifolia*	Sabiaceae	March-April	N
34	*Memecylon umbellatum*	Melastomataceae	April-May	NP
35	*Mimusops elengi*	Sapotaceae	April-June	N
36	*Olea dioica*	Oleaceae	Dec-Feb	NP
37	*Persea americana*	Lauraceae	Dec-Jan	NP
38	*Phyllanthus emblica*	Phyllanthaceae	Dec-May	NP
39	*Pongamia pinnata*	Faboideae	March-April	NP
40	*Pterocarpus marsupium*	Faboideae	March-April	NP
41	*Sapindus emarginatus*	Sapindaceae	Dec-Jan	NP
42	*Sageraea laurifolia*	Annonaceae	Nov-Dec	N
43	*Spondias pinnata*	Anacardiaceae	Feb-March	N
44	*Syzygium zeylanicum*	Myrtaceae	May-June	N
45	*Tabebuia argentea*	Bignoniaceae	Dec-Feb	P
46	*Terminalia bellirica*	Combretaceae	Feb-March	NP
47	*Terminalia catappa*	Combretaceae	Feb-March	NP
48	*Terminalia chebula*	Combretaceae	April-May	NP
49	*Toona ciliata*	Meliaceae	Dec-Mar	N
50	*Trichilia connaroides*	Meliaceae	Feb-March	N
51	*Vitex negundo*	Lamiaceae	Sep-Nov	N

Note: N- Nectar, P- Pollen and NP-Both Nectar and Pollen

Table 4. Details of bee forage trees recorded in sacred groves of evergreen ecosystem

Sl. No.	Scientific name	Family	Flowering period	Source
1	*Acronychia pedunculata*	Rutaceae	Dec-Feb	NP
2	*Alstonia scholaris*	Apocynaceae	Jan-March	NP
3	*Apodytes dimidiata*	Icacinaceae	March-April	NP
4	*Artocarpus lakoocha*	Moraceae	April-June	P
5	*Bischofia javanica*	Phyllanthaceae	Sep-Nov	N
6	*Canarium strictum*	Burseraceae	Feb-April	NP
7	*Canthium dicoccum*	Rubiaceae	Dec-Feb	NP
8	*Careya arborea*	Lecythidaceae	Feb-April	NP
9	*Caryota urens*	Arecaceae	Throughout the year	NP
10	*Celtis tetrandra*	Ulmaceae	Feb-April	N
11	*Chrysophyllum roxburghii*	Sapotaceae	April-Nov	NP
12	*Dimocarpus longan*	Sapindaceae	March-April	P

Sl. No.	Scientific name	Family	Flowering period	Source
13	*Diospyros buxifolia*	Ebenaceae	April-June	N
14	*Dipterocarpus indicus*	Dipterocarpaceae	Feb-July	N
15	*Dysoxylum malabaricum*	Meliaceae	Feb-June	N
16	*Elaeocarpus marsupium*	Elaeocarpaceae	Sep – Apr	NP
17	*Elaeocarpus munroii*	Elaeocarpaecae	Sep-April	N
18	*Elaeocarpus tuberculatus*	Elaeocarpaecae	Jan-April	N
19	*Ficus amplissima*	Moraceae	Sep – Mar	N
20	*Garcinia indica*	Clusiaceae	Nov-Feb	N
21	*Garcinia xanthochymus*	Clusiaceae	Jan-April	N
22	*Holigarna arnottiana*	Anacardiaceae	April-May	NP
23	*Holigarna ferruginea*	Anacardiaceae	April-May	NP
24	*Hopea parviflora*	Dipterocarpaceae	Jan-April	N
25	*Hopea wightiana*	Dipterocarpaceae	April-May	N
26	*Mangifera indica*	Anacardiaceae	Jan-April	NP
27	*Manilkara hexandra*	Sapotaceae	Jan-Dec	P
28	*Memecylon umbellatum*	Melastomataceae	April-May	P
29	*Mimusops elengi*	Sapotaceae	April-June	NP
30	*Palaquium ellipticum*	Sapotaceae	Feb-July	NP
31	*Persea macrantha*	Lauraceae	Dec-March	NP
32	*Prunus ceylanica*	Rosaceae	Jan-Dec	P
33	*Sapindus emarginatus*	Sapindaceae	Oct-Dec	NP
34	*Schefflera wallichiana*	Araliaceae	April-May	N
35	*Spathodea campanulata*	Bignoniaceae	Throughout the year	NP
36	*Spondias pinnata*	Anacardiaceae	March-May	N
37	*Syzygium cumini*	Myrtaceae	March-May	NP
38	*Syzygium hemisphericum*	Myrtaceae	March-May	NP
39	*Tamarindus indica*	Caesalpiniaceae	April-May	N
40	*Trichilia connaroides*	Meliaceae	Feb-March	NP
41	*Vateria indica*	Dipterocarpaceae	Jan-April	NP
42	*Vitex negundo*	Lamiaceae	Sep-Nov	NP
43	*Ziziphus rugosa*	Cannabinaceae	April-Oct	N

Note: N- Nectar, P- Pollen and NP-Both Nectar and Pollen

Moist deciduous ecosystems presented a different pattern, with sacred groves showing the lowest species diversity (H’=3.48, D=0.020) and richness (35 species) but the highest species evenness (E=0.96) (Table 6). Seasonal moisture fluctuations restrict the establishment of certain species, leading to lower overall richness (Mallick et al., 2022). Research indicates that in seasonally dry tropical forests, diversity typically increases with mean annual precipitation (MAP), though this relationship can be influenced by factors like fire frequency (Dattaraja et al., 2018). The lower species richness in moist deciduous groves likely stems from these seasonal shifts. Despite lower richness, these groves maintain high species evenness (E=0.96), indicating a more uniform distribution of species (Barik et al., 2023). Coffee plantations in this ecosystem exhibited the lowest overall diversity (H’=2.95, D=0.04) and richness (24 species) (Table 7)., largely due to the simplification of vegetation structure and open canopy associated with intensive coffee production, which reduces native tree density and overall biodiversity (Gillison et al., 2016). Nevertheless, species evenness in these plantations remained moderate, indicating a relatively uniform distribution among the remaining species. Despite the evident advantages of sacred groves, it is essential to consider the impact of urbanization and invasive species on their biodiversity, which poses a significant threat to their ecological integrity (Nayak et al., 2023; Saste and Bhagat, 2024).

Table 5. Details of bee forage trees recorded in sacred groves of evergreen ecosystem

1	*Acronychia pedunculata*	Rutaceae	Dec-Feb	NP
2	*Actinodaphne malabarica*	Lauraceae	Dec-Feb	N
3	*Alstonia scholaris*	Apocynaceae	Jan-March	NP
4	*Anacardium occidentale*	Anacardiaceae	Dec-March	NP
5	*Antidesma menasu*	Euphorbiaceae	Dec-Jan	P
6	*Aporosa lindleyana*	Euphorbiaceae	Nov-Jan	NP
7	*Areca catechu*	Arecaceae	June-Dec	P

8	*Chionanthus malabarica*	Oleaceae	Jan-March	P
9	*Cinnamomum malabatrum*	Lauraceae	Jan-March	P
10	*Cocos nucifera*	Arecaceae	Throughout the year	NP
11	*Cythroxylon quadrangularis*	Verbenaceae	July-Sep	N
12	*Dimocarpus longan*	Sapindaceae	March-April	NP
13	*Dysoxylum malabaricum*	Meliaceae	Feb-June	NP
14	*Elaeocarpus tuberculatus*	Elaecarpaceae	Jan-Feb	NP
15	*Garcinia indica*	Clusiaceae	Nov-Feb	NP
16	*Garcinia xanthochymus*	Clusiaceae	Jan-April	P
17	*Holigarna arnottiana*	Anacardiaceae	April-May	NP
18	*Holigarna ferriginea*	Anacardiaceae	April-May	P
19	*Mangifera indica*	Anacardiaceae	Feb-April	NP
20	*Meliosma simplicifolia*	Sabiaceae	March-April	N
21	*Memecylon umbellatum*	Melastomataceae	April-May	N
22	*Mimusops elengi*	Sapotaceae	April-June	P
23	*Olea dioica*	Oleaceae	Dec-Feb	NP
24	*Persea americana*	Lauraceae	Oct-Dec	NP
25	*Pongamia pinnata*	Faboideae	March-April	NP
26	*Syzygium zeylanicum*	Myrtaceae	May-June	NP
27	*Terminalia bellirica*	Combretaceae	Feb-March	NP
28	*Terminalia catappa*	Combretaceae	Feb-March	NP

Note: N- Nectar, P- Pollen and NP-Both Nectar and Pollen

Table 6. Details of bee forage trees recorded in sacred groves of moist deciduous ecosystem

Sl. No.	Scientific name	Family	Flowering period	Source
1	*Acronychia pedunculata*	Rutaceae	Feb-April	P
2	*Aporosa lindleyana*	Euphorbiaceae	Dec-June	N
3	*Atalantia racemosa*	Rutaceae	Nov-Dec	NP
4	*Atalantia wightii*	Rutaceae	March -May	N
5	*Bischofia javanica*	Phyllanthaceae	Oct-Nov	NP
6	*Bombax malabarica*	Malvaceae	Feb-March	N
7	*Butea monosperma*	Fabaceae	Oct-Feb	NP
8	*Calliandra haematocephala*	Mimosaceae	Oct-Jan	P
9	*Callicarpa tomentosa*	Verbenaceae	April-July	N
10	*Caryota urens*	Arecaceae	Throughout the year	NP
11	*Chukrasia tabularis*	Meliaceae	Feb-July	NP
12	*Cinnamomum malabatrum*	Lauraceae	March-April	NP
13	*Cordia dichotoma*	Boraginaceae	Dec-Feb	P
14	*Dalbergia latifolia*	Fabaceae	March-April	N
15	*Diospyros montana*	Ebenaceae	Jan-April	P
16	*Gmelina arborea*	Lamiaceae	Feb-April	NP
17	*Grewia tiliifolia*	Malvaceae	April-Aug	N
18	*Haldina cordifolia*	Rubiaceae	Oct-June	N
19	*Holarrhena antidysenterica*	Apocynaceae	April-July	NP
20	*Kydia calycina*	Malvaceae	March-April	NP
21	*Lagerstroemia microcarpa*	Lythraceae	March-April	NP
22	*Lawsonia inermis*	Lythraceae	March-May	P
23	*Mallotus philippensis*	Euphorbiaceae	Aug-Nov	P
24	*Mangifera indica*	Anacardiaceae	Jan-March	NP
25	*Mitragyna parvifolia*	Rubiaceae	Feb-July	NP
26	*Phyllanthus emblica*	Euphorbiaceae	Nov-Feb	NP
27	*Randia dumetorum*	Rubiaceae	March-Oct	P
28	*Schleichera oleosa*	Sapindaceae	Feb-March	NP
29	*Shorea roxburghii*	Dipterocarpacece	Feb -May	N
30	*Spondias pinnata*	Anacardiaceae	March -May	N
31	*Syzygium zeylanicum*	Myrtaceae	March-June	N
32	*Tamarindus indica*	Caesalpiniaceae	April-May	N
33	*Terminalia bellirica*	Combrataceae	April-June	NP
34	*Terminalia paniculata*	Combrataceae	Oct-Dec	NP
35	*Xylia xylocarpa*	Mimosaceae	March-April	P

Note: N- Nectar, P- Pollen and NP-Both Nectar and Pollen

Table 7. Details of bee forage trees recorded in coffee plantations of moist deciduous ecosystem

Sl. No.	Scientific name	Family	Flowering period	Source
1	*Acacia catechu*	Fabaceae	July-Aug	N
2	*Annona reticulata*	Annonaceae	July-Aug	P
3	*Aporosa lindleyana*	Euphorbiaceae	Nov-Jan	N
4	*Callicarpa tomentosa*	Verbenaceae	Aug-Nov	P
5	*Careya arborea*	Lecythidaceae	Feb-March	NP
6	*Caryota urens*	Arecaceae	Throughout the year	NP
7	*Dalbergia latifolia*	Faboideae	Feb-March	N
8	*Flacourtia sepiaria*	Flacourtiaceae	Feb-March	P
9	*Gmelina arborea*	Verbenaceae	May-July	NP
10	*Grewia tiliifolia*	Tiliaceae	June-July	N
11	*Kydia calycina*	Malvaceae	March-April	N
12	*Lagerstroemia microcarpa*	Lythraceae	March-April	NP
13	*Lannea coromandelica*	Anacardiaceae	Feb-March	NP
14	*Mangifera indica*	Anacardiaceae	Feb-April	NP
15	*Persea americana*	Lauraceae	Oct-Nov	N
16	*Pongamia pinnata*	Faboideae	March-April	NP
17	*Pterocarpus marsupium*	Faboideae	March-April	NP
18	*Sapindus emarginatus*	Sapindaceae	Dec-Jan	NP
19	*Spondias pinnata*	Anacardiaceae	Feb-March	P
20	*Sterculia guttata*	Sterculiaceae	Jan-March	P
21	*Tabernaemontana heyneana*	Apocynaceae	Sep-Nov	N
22	*Terminalia bellirica*	Combretaceae	Feb-March	NP
23	*Terminalia catappa*	Combretaceae	Feb-March	NP
24	*Trichilia connaroides*	Meliaceae	Feb-March	NP

Note: N- Nectar, P- Pollen and NP-Both Nectar and Pollen

4. CONCLUSION

The study emphasized the critical role of Kodagu's sacred groves and coffee agro ecosystems in supporting wild honeybee populations, essential for biodiversity and crop productivity. Sacred groves, with their high species diversity, stability, and year-round floral availability, act as reliable forage sources for bees, benefiting overall pollinator health. Coffee plantations, particularly semi-evergreen systems, also support significant bee diversity when native trees are retained, enhancing agricultural resilience. However, maintaining these ecological advantages requires careful land management and conservation strategies. Protecting sacred groves and promoting biodiversity-friendly coffee practices are vital for sustaining pollinator populations, which directly benefit local communities and agricultural productivity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that, we have used generative AI technology for sentence modification during the writing or editing of this manuscript. Specifically, we used ChatGPT (GPT-4), developed by OpenAI, accessed *via* the official platform. The prompts provided to the AI were related to sentence refinement, grammar correction and improving clarity while preserving the original meaning. All content generated by the AI was carefully reviewed and validated by the authors to ensure accuracy and relevance.

ACKNOWLEDGEMENTS

The authors would like to extend their sincere gratitude to all individuals and institutions who have contributed to the successful completion of this original research manuscript. We acknowledge the invaluable support, guidance, and resources provided by the College of Forestry, Ponnampet affiliated to Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Ammann, L., Bosem-Baillod, A., Herzog, F., Frey, D., Entling, M. H., & Albrecht, M. (2024). Spatio-temporal complementarity of floral resources sustains wild bee pollinators in agricultural landscapes. *Agriculture, Ecosystems & Environment, 359*, 108754. https://doi.org/10.1016/j.agee.2023.108754

Bhagwat, S. A., & Rutte, C. (2006). Sacred groves: Potential for biodiversity management. *Frontiers in Ecology and the Environment, 4*(10), 519-524. https://doi.org/10.1890/1540-9295(2006)4[519:SGPFBM]2.0.CO;2

Bhagwat, S. A., Kushalappa, C. G., Williams, P. H., & Brown, N. D. (2005). A landscape approach to biodiversity conservation of sacred groves in the Western Ghats of India. *Conservation Biology, 19*(6), 1853-1862. https://doi.org/10.1111/j.1523-1739.2005.00212.x

Boreux, V., Kushalappa, C. G., Vaast, P., & Ghazoul, J. (2013). Interactive effects among ecosystem services and management practices on crop production: Pollination in coffee agroforestry systems. *Proceedings of the National Academy of Sciences, 110*(21), 8387-8392. https://doi.org/10.1073/pnas.1300500110

Casanelles-Abella, J., Simone, F., Bertrand, F., David, F., & Marco, M. (2022). Low resource availability drives feeding niche partitioning between wild bees and honeybees in a European city. *Ecological Applications, 33*(1), e2727. https://doi.org/10.1002/eap.2727

Depecker, J., Vandelook, F., Jordaens, K., Dorchin, A., Katshela, B. N., Broeckhoven, I., Dhed'a, B., Devriese, A., Deckers, L., Stoffelen, P., & Honnay, O. (2025). Comparative pollinator conservation potential of coffee agroforestry relative to coffee monoculture and tropical rainforest in the DR Congo. *Agriculture, Ecosystems & Environment, 379*, 109375. https://doi.org/10.1016/j.agee.2023.109375

Dequenne, I., Philippart de Foy, J. M., & Cani, P. D. (2022). Developing strategies to help bee colony resilience in changing environments. *Animals, 12*(23), 3396. https://doi.org/10.3390/ani12223396

Khan, M. L., Khumbongmayum, A. D., & Tripathi, R. S. (2008). The sacred groves and their significance in conserving biodiversity: An overview. *International Journal of Ecology and Environmental Sciences, 34*(3), 277-291.

Krishnan, S., Cheppudira, K. G., & Ghazoul, J. (2017). Pollinator services in coffee agroforests of the Western Ghats. In *Agroforestry: Anecdotal to Modern Science* (pp. 771-795).

Koutouleas, A., Bosselmann, A. S., & Rahn, E. (2024). Is agroforestry a sustainable management system for future coffee production? *Agriculture, Ecosystems & Environment*.

Machado, P. A. C., Baronio, G. J., Soares Novaes, C., Ollerton, J., Wolowski Torres, M., Natalina Silva Lopes, D., & Rech, A. R. (2024). Optimizing coffee production: Increased floral visitation and bean quality at plantation edges with wild pollinators and natural vegetation. *Journal of Applied Ecology, 61*(3), 465-475. https://doi.org/10.1111/1365-2664.14196

Maurer, C., Sutter, L., Martínez-Núñez, C., Pellissier, L., & Albrecht, M. (2022). Different types of semi-natural habitat are required to sustain diverse wild bee communities across agricultural landscapes. *Journal of Applied Ecology, 59*(10), 2604-2615. https://doi.org/10.1111/1365-2664.14071

Roubik, D. W. (2002). The value of bees to the coffee harvest. *Nature, 417*(6890), 708-708. https://doi.org/10.1038/417708a

Saepudin, R. (2014). Sustainability analysis and the effect of honeybee-coffee plantation integration model on improving. *Jurnal Ilmiah Ilmu-Ilmu Peternakan, 17*(1), 1-9.

Silva, C. B. D., Hautequestt, A. P., Matos, V. R., Mendonça, C. B. F., Goncalves Lourenço Esteves, V., Freitas, L., & Gaglianone, M. C. (2024). Pollen sources used by the stingless bee *Schwarziana quadripunctata* in a coffee-growing landscape. *Palynology, 2301441*, 1-11. https://doi.org/10.1080/01916122.2023.2301441

Roulston, T. A. H., & Goodell, K. (2011). The role of resources and risks in regulating wild bee populations. *Annual Review of Entomology, 56*(1), 293-312. https://doi.org/10.1146/annurev-ento-120710-100718

Ahmed, M., Sharma, V., & Dhiman, M. (2023). Sacred groves: The gene banks of threatened and ethnomedicinal flora, associated taboos, and role in biodiversity conservation in the Peer Panchal range of North Western Himalayas, India. *Ecological Questions, 34*(3), 1-20.

Barik, S., Parvez, A. K. M., Sewak, S., & Dey, A. (2023). Sacred groves of Badampahar Forest Range, Rairangpur Forest Division, Odisha, India. *Ecology, Environment, and Conservation, 29*(2), 989-1001.

Deepanshu, & Manju. (2021). Role of sacred groves in phytodiversity conservation of Block Nud, District Samba (J&K). *Environmental Science, 10*(11), 1390-1395.

Dattaraj, H. R., Sridhar, K. R., & Jagadish, B. R. (2020). Diversity and bioprospect significance of macrofungi in the scrub jungles of southwest India. *Biodiversity and Biomedicine, 2*(3), 235-246.

Gillison, A. N., Asner, G. P., Fernandes, E. C., Mafalacusser, J., Banze, A., Izidine, S., da Fonseca, A. R., & Pacate, H. (2016). Biodiversity and agriculture in dynamic landscapes: Integrating ground and remotely-sensed baseline surveys. *Journal of Environmental Management, 177*(14), 9-19.

Kulkarni, A., Upadhye, A., Dahanukar, N., & Datar, M. N. (2018). Floristic uniqueness and effect of degradation on diversity: A case study of sacred groves from northern Western Ghats. *Tropical Ecology, 59*(1), 119-127.

Mallick, D., Dasgupta, S., Paul, P., Mondal, S., Pal, A., & Chowdhury, M. (2022). Tree diversity in tropical moist deciduous forests of Gorumara National Park, India. *Indian Forester, 148*(11), 1079-1093.

Mondal, S., & Mondal, A. (2024). Diversity of insect fauna in three selected sacred groves of Murshidabad District, West Bengal, India. *Journal of Entomology and Zoology Studies*, 12(3), 162-171.

Nayak, A., Ram, K., Bhakat, P. K., & Pandit. (2023). Ecofloristics and conservation status of sacred groves: A comparative study from Bankura District, West Bengal. *The Indian Forester, 146*(9), 895-907.

Parida, N., Sahoo, B. K., Satapathy, S. N., Singh, S., Paikaray, S. S., & Mohapatra, A. (2023). Studies on foraging behaviour of honeybees on flowers of rapeseed crop. *International Journal of Environment and Climate Change, 13*(11), 707-712.

Philpott, S. M., Arendt, W. J., Armbrecht, I., Bichier, P., Diestch, T. V., Gordon, C., Greenberg, R., Perfecto, I., Reynoso-Santos, R., Soto-Pinto, L., & Tejeda-Cruz, C. (2008). Biodiversity loss in Latin American coffee landscapes: Review of the evidence on ants, birds, and trees. *Conservation Biology, 22*(5), 1093-1095.

Prasad, K. S., Nambiar, G. R., & Raveendran, K. (2010). Sacred groves of north Malabar: Treasure trove of endemic and rare medicinal plants. *Open Access Journal of Medicinal and Aromatic Plants, 1*(2).

Rathore. (2024). Sacred groves: A bastion of biodiversity and cultural heritage. *International Education and Research Journal, 10*(1), 1-4.

Sharma, S., & Devi, R. (2014). Sacred groves: traditional way of conserving plant diversity in Block Bhalwal of Jammu District (J&K). *International Journal of Science and Research*, 3(2), 239-242.

Saste, K. H., & Bhagat, R. B. (2024). Status of floristic diversity and impact of development on two sacred groves from Maval Tehsil (Maharashtra, India) after a century. *Journal of Threatened Taxa, 16*(3), 24838-24853.

Singh, M., & Mall, P. (2024). Biodiversity and foraging behaviour of major insect pollinators on some fruit crops. *Journal of Scientific Research and Reports, 30*(5), 879-888. https://doi.org/10.9734/jsrr/2024/v30i52005

Tankou, C. M., de Snoo, G. R., de Iongh, H. H., & Persoon, G. (2014). Variation in plant biodiversity across sacred groves and fallows in Western Highlands of Cameroon. *African Journal of Ecology, 52*(1), 10-19.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/128234