Original Research Article

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

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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. Bee forage tree diversity, species richness, and evenness were measured in sacred groves and coffee plantations across three ecosystems: evergreen, semi-evergreen, and moist deciduous. Findings showed that sacred groves consistently surpass coffee plantations in floral diversity and forage stability, particularly in semi-evergreen groves, which record the highest diversity and richness (H'=3.75, 52 species). However, coffee plantations exhibit moderate diversity (H'=3.35, 54 species) when integrated with native trees, supporting productive bee populations. These results accentuate the need to balance biodiversity conservation and agricultural practices in Kodagu, leveraging sacred groves and ecologically managed coffee agro ecosystems to sustain bee populations essential for both ecosystem health and crop productivity.

Keywords: *Bee forage resources, Biodiversity conservation, Pollinator diversity, Floral resources*

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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 (Chandran et al., 1997). 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 (Perfecto and Vandermeer, 2008).

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. 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. MATERIAL 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. 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.

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) (Table 1, 2, 3 and 4).

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

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.

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

Sl. No.	Scientific name	Family	Flowering period	Source
1	*Acrocarpusfraxinifolius*	Caesalpiniaceae	Feb-March	N
2	*Acronychia pedunculata*	Rutaceae	Feb-April	NP
3	*Actinodaphne hookeri*	Lauraceae	April-May	NP
4	*Actinodaphnemalabarica*	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	*Alstoniascholaris*	Apocynaceae	Feb-March	NP
9	*Antidesmamenasu*	Euphorbiaceae	Dec-Jan	P
10	*Aphananthecuspidata*	Cannabaceae	Jan-March	P
11	*Apodytes dimidiate*	Icacinaceae	April-Oct	NP
12	*Aporosalindleyana*	Euphorbiaceae	Dec-June	N
13	*Atalantia racemosa*	Rutaceae	Nov-Dec	N
14	*Atalantiawightii*	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	*Canthiumdicoccum*	Rubiaceae	Nov-Jan	N
20	*Caralliabrachiata*	Rhizophoraceae	Feb-Oct	N
21	*Caryotaurens*	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	*Dilleniapentagyna*	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	*Mallotusphilippensis*	Bignoniaceae	Aug-Nov	P
35	*Mesua ferrea*	Calophyllaceae	March-May	NP
36	*Palaquiumellipticum*	Sapotaceae	Feb-July	NP
37	*Perseamacrantha*	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	*Sapindusemarginatus*	Sapindaceae	Dec-Jan	NP
43	*Syzygiumhemisphericum*	Myrtaceae	March-May	NP
44	*Syzygiumjambos*	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	*Trichiliaconnaroides*	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	*Acrocarpusfraxinifolius*	Caesalpinioideae	Feb-March	N
4	*Acronychia pedunculata*	Rutaceae	Feb-April	NP
5	*Actinodaphnemalabarica*	Lauraceae	Dec-Feb	NP
6	*Anacardium occidentale*	Anacardiaceae	Dec-March	NP
7	*Antidesmamenasu*	Euphorbiaceae	Dec-Jan	P
8	*Aphananthecuspidata*	Ulmaceae	Jan-March	P
9	*Aporosalindleyana*	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	*Caryotaurens*	Arecaceae	Throughout the year	NP
15	*Casearia ovata*	Flacourtiaceae	March-May	N
16	*Canthiumdicoccum*	Rubiaceae	Nov-Jan	P
17	*Celtis tetrandra*	Ulmaceae	Feb-April	NP
18	*Chionanthusmalabarica*	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	*Flacourtiamontana*	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	*Lanneacoromandelica*	Anacardiaceae	Feb-March	NP
30	*Litsea floribunda*	Lauraceae	Sep-Dec	P
31	*Mallotusphilippensis*	Euphorbiaceae	Aug-Nov	P
32	*Mangifera indica*	Anacardiaceae	Feb-April	NP
33	*Meliosmasimplicifolia*	Sabiaceae	March-April	N
34	*Memecylon umbellatum*	Melastomataceae	April-May	NP
35	*Mimusopselengi*	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	*Sapindusemarginatus*	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	*Trichiliaconnaroides*	Meliaceae	Feb-March	N
51	*Vitex negundo*	Lamiaceae	Sep-Nov	N

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

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 (Table 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).

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	*Alstoniascholaris*	Apocynaceae	Jan-March	NP
3	*Apodytesdimidiata*	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	*Canthiumdicoccum*	Rubiaceae	Dec-Feb	NP
8	*Careya arborea*	Lecythidaceae	Feb-April	NP
9	*Caryotaurens*	Arecaceae	Throughout the year	NP
10	*Celtis tetrandra*	Ulmaceae	Feb-April	N
11	*Chrysophyllumroxburghii*	Sapotaceae	April-Nov	NP
12	*Dimocarpus longan*	Sapindaceae	March-April	P
13	*Diospyros buxifolia*	Ebenaceae	April-June	N
14	*Dipterocarpus indicus*	Dipterocarpaceae	Feb-July	N
15	*Dysoxylummalabaricum*	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	*Holigarnaarnottiana*	Anacardiaceae	April-May	NP
23	*Holigarnaferruginea*	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	*Mimusopselengi*	Sapotaceae	April-June	NP
30	*Palaquiumellipticum*	Sapotaceae	Feb-July	NP
31	*Perseamacrantha*	Lauraceae	Dec-March	NP
32	*Prunus ceylanica*	Rosaceae	Jan-Dec	P
33	*Sapindusemarginatus*	Sapindaceae	Oct-Dec	NP
34	*Schefflera wallichiana*	Araliaceae	April-May	N
35	*Spathodeacampanulata*	Bignoniaceae	Throughout the year	NP
36	*Spondias pinnata*	Anacardiaceae	March-May	N

37	*Syzygiumcumini*	Myrtaceae	March-May	NP
38	*Syzygiumhemisphericum*	Myrtaceae	March-May	NP
39	*Tamarindus indica*	Caesalpiniaceae	April-May	N
40	*Trichiliaconnaroides*	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

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

1	*Acronychiapendunculata*	Rutaceae	Dec-Feb	NP
2	*Actinodaphnemalabarica*	Lauraceae	Dec-Feb	N
3	*Alstoniascholaris*	Apocynaceae	Jan-March	NP
4	*Anacardium occidentale*	Anacardiaceae	Dec-March	NP
5	*Antidesmamenasu*	Euphorbiaceae	Dec-Jan	P
6	*Aporosalindleyana*	Euphorbiaceae	Nov-Jan	NP
7	*Areca catechu*	Arecaceae	June-Dec	P
8	*Chionanthusmalabarica*	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	*Dysoxylummalabaricum*	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	*Holigarnaarnottiana*	Anacardiaceae	April-May	NP
18	*Holigarnaferriginea*	Anacardiaceae	April-May	P
19	*Mangifera indica*	Anacardiaceae	Feb-April	NP
20	*Meliosmasimplicifolia*	Sabiaceae	March-April	N
21	*Memecylon umbellatum*	Melastomataceae	April-May	N
22	*Mimusopselengi*	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

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 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	*Aporosalindleyana*	Euphorbiaceae	Dec-June	N
3	*Atalantia racemosa*	Rutaceae	Nov-Dec	NP
4	*Atalantiawightii*	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	*Caryotaurens*	Arecaceae	Throughout the year	NP
11	*Chukrasiatabularis*	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	*Holarrhenaantidysenterica*	Apocynaceae	April-July	NP
20	*Kydiacalycina*	Malvaceae	March-April	NP
21	*Lagerstroemia microcarpa*	Lythraceae	March-April	NP
22	*Lawsonia inermis*	Lythraceae	March-May	P
23	*Mallotusphilippensis*	Euphorbiaceae	Aug-Nov	P
24	*Mangifera indica*	Anacardiaceae	Jan-March	NP
25	*Mitragynaparvifolia*	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	*Shorearoxburghii*	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	*Aporosalindleyana*	Euphorbiaceae	Nov-Jan	N
4	*Callicarpa tomentosa*	Verbenaceae	Aug-Nov	P
5	*Careya arborea*	Lecythidaceae	Feb-March	NP
6	*Caryotaurens*	Arecaceae	Throughout the year	NP
7	*Dalbergia latifolia*	Faboideae	Feb-March	N
8	*Flacourtiasepiaria*	Flacourtiaceae	Feb-March	P
9	*Gmelina arborea*	Verbenaceae	May-July	NP
10	*Grewia tiliifolia*	Tiliaceae	June-July	N
11	*Kydiacalycina*	Malvaceae	March-April	N
12	*Lagerstroemia microcarpa*	Lythraceae	March-April	NP
13	*Lanneacoromandelica*	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	*Sapindusemarginatus*	Sapindaceae	Dec-Jan	NP
19	*Spondias pinnata*	Anacardiaceae	Feb-March	P
20	*Sterculia guttata*	Sterculiaceae	Jan-March	P
21	*Tabernaemontanaheyneana*	Apocynaceae	Sep-Nov	N
22	*Terminalia bellirica*	Combretaceae	Feb-March	NP
23	*Terminalia catappa*	Combretaceae	Feb-March	NP
24	*Trichiliaconnaroides*	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.

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