

Spatiotemporal analysis of melliferous flora in Madhya Pradesh, India: implications for beekeeping and pollinator support

Durgesh Khobragade¹, Mahendra Baghele¹, Chuleui Jung^{2,3} and Sampat Ghosh^{1#}

Summary

Madhya Pradesh, in central India, is rich in biodiversity and hosts native honey bee species like *Apis dorsata*, *A. florea*, and *A. cerana*, with diverse melliferous flora offering strong potential for beekeeping. However, regional apiculture varies greatly—for example, migratory beekeeping thrives in Bundelkhand and Chambal valley due to seasonal floral abundance and farmer awareness, while areas like Satpura, despite abundant wild bees, show minimal managed beekeeping, likely due to inconsistent forage availability. This study assesses the composition, diversity, and seasonal dynamics of nectar and pollen sources for honey bees across seven ecogeographical zones of Madhya Pradesh, encompassing both agroecosystems and forest ecosystems. Field surveys, literature reviews, and stakeholder consultations were used to document melliferous flora, and statistical analyses identified regional and seasonal patterns of floral resources. In forest ecosystems of Madhya Pradesh, melliferous plant species richness varied regionally, ranging from 22 species in Satpura to 35 species in Madhya Bharat, with Rewa-Panna and Bundelkhand also showing high diversity (34 species each). Results reveal distinct nectar and pollen availability peaks in regions such as Bundelkhand and Madhya Bharat, favoring stationary or migratory beekeeping, while Satpura and Baghelkhand have lower floral resource density and continuity, limiting apicultural expansion. Seasonal dearths, especially in June and post-monsoon months, highlight critical challenges to colony health and productivity. The study emphasizes the ecological importance of forest flora in supporting both wild and managed bee populations and suggests targeted floral enrichment and migratory strategies to enhance sustainable beekeeping. These findings provide a baseline for region-specific apicultural planning, aiming to improve honey production, pollinator conservation, and rural livelihoods across Madhya Pradesh.

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Keywords: Beekeeping, Nectar and pollen sources, Apiculture, *Apis dorsata*, Nutrition, Native honey bees, Livelihood

Introduction

Beekeeping is a traditional practice that has been intricately linked with human civilization since ancient times, providing food, income, and essential pollination services across culture. In India, beekeeping continues to be practiced predominantly on a small scale, often serving as a supplementary livelihood alongside agriculture (Abrol 2023). However, Indian apiculture remains largely honey-centric, limiting its broader contribution to rural development, potential for enhancing rural livelihoods, promoting biodiversity conservation, and improving agricultural productivity through pollination services (Haldhar et al. 2021a,b; Ranguwal 2023; Chauhan et al. 2024; Ghosh & Jung 2024, Ghosh et al. 2025). Honey bees play a vital role as pollinators, enhancing agricultural yields and, by extension, to food and nutritional security (Singh et al. 2015; Ghosh & Jung 2018; 2024), yet the number of

managed colonies in India remains insufficient for its vast and diverse agroecosystems (https://agritech.tnau.ac.in/farm_enterprises/fe_api_bee_floraapollin.html). A major yet understudied constraint to expanding apiculture is the limited systematic documentation of region-specific bee flora, particularly within forest ecosystems that may significantly influence colony sustainability and productivity. Madhya Pradesh, situated in the central India, encompasses diverse ecological zones, rich biodiversity, supporting native honey bee species such as *Apis dorsata*, *A. florea*, and *A. cerana*, along with abundant melliferous (nectar- and pollen-yielding) flora. Given these favorable ecological conditions, the state holds immense potential for beekeeping. However, marked regional disparities exist in organized apicultural development. For example, the Bundelkhand region and the Chambal valley, particularly in districts such as Morena, support migratory beekeeping operations, driven by seasonal floral availability and improved awareness among farmers and apiculturists (Singh et al. 2020; Singh et al. 2022; Naveen et al. 2021; Haldhar et al. 2025). In contrast, regions like Satpura especially in the districts of Balaghat and adjoining

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forested landscapes—exhibit minimal organized beekeeping activity, even though wild honey bee populations are abundant. This paradox—presence of wild bees without corresponding beekeeping efforts—raises important ecological and socio-economic questions. One plausible hypothesis is that the scarcity or seasonal inconsistency of bee forage (i.e., nectar and pollen resources) in certain regions may be a limiting factor. The limited understanding of spatial and seasonal dynamics of bee forage, particularly in forest-dominated regions, may constrain managed colony establishment. Bee nutrition, heavily reliant on the diversity and abundance of floral resources, is a critical determinant of honey bee health, colony strength, and productivity (Vaudo et al. 2015; Nidhi et al. 2025). A deficiency in nutritionally rich and continuous forage could hinder the successful establishment and maintenance of managed bee colonies, even in areas where wild bees thrive. Floral resources for honey bees primarily originate from two broad ecological systems: agroecosystems and forest ecosystems. While the agroecosystem-based bee flora primarily constituted by cultivated crops and field margins—tends to be relatively similar across much of Madhya Pradesh due to uniform cropping patterns, the forest ecosystems exhibit more complex and region-specific floristic compositions. Yet, systematic and comparative data on forest-based bee flora across different ecogeographical zones of the

state remain scarce, representing a critical research gap. In this context, the present study assesses and compares the composition, diversity, and seasonal dynamics of bee flora across distinct ecogeographical zones of Madhya Pradesh. By documenting the nectar and pollen sources in both agro- and forest ecosystems, this study aims to generate evidence that can guide strategic apiary placement, seasonal colony management, pollinator conservation, and sustainable livelihood-oriented expansion of apiculture in the state. Such region-specific insights are essential for strengthening pollinator health, enhancing honey production, and supporting biodiversity conservation and rural development.

Materials and Methods

Study Area

The study was conducted across seven ecogeographical zones of Madhya Pradesh, India—Satpura, Baghelkhand, Bundelkhand, Rewa-Panna, Madhya-Bharat, Malwa and Narmada Ghati (Figure 1). These regions represent diverse topographies, climatic conditions, vegetation types, and land-use patterns (Table 1). Each zone comprises a unique blend of agroecosystems and forest ecosystems, influencing the availability and diversity of floral resources for honey bees. Forest ranges, agroforestry interfaces, and rural agricultural landscapes were included to capture comprehensive data on melliferous flora.

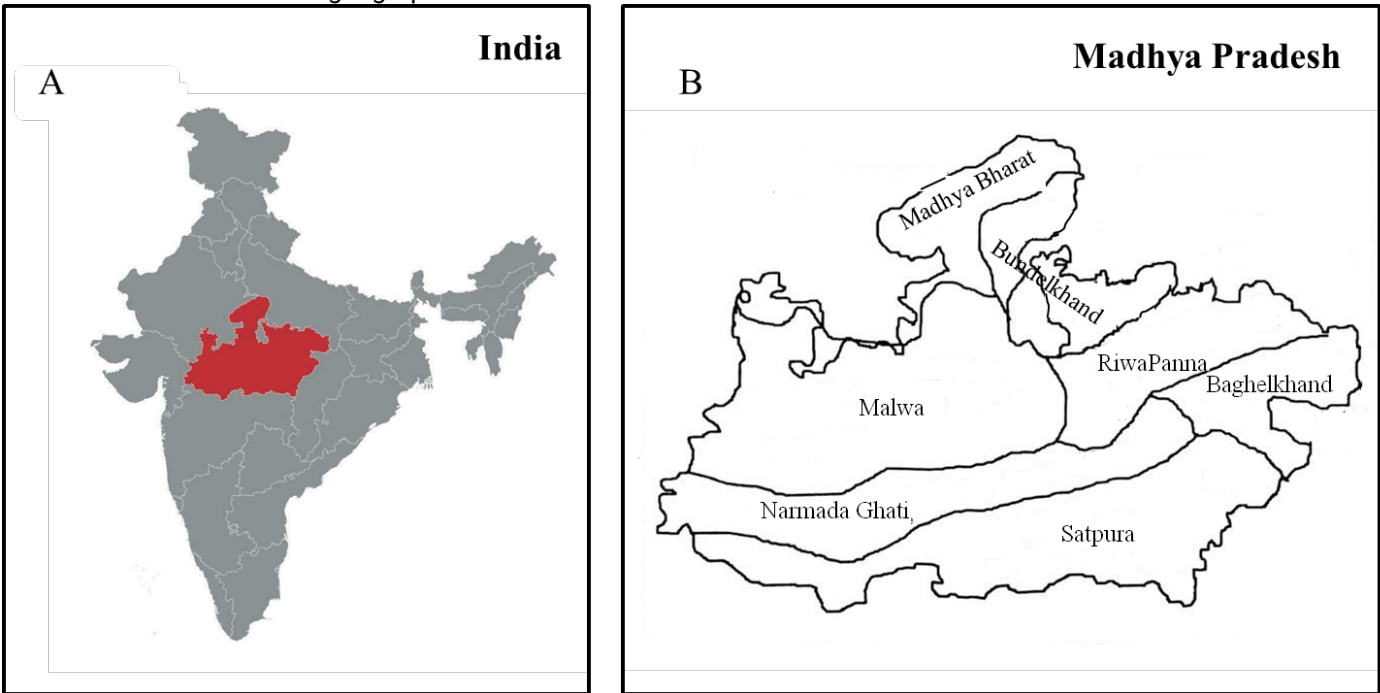


Figure 1. (A) Location of state of Madhya Pradesh in India; (B) Different eco-geographical regions of the state

Table 1. Vegetation types and climatic conditions of the seven ecogeographical regions of Madhya Pradesh [Data obtained from (Botanical Survey of India 1993, Forest Survey of India 2019, Satpura Tiger Reserve [<https://www.satpuratigerreserve.org/>], Department of Housing and Environment, Govt. of Madhya Pradesh [mphed.nic.in])

Region	Vegetation type	Climatic Conditions						
		Parameters	Summer		Monsoon		Winter	
			Min	Max	Min	Max	Min	Max
Satpura	Tropical moist deciduous forest, Tropical dry deciduous	Temperature (°C)	25	42	22	30	01	15
		RH (%)	30	45	85	98	55	75

	forest, Hill forest, Riverine, Grassland	Precipitation (cm)	100-150 cm					
Baghelkhand	Tropical moist deciduous forest, Tropical dry deciduous forest, Grassland, Riverine	Temperature (°C)	35.5	42	22	30	8	25
		RH (%)	20	35	80	95	45	65
		Precipitation (cm)	50-100 cm					
Bundelkhand	Tropical dry deciduous forest, Tropical thorn forest, Grassland, Riverine	Temperature (°C)	40	46	22	25	8	25
		RH (%)	15	25	70	80	40	60
		Precipitation (cm)	75-125 cm					
Rewa-Panna	Tropical dry deciduous forest, Sub-tropical broad leaf hill forest, Scrub/open forest, Grassland	Temperature (°C)	40	45	25	30	5	8
		RH (%)	15	25	75	85	70	80
		Precipitation (cm)	50-100 cm					
Madhya Bharat	Tropical dry deciduous forest, Tropical thorn deciduous forest, Agriculture/Crop land, Riverine	Temperature (°C)	40	45	22	35	15	18
		RH (%)	10	20	70	85	50	70
		Precipitation (cm)	55-75 cm					
Malwa	Tropical dry deciduous forest, Agriculture/Crop land	Temperature (°C)	40	42	20	25	15	18
		RH (%)	20	35	75	90	40	60
		Precipitation (cm)	80-150 cm					
Narmada Ghati	Tropical moist deciduous forest, Tropical dry deciduous forest	Temperature (°C)	42	46	22	25	10	14
		RH (%)	25	35	80	95	50	70
		Precipitation (cm)	125-150 cm					

Data Collection

Data on melliferous plant species were collected through a combination of seasonal field observations, secondary literature review, and stakeholder interactions (Botanical Survey of India 1993). Field surveys were conducted across representative sites in the seven major regions of Madhya Pradesh—covering both forested areas and agroecosystems. During each visit, observations were made on flowering species, their abundance, blooming period, and their value as nectar and/or pollen sources for honey bees. Plant identification was supported by botanical keys, photographic documentation, and reference to standard flora. Local ecological knowledge was gathered through informal interviews with beekeepers, farmers, and forest officials, providing insights into region-specific bee forage plants, migratory beekeeping practices, and seasonal trends. Additional data were compiled from published floristic records and apicultural manuals to strengthen species lists and confirm blooming periods.

The preliminary floral calendars were reviewed and validated through repeated field visits and stakeholder consultations, ensuring accuracy and practical

relevance. Species with inconsistent flowering patterns or rare bee visitation were excluded from primary recommendations.

Statistical Analysis

Heatmaps were generated using ggplot2 and the heatmap package to display monthly variation in species richness across regions. Hierarchical cluster analysis was performed in R using the stats package. A Bray–Curtis similarity (dissimilarity) matrix was computed based on seasonal species composition data to quantify pairwise regional differences in nectar and pollen flora. The resulting distance matrix was subjected to agglomerative hierarchical clustering using Ward's linkage method (Ward.D2 criterion) to minimize within-cluster variance and generate compact clusters. Dendrograms were constructed to visualize regional grouping patterns.

Results

Agroecosystem

Table 2 reveals the month wise crop systems which is beneficial for honey bees. However, we have not found any major differences of the crop system across the regions, in most of the cases, the crop systems were consistent across the different region.

Table 2. Season wise crop production which helps honey bees

Common Name	Local Name	Botanical Name	Nectar	Pollen	11	12	1	2	3	4	5	6	7	8	9	10
Niger	Ramtil	<i>Guizotia abyssinica</i>	N	P												
Mustard	Sarson	<i>Brassica jincea</i>	N	P												
Coriander	Dhaniya	<i>Coriandrum sativum</i>	N	P												
Sunflower	Surajmukhi	<i>Helianthus annuus</i>	N	P												
Fenugreek	Methi	<i>Trigonella foenum</i>	N	P												
Onion	Pyaz	<i>Allium cepa</i>	N													
Opium poppy	Breadseed	<i>Papaver somniferum</i>	N													
Citrus	Nimbu	<i>Citrus spp.</i>	N	P												

Watermelon	Tarbooj	<i>Citrulluslanatus</i>	N	P
Cucumber	Kheera	<i>Cucumissativus</i>	N	P
Okra	Bhindi	<i>Abelmoschusesculentus</i>	N	
Maize	Makka	<i>Zea mays</i>		P
Green gram	Moong	<i>Vignaradiata</i>	N	
Black gram	Urad	<i>Vignamungo</i>	N	
Pumpkin	Kaddu	<i>Cucurbita maxima</i>	N	P
Bean	Green Bean	<i>Phaseolus vulgaris</i>	N	P
Cotton	Kapas	<i>Gossypium spp.</i>	N	P
Sesame	Til	<i>Sesamumindicum</i>	N	P
Pigeon pea	Arhar	<i>Cajanuscajan</i>	N	P

Forest ecosystem- Nectar sources

A region-wise list of melliferous tree species recorded in the forest ecosystem is provided in the Table 3. The number of melliferous plant species recorded across forest ecosystems in Madhya Pradesh varied by region, with Madhya Bharat exhibiting the highest richness (35 species), followed by Rewa-Panna and Bundelkhand (34 species each), Malwa (31 species), Narmada Ghati (30 species), Baghelkhand (23 species), and Satpura showing the lowest richness (22 species). Figures 2(A

and B) heatmaps illustrating the monthly distribution of bee forage resources across various regions of Madhya Pradesh. The color intensity in the heatmaps reflects the relative abundance of forage plants, with darker shades indicating a higher number of species. Accompanying cluster dendrograms, depicted in Figure 3(A and B) reveal the similarity among different regions based on the composition and seasonal availability of bee forage plants.

Table 2. Region-wise list of melliferous tree species found in the forest ecosystem (number represents the months of the year respectively) [Y= Yes, N= No, N/L= No/Negligible]

	1	2	3	4	5	6	7	8	9	10	11	12	Nectar	Pollen
Rewa-Panna														
Doob/Bermuda Grass (<i>Cynodon dactylon</i>)													N	N
Palash (<i>Butea monosperma</i>)													Y	Y
Adusa (<i>Justicia adhatoda</i>)													Y	Y
Semal (<i>Bombax ceiba</i>)													Y	Y
Satyanashi (<i>Argemone mexicana</i>)													Y	Y
Kachnar (<i>Bauhinia variegata</i>)													Y	Y
Sita Ashok (<i>Saraca asoca</i>)													Y	Y
Mahua (<i>Madhuca indica</i>)													Y	Y
Tendu (<i>Diospyros melanoxylon</i>)													N/L	Y
Neem (<i>Azadirachta indica</i>)													Y	Y
Amaltas (<i>Cassia fistula</i>)													Y	Y
Harra (<i>Terminalia chebula</i>)													N/L	Y
Arjun (<i>Terminalia arjuna</i>)													N/L	Y
Bel (<i>Aegle marmelos</i>)													Y	Y
Baheda (<i>Terminalia bellirica</i>)													N/L	Y
Teak (<i>Tectona grandis</i>)													N	Y
Karanj (<i>Millettia pinnata</i>)													Y	Y
Gokhru (<i>Tribulus terrestris</i>)													N/L	Y
Bhui Amla (<i>Phyllanthus niruri</i>)													N	Y
Kanthkari (<i>Solanum xanthocarpum</i>)													N/L	Y
Giloy (<i>Tinospora cordifolia</i>)													N	N
Shankhpushpi (<i>Clitoria ternatea</i>)													N/L	Y
Kaladana (<i>Cardiospermum halicacabum</i>)													N	Y

Kundru (<i>Coccinia grandis</i>)																Y	Y
Lagerstroemia (<i>Lagerstroemia parviflora</i>)																Y	Y
Bhringraj (<i>Eclipta prostrata</i>)																N/L	Y
Apamarg (<i>Achyranthes aspera</i>)																N	Y
Chirchita (<i>Triumfetta rhomboidea</i>)																N	Y
Sweet potato (<i>Ipomoea batatas</i>)																Y	Y
Nagarmotha (<i>Cyperus rotundus</i>)																N	N
Amla (<i>Phyllanthus emblica</i>)																N/L	Y
Datura (<i>Datura metel</i>)																Y	Y
Alstonia (<i>Alstonia scholaris</i>)																Y	Y
Salai (<i>Boswellia serrata</i>)																N/L	Y
Madhya Bharat																	
Palash (<i>Butea monosperma</i>)																Y	Y
Adusa (<i>Justicia adhatoda</i>)																Y	Y
Ber (<i>Ziziphus mauritiana</i>)																Y	Y
Semal (<i>Bombax ceiba</i>)																Y	Y
Satyanashi (<i>Argemone mexicana</i>)																Y	Y
Kachnar (<i>Bauhinia variegata</i>)																Y	Y
Sita Ashok (<i>Saraca asoca</i>)																Y	Y
Mahua (<i>Madhuca indica</i>)																Y	Y
Tendu (<i>Diospyros melanoxylon</i>)																N/L	Y
Neem (<i>Azadirachta indica</i>)																Y	Y
Hingot (<i>Balanites aegyptiaca</i>)																Y	Y
Amaltas (<i>Cassia fistula</i>)																Y	Y
Harra (<i>Terminalia chebula</i>)																N	Y
Kheksa (<i>Capparis decidua</i>)																N	Y
Khejri (<i>Prosopis cineraria</i>)																Y	Y
Reunjha (<i>Acacia leucophloea</i>)																Y	Y
Baheda (<i>Terminalia bellirica</i>)																N/L	Y
Siris (<i>Albizia lebbbeck</i>)																Y	Y
Babool (<i>Acacia nilotica</i>)																Y	Y
Lagerstroemia (<i>Lagerstroemia parviflora</i>)																Y	Y
Karanj (<i>Milettia pinnata</i>)																Y	Y
Phog (<i>Calligonum polygonoides</i>)																Y	Y
BhuiAmla (<i>Phyllanthus niruri</i>)																N	Y
Giloy (<i>Tinospora cordifolia</i>)																N	N
Shankpushpi (<i>Clitoria ternatea</i>)																N/L	Y
Kaladana (<i>Cardiospermum halicacabum</i>)																N	Y
Kundru (<i>Coccinia grandis</i>)																Y	Y
Gokhru (<i>Tribulus terrestris</i>)																N/L	Y
Kanthkari (<i>Solanum xanthocarpum</i>)																N/L	Y
Indian Jalap (<i>Operculina turpethum</i>)																N	Y
Apamarg (<i>Achyranthes aspera</i>)																N	Y
Chirchita (<i>Triumfetta rhomboidea</i>)																N	Y
Amla (<i>Phyllanthus emblica</i>)																N/L	Y

[illegible]

Karanj (<i>Milettia pinnata</i>)														Y	Y
Kusum (<i>Schleichera oleosa</i>)														Y	Y
Harra (<i>Terminalia chebula</i>)														N	Y
Arjun (<i>Terminalia arjuna</i>)														N/L	Y
Baheda (<i>Terminalia bellirica</i>)														N/L	Y
Teak (<i>Tectona grandis</i>)														N	Y
Kantakari (<i>Solanum xanthocarpum</i>)														N/L	Y
Giloy (<i>Tinospora cordifolia</i>)														N	N
Shankhpushpi (<i>Clitoria ternatea</i>)														N/L	Y
BhuiAmla (<i>Phyllanthus niruri</i>)														N	Y
Gokhru (<i>Tribulus terrestris</i>)														N/L	Y
Lagerstroemia (<i>Lagerstroemia parviflora</i>)														Y	Y
Kundru (<i>Coccinia grandis</i>)														Y	Y
Apamarg (<i>Achyranthes aspera</i>)														N	Y
Bhringraj (<i>Eclipta prostrata</i>)														N/L	Y
Chirchita (<i>Triumfetta rhomboidea</i>)														N	Y
Kaladana (<i>Cardiospermum halicacabum</i>)														N	Y
Amla (<i>Phyllanthus emblica</i>)														N/L	Y
Datura (<i>Datura metel</i>)														Y	Y
Alstonia (<i>Alstonia scholaris</i>)														Y	Y
Baghelkhand															
Palash (<i>Butea monosperma</i>)														Y	Y
Adusa (<i>Justicia adhatoda</i>)														Y	Y
Sal (<i>Shorea robusta</i>)														N/L	Y
Semal (<i>Bombax ceiba</i>)														Y	Y
Satyanashi (<i>Argemone mexicana</i>)														Y	Y
Mahua (<i>Madhuca indica</i>)														Y	Y
Amaltas (<i>Cassia fistula</i>)														Y	Y
Tendu (<i>Diospyros melanoxylon</i>)														N/L	Y
Harra (<i>Terminalia chebula</i>)														N	Y
Arjun (<i>Terminalia arjuna</i>)														N/L	Y
Bel (<i>Aegle marmelos</i>)														Y	Y
Baheda (<i>Terminalia bellirica</i>)														N/L	Y
Teak (<i>Tectona grandis</i>)														N	Y
BhuiAmla (<i>Phyllanthus niruri</i>)														N	Y
Nirgundi (<i>Vitex negundo</i>)														Y	Y
Giloy (<i>Tinospora cordifolia</i>)														N	N
Bhringraj (<i>Eclipta prostrata</i>)														N/L	Y
Kaladana (<i>Cardiospermum halicacabum</i>)														N	Y
Morning Glory (<i>Ipomoea spp.</i>)														Y	Y
Apamarg (<i>Achyranthes aspera</i>)														N	Y
Datura (<i>Datura metel</i>)														Y	Y
Amla (<i>Phyllanthus emblica</i>)														N/L	Y
Salai (<i>Boswellia serrata</i>)														N/L	Y
Bundelkhand															

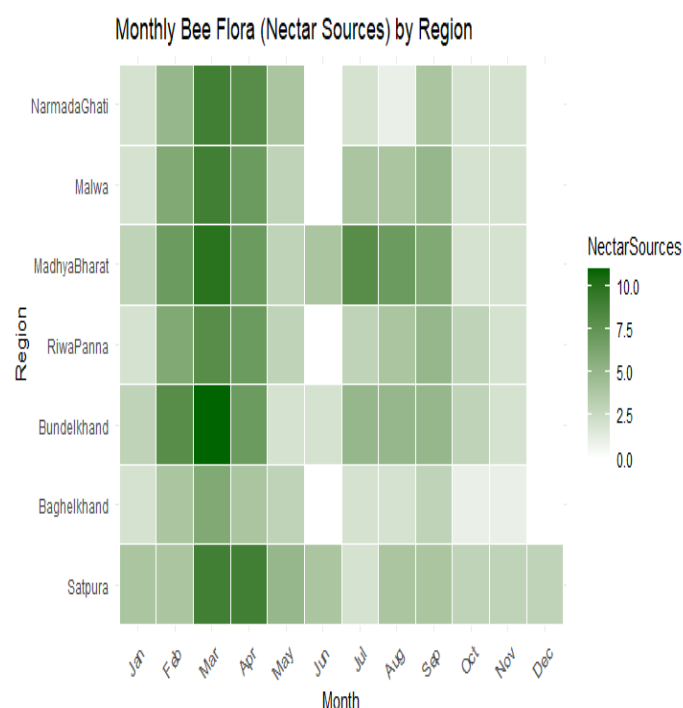
Palash (<i>Butea monosperma</i>)															Y	Y
Ber (<i>Ziziphus mauritiana</i>)															Y	Y
Adusa (<i>Justicia adhatoda</i>)															Y	Y
Semal (<i>Bombax ceiba</i>)															Y	Y
Satyanashi (<i>Argemone mexicana</i>)															Y	Y
Kachnar (<i>Bauhinia variegata</i>)															Y	Y
Sita Ashok (<i>Saraca asoca</i>)															Y	Y
Indian Coral Tree (<i>Erythrina variegata</i>)															Y	Y
Mahua (<i>Madhuca indica</i>)															Y	Y
Amaltas (<i>Cassia fistula</i>)															Y	Y
Neem (<i>Azadirachta indica</i>)															Y	Y
Tendu (<i>Diospyros melanoxylon</i>)															N/L	Y
Arjun (<i>Terminalia arjuna</i>)															N/L	Y
Harra (<i>Terminalia chebula</i>)															N	Y
Teak (<i>Tectona grandis</i>)															N	Y
Siris (<i>Albizia lebbbeck</i>)															Y	Y
Kadamba (<i>Neolamarckia cadamba</i>)															Y	Y
Gokhru (<i>Tribulus terrestris</i>)															N/L	Y
BhuiAmla (<i>Phyllanthus niruri</i>)															N	Y
Kanthkari (<i>Solanum xanthocarpum</i>)															N/L	Y
Giloy(<i>Tinospora cordifolia</i>)															N	N
Shankhpushpi (<i>Clitoria ternatea</i>)															N/L	Y
Kundru (<i>Coccinia grandis</i>)															Y	Y
Kaladana (<i>Cardiospermum halicacabum</i>)															N	Y
Lagerstroemia (<i>Lagerstroemia parviflora</i>)															Y	Y
Karanj (<i>Milettia pinnata</i>)															Y	Y
Baheda (<i>Terminalia bellirica</i>)															N/L	Y
Bhringraj (<i>Eclipta prostrata</i>)															N/L	Y
Apamarg (<i>Achyranthes aspera</i>)															N	Y
Morning Glory (<i>Ipomoea spp.</i>)															Y	Y
Datura (<i>Datura metel</i>)															Y	Y
Amla (<i>Phyllanthus emblica</i>)															N/L	Y
Alstonia(<i>Alstonia scholaris</i>)															Y	Y
Salai (<i>Boswellia serrata</i>)															N/L	Y
Satpura Range																
Sal (<i>Shorea robusta</i>)															N/L	Y
Palash (<i>Butea monosperma</i>)															Y	Y
Lokhandi (<i>Ixora pavetta</i>)															Y	Y
Mango (<i>Mangifera indica</i>)															N	Y
Lanceleaf Blumea (<i>Blumea lanceolaria</i>)															N	Y
Shallaki (<i>Boswellia serrata</i>)															N	Y
Melastoma malabathricum															N	Y
Mahua (<i>Madhuca indica</i>)															Y	Y
Jasmine (<i>Jasminum officinale.</i>)															Y	Y
Sunfiower (<i>Helianthus annuus</i>))															Y	Y

Tendu (<i>Diospyros melanoxylon</i> Roxb)														N/L	Y
Dhava (<i>Anogeissus latifolia</i>)														Y	Y
Giria (<i>Chloroxylon swietenia</i>)														Y	Y
Kosam (<i>Schleichera oleosa</i>)														Y	Y
Jamun (<i>Syzygium cumini</i>)														Y	Y
Orange Jasmine (<i>Murraya paniculata</i>)														Y	Y
Chinese hat plant (<i>Holmskioldia sanguinea</i>)														Y	Y
Bel (<i>Aegle marmelos</i>)														Y	Y
Arjun (<i>Terminelia arjuna</i>)														N/L	Y
Teak (<i>Tectona grandis</i>)														N	Y
Lotus (<i>Nelumbo nucifera</i>)														Y	Y
Adavibilu (<i>Sophora interrupta</i>)														Y	Y

The heatmap illustrating monthly nectar resource availability across seven ecogeographical zones (Figure 2) reveals clear seasonal patterns of melliferous flora across different regions of Madhya Pradesh. Nectar abundance peaks during the pre-summer months (March and April) in most regions, with Bundelkhand exhibiting the highest species richness of nectar-

yielding plant species during this period. A secondary bloom is evident during the monsoon months (July–August), especially in Madhya Bharat, Malwa, and Rewa-Panna. In contrast, June and the late post-monsoon months (November–December) exhibit comparatively lower nectar availability across most regions.

A



B

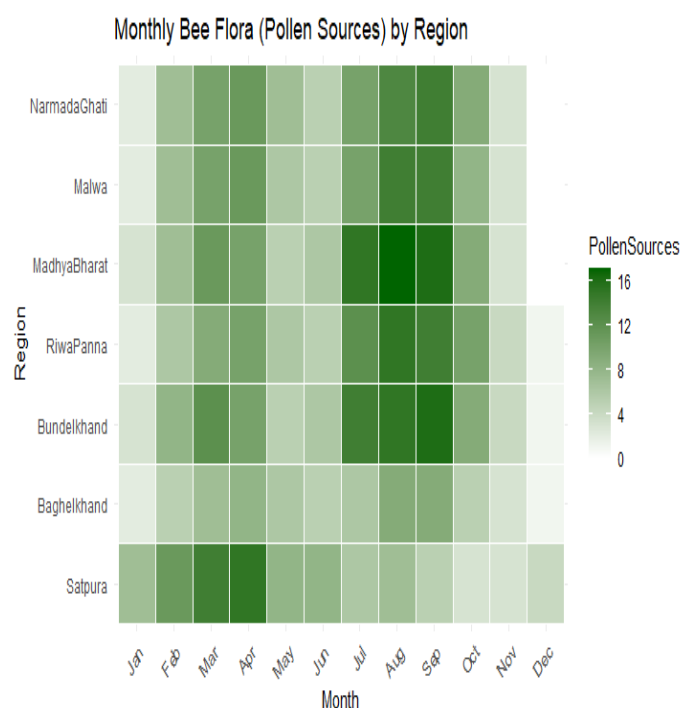


Figure 2. Heatmaps depicting the monthly distribution of bee forage resources across regions of Madhya Pradesh. (A) Monthly availability of nectar-yielding plant species; (B) Monthly availability of pollen-yielding plant species. Color intensity indicates relative abundance, with darker shades representing higher numbers of forage species.

Among the regions, Bundelkhand and Madhya Bharat display the most pronounced and well-defined flowering peaks during spring. Satpura and Baghelkhand exhibit comparatively lower and evenly spread nectar species richness throughout the year. Malwa, Rewa-Panna, and Narmada Ghati display moderate nectar resource availability with seasonal fluctuations.

The cluster dendrogram (Figure 3) identifies two primary regional groupings. Baghelkhand, Narmada

Ghati, Rewa-Panna, and Malwa form one major cluster, suggesting similarity in nectar flora composition and seasonal patterns. Satpura, Bundelkhand, and Madhya Bharat form a separate cluster, with Bundelkhand and Madhya Bharat showing similarity. Interestingly, Satpura, despite having less intense nectar peaks, aligns more closely with Bundelkhand–Madhya Bharat than with the central cluster, indicating moderate floral overlap.

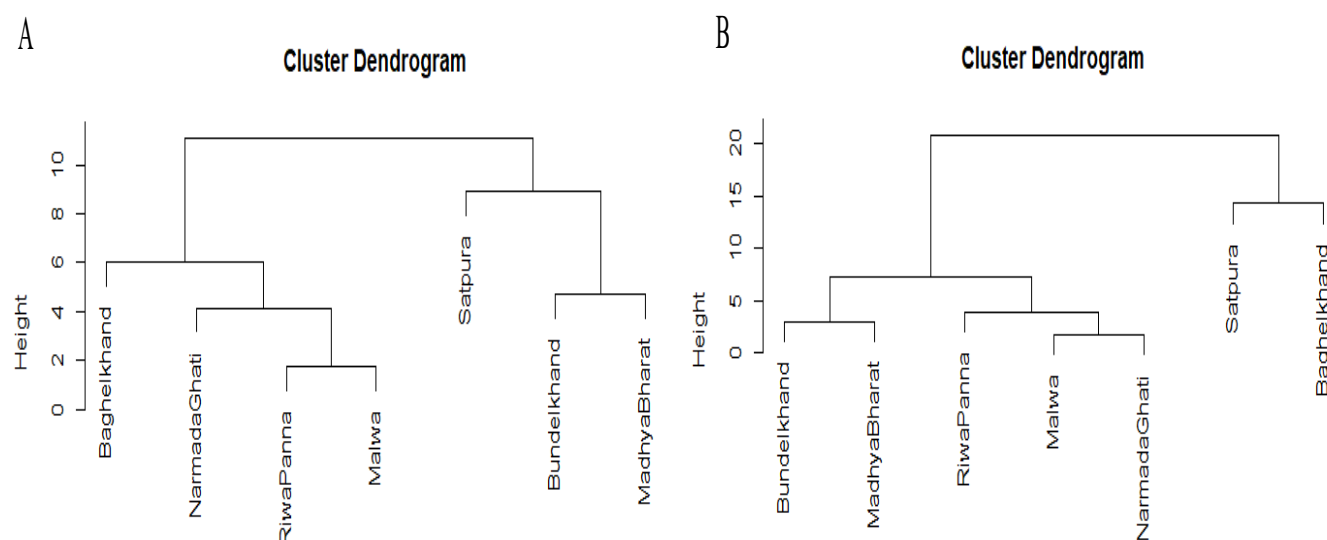


Figure 3. Cluster dendrograms illustrating the similarity among different regions of Madhya Pradesh based on the composition and seasonal availability of bee forage plants. (A) Nectar-yielding species; (B) Pollen-yielding species. Regions clustered closely indicate comparable flowering patterns and similar forage potential for honey bees.

Forest ecosystem- Pollen sources

The heatmap illustrates the seasonal dynamics of pollen-yielding bee flora across different regions of Madhya Pradesh (Figure 2). Pollen sources appear to be more evenly distributed throughout the year compared to nectar resources. An overall increase in pollen species richness is observed from March to September, with peak availability during the monsoon and post-monsoon months (July to September), particularly in regions like Madhya Bharat, Bundelkhand, and Rewa-Panna. Conversely, December and January show the lowest availability of pollen sources across most regions. The cluster dendrogram (Figure 3) reveals two distinct regional groupings. Bundelkhand, Madhya Bharat, Rewa-Panna, Malwa, and Narmada Ghati form a closely linked cluster, indicating similarity in pollen flowering patterns. Within this cluster, Bundelkhand and Madhya Bharat show the highest similarity. Satpura and Baghelkhand form a separate cluster, reflecting differences in pollen species composition and seasonal dynamics relative to other zones.

Discussion

Importantly, the study underscores the significant ecological role of forest bee flora. Spring nectar peaks promote intense foraging, whereas intermittent low-resource periods may create nutritional stress, highlighting the need to align colony management and migration with flowering cycles. Regional clustering suggests some zones can share forage planning approaches, while others require location-specific strategies. More consistent pollen availability supports brood rearing during nectar decline, though regional differences may still influence colony performance. Overall, strong spatial and seasonal variation in floral resources calls for zone-specific, adaptive beekeeping rather than uniform management practices.

Forest ecosystems in regions like Satpura and Rewa-Panna contribute substantially in sustaining wild honey bees. These natural habitats function as reservoirs of genetic diversity and ecological stability for native pollinators. Beyond their ecological value, forest landscapes present significant scope for carefully regulated forest-based beekeeping models that integrate conservation with livelihood enhancement. Community-based apiculture, buffer-zone apiaries, and non-destructive harvesting practices could help balance biodiversity protection with income generation. However, their limited integration in formal apiculture systems reflects untapped potential that could be harnessed through alignment with regional floral calendars and sustainable management guidelines.

A key implication of this study is the occurrence of seasonal floral dearth, particularly during June and the late post-monsoon period (November–December). These resource gaps may compromise colony strength, brood development, and honey yield (Roulston & Goodell 2011; Ghosh & Jung 2024), especially in regions lacking continuous forage, where supplemental feeding or migration becomes necessary (Kartik et al. 2024). Strategic enrichment planting of off-season melliferous species in forest fringes, agroforestry systems, and community lands could enhance forage continuity and strengthen ecological resilience (Muschler 2016).

While this study provides valuable insights into the spatial and temporal distribution of nectar and pollen-yielding flora across Madhya Pradesh, several limitations should be acknowledged.

- The assessment is based on seasonal presence-absence data and does not quantify species abundance or dominance.
- Direct measurement of nectar volume, sugar concentration, and pollen yield were not

undertaken, limiting evaluation of true nutritional value (Pasquale et al. 2013; Fowler et al. 2016).

- Bee visitation rates and species-specific forage preferences were not examined, restricting insight into plant-pollinator interaction strength.

Future research integrating quantitative floral traits, resource productivity, and pollinator behaviour would strengthen ecological inference and applied recommendations.

The practical relevance of this work lies in its application to apiculture planning. Seasonal floral calendars can guide migratory scheduling, apiary site selection, and timely management interventions during dearth periods. At a broader scale, this region-specific floral assessment can inform state-level apiculture development programs, extension training modules, and resource allocation strategies. Embedding such data into policy and farmer awareness initiatives would promote more adaptive, climate-resilient, and sustainable beekeeping systems across Madhya Pradesh.

Conclusion

This study demonstrating clear spatial and temporal variation in nectar- and pollen-yielding flora across Madhya Pradesh, identifying regional strengths as well critical flowering gaps during June and the post-monsoon months. These seasonal shortages highlight the need for strategic forage enrichment and well-planned migratory management to sustain colony productivity. By integrating agro- and forest-based floral calendars, the study offers a consolidated framework for region-specific apicultural planning, improved migratory route design, and targeted floral enhancement, particularly in ecologically promising zones such as Satpura and Baghelkhand. Beyond improving honey production, these insights support pollinator conservation, strengthen rural livelihoods, and can inform state-level apiculture programs, extension services, and rural development initiatives aimed at promoting sustainable and climate-resilient beekeeping systems.

Declarations of interests

All authors of this manuscript declare that they have no conflict of interest.

Data sharing

All relevant data are within the manuscript including Appendix.

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