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Original research article

Addressing Nutritional Gaps in Honey Bee Colonies: Synthesis of Existing Studies and Implications for Beekeeping Sustainability in West Bengal, India

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Abstract Beekeeping in West Bengal faces several challenges that hinder its growth and sustainability, particularly when it comes to honey bee nutrition. Despite being a significant player in honey production, the region's beekeeping industry is limited by a lack of understanding regarding the nutritional needs of honey bee colonies, particularly in terms of the pollen they consume. The overemphasis on honey production has led to the neglect of other valuable hive products, including bee-pollen, which plays a crucial role in colony health. Furthermore, limited knowledge of the diversity, quantity, and nutritional composition of the pollen collected by bees creates significant barriers to optimizing bee nutrition and colony management. Seasonal fluctuations in forage availability, particularly during the dearth season, exacerbate these challenges, while inadequate infrastructure and insufficient awareness among beekeepers prevent effective nutritional interventions. This paper highlights the importance of investigating the nutritional value of pollen, as well as the need for supplementary feeding practices, to ensure optimal colony health. Understanding and addressing these nutritional gaps is essential not only for improving colony strength but also for enhancing the sustainability of beekeeping as a livelihood in West Bengal.

Keywords Apiary management, Bee-flora, Bee nutrition, Bee-pollen, Feed fortification, Mellisopalynology, Nutrients, Pollen patty, Supplementary feeding

INTRODUCTION

Beekeeping, an age-old practice integral to sustainable agriculture and rural livelihoods, has immense potential beyond honey production, yet remains underutilized in many parts of India, including West Bengal. Beekeeping, or apiculture, with *Apis mellifera* and *A. cerana*, is often featured in conversations about sustainable development and livelihood enhancement in India (Abrol, 2023; Basu and Purkait, 2023); however, in practice, most initiatives continue to focus predominantly on honey production. Despite various governmental efforts to support the sector (Narang *et al.*, 2022), the industry remains predominantly focused on honey as the primary source of income for beekeepers. This narrow focus often results in the neglect of other valuable hive products such as bee pollen, royal jelly, propolis, and bee venom, which hold significant potential for economic diversification and increased revenue (Ghosh *et al.*, 2021a). Recent proposals have emphasized the nutritional potential of honey bee brood, particularly drone brood, as a source of food and animal feed due to its rich nutritional profile (Ghosh *et al.*, 2021b). However, despite being a leading producer of honey globally, the Indian beekeeping industry still faces concerns regarding quality (CSE, 2020) and falls behind its counterparts in industrialized nations, where the diversification of hive products significantly contributes to sector growth and resilience. This over-reliance on honey

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limits the overall expansion and economic viability of apiculture in India, including in regions such as West Bengal.

BEE-FLORA OF WEST BENGAL

As highlighted by Narang *et al*. (2022), the availability of diverse bee flora throughout the year, albeit with seasonal variation, serves as a significant advantage or strength for beekeeping. Similarly, the favourable environment of West Bengal offers a range of floral diversity crucial for the nourishment of bees. West Bengal's diverse geographical landscape, from the Himalayan foothills in the north to the southern coastal regions, creates significant variations in climate that impact plant and crop blooming times across its districts. In the cooler northern districts like Darjeeling and Kalimpong, a temperate climate promotes early blooming of tea plants and flowering of orchids like *Dendrobium* due to consistent mist and cooler temperatures (Fig. 1). In contrast, the central and western districts such as Purulia, Bankura, and Birbhum experience a drier, hotter climate with marked seasonal shifts, where mango trees bloom later compared to northern areas, and crops like mustard are timed to match the arid conditions. The humid subtropical climate of eastern districts like Nadia and Murshidabad encourages earlier blooming of *Boro rice* and litchi trees in spring, benefitting from high temperatures and ample rainfall. Meanwhile, the southern coastal districts, including South 24 Pargonas and East Midnapore, have a tropical climate influenced by the monsoon, fostering early flowering of mangrove trees like *Sundari* and year-round cultivation of crops like coconut and betel leaf due to persistent moisture. This diverse range of climatic conditions showcases the unique agricultural practices needed for different parts of West Bengal to thrive.

1. Diversity of bee-flora

Nectar and pollen are essential nutritional sources for honey bees. Nectar, primarily providing carbohydrates, is collected from plants known as nectariferous plants. Pollen, on the other hand, is a source of protein (including essential amino acids), fats (including essential fatty acids), and micronutrients (vitamins, and minerals). Plants that provide pollen are referred to as polleniferous plants. Identifying the botanical sources that nourish honey bees

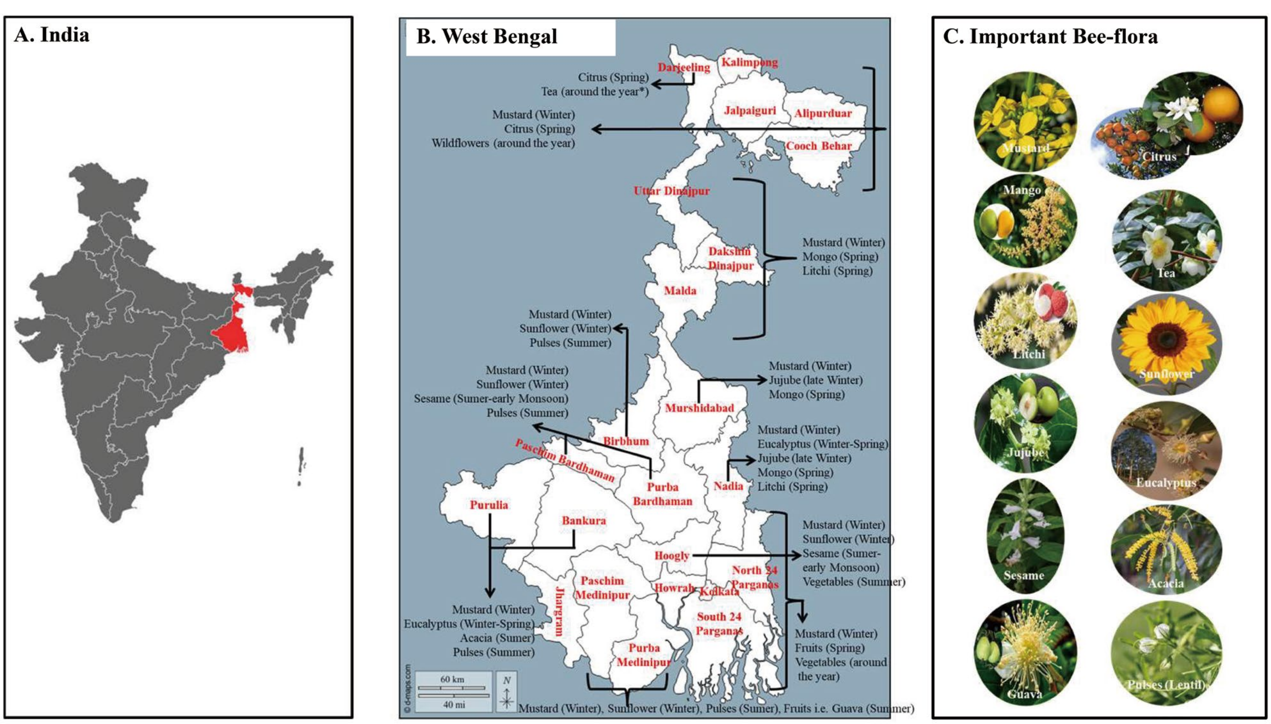

Fig. 1. Study area - (A) The location of state of West Bengal in India; (B) Districts of West Bengal and key bee-flora especially for beekeeping of the state; (C) Photographs of some of the bee-flora of the districts [Map outlines and photographs were sourced from web].

can be done by analysing honey (to find out nectar source) to extract and identify pollen or by using pollen traps to collect bee-foraged pollen (to find out pollen source) directly for identification.

Mukhopadhyay *et al.* (2007) conducted an analysis of honey samples (from *A. cerana* indica and *Apis florea*) collected during summer, autumn, and winter from rural areas of Darjeeling and Jalpaiguri districts. They aimed to identify the botanical origins of nectar sources. The study revealed 165 pollen taxa across 73 plant families. Notably, 18 of 50 studied unifloral honey samples were dominated by pollens from *Rosa* sp., *Ageratum conyzoides*, *Rubus ellipticus*, *Prunus* sp., *Millettia pulchra*, *Trifolium repens*, *Primula* sp., *Schima wallichii*, *Fragaria* sp., and *Potentilla* sp. in summer; *A. conyzoides*, *S. wallichii*, *Sedum multicaule* in autumn; and *Aristolochia* sp., *Rosa* sp. in winter. Basak *et al.* (2025) analyzed honey of *A. cerana* to identify the major and minor nectar sources in the Sub-Himalayan region of West Bengal, focusing on areas such as Kolakham, Buxa, and Jayanti, and compiled a month-wise nectar calendar. Among the major nectar sources, *Mimosa pudica* served as a key nectar source from January to March. In March, *Imperata cylindrica* and *Syzygium cumini* were significant, while *Erigeron karvinskianus* dominated from April to September. Other major sources included *Prunus persica* in April, *Pavetta indica* in May, *Tectona grandis*, *Mimosa rubicaulis*, and *Saccharum* spp. from June to October, *Cestrum aurantiacum* from June to December, *Macaranga indica* in August and September, *Dicliptera bupleuroides* in September and October, and *Clematis buchananiana* from October to December (Basak *et al.*, 2025). Additionally, minor bee-flora in the region included *Borassus flabellifer*, *Meyna spinosa*, *Eucalyptus globulus*, *Combretum decandrum*, *Grewia optiva*, *Albizia lebbeck*, and *Fuchsia magellanica*, among others (Basak *et al.*, 2025).

Layek *et al.* (2020a) investigated *A. mellifera* pollen foraging across four different places in districts in southern West Bengal (Nadia, Burdwan, Bankura, and Paschim Midnapore). They found significant seasonal variations in pollen taxa, with the highest collection in winter and spring and the lowest during the monsoon (a dearth period). Key biomass-contributing plants included *Brassica nigra*, *Eucalyptus globulus*, *Borassus flabellifer*, *Sesamum indicum*, *Acacia auriculiformis*, *Coriandrum sativum*, *Cocos nucifera*, *Phoenix sylvestris*, and *Mikania scandens*. Mondal *et al.* (2023) reported major pollen sources for *A. cerana* in Paschim Medinipur, including *Acacia auriculiformis*, *Brassica juncea* (brown mustard), *C. nucifera*, *Eucalyptus* sp., *Neolamarckia cadamba*, *Peltophorum pterocarpum*, *Sesamum indicum*, and *Tridax procumbens*. Pal and Karmakar (2013) documented that the forage spectrum of *A. mellifera* in Gangetic West Bengal encompasses a total of 77 species of flowering plants, and they developed a month-by-month floral calendar. Key pollen sources among these include *C. nucifera*, *P. sylvestris*, *B. flabellifer*, *Citrus maxima*, *Carica papaya*, *Pongamia pinnata*, *Luffa acutangula*, *Croton bonplandianus*, *Terminalia arjuna*, *Bauhinia malabarica*, *Averrhoa carambola*, *Chrozophora rottleri*, *Monochoria hastate*, *Anthocephalus cadamba*, *A. auriculiformis*, *Murraya paniculata*, *Cleome viscosa*, *E. globulus*, and *Xanthium strumarium*. Notable nectar sources include *B. nigra*, *Moringa oleifera*, *B. flabellifer*, *Syzygium cumini*, *S. indicum*, *A. cadamba*, *Impatiens balsamina*, *E. globulus*, *A. auriculiformis*, and *M. scandens*. Das *et al.* (2024) studied the pollen foraging pattern of *A. mellifera*, *A. cerana*, and *Tetragonula bengalensis* in the lower Gangetic alluvium of West Bengal during dearth period. Predominant pollen sources included *Commelina diffusa*, *Aeschynomene aspera*, *C. nucifera*, and *E. globulus*, with clear evidence of resource partitioning among the species.

An investigation into the botanical origin of winter honey from Howrah district revealed that pollen grains from *B. nigra*, *C. sativum*, and *C. nucifera* were predominant in most honey samples, indicating their source in the region's winter crops and plantations. Additionally, pollen from some anemophilous plants, particularly those belonging to Poaceae and Cyperaceae families, were noted as significant minor contributors. The analysis also identified pollen from various weeds such as *C. bonplandianus*, *Leucas* sp. and *Parthenium hysterophorus* as minor components within the honey samples, alongside the pollen from economically valuable and cultivated plants (Chakraborty *et al.*, 2023).

Kamble *et al.* (2015) conducted melittopalynological analyses of honey samples from the Sundarbans mangrove region of West Bengal. Their study of *A. mellifera* honey identified six unifloral and three multifloral samples. *Ceriops decandra* was the predominant pollen type in five samples, while *Aegiceras corniculatum* dominated one. Secondary pollen sources included *Bruguiera gymnorrhiza*, *Sonneratia apetala*, and *Bunium persicum*. Overall, 37 plant species were recognized as forage sources. For *Apis dorsata*, *C. decandra* appeared as the predominant pollen in two samples and secondary in one, while *Kandelia candel* was present in all *A. dorsata* samples as a secondary source but absent in *A. mellifera*, suggesting resource partitioning between these species.

Table 1 presents information on the bee flora of West Bengal, derived from studies on honey and bee-pollen. While these findings have been primarily obtained through investigative and microscopic analyses, it is important to note that there is potential for numerous other floral re-

Table 1. Information on the bee-flora of West Bengal, derived from scientific studies on honey and bee-pollen

Scientific name	Family	Common name	Local name*
Acacia auriculiformis	Fabaceae	Earleaf acacia	Babool/ Aakashmani
Aegiceras corniculatum	Primulaceae	Black mangrove	Khalsi
Aeschynomene aspera	Fabaceae	Indian harsh joint vetch	Shola
Ageratum conyzoides	Asteracea	Billygoatweed/Chick weed	Oochunti
Anthocephalus cadamba or *Neolamarckia cadamba*	Rubiaceae	Bur-flower tree	Kadam
Aristolochia sp.	Aristolochiaceae	Birthwort/ Pipevine	Ishormul / Isheri
Averrhoa carambola	Oxalidaceae	Star fruit	Kamranga
Azadirachta indica	Meliaceae	Neem	Neem
Bauhinia malabarica	Fabaceae	Malabar bauhinia	Kanchan/ Karmai
Borassus flabellifer	Arecaceae	Palmyra palm	Tal
Brassica campestris or *Brassica rapa*	Brassicaceae	Rapeseed	Sorisha/Sorshe
Brassica juncea	Brassicaceae	Indian mustard/Brown mustard	Sorisha/Sorshe
Brassica nigra	Brassicaceae	Black mustard	Kalo sorisha/Sorshe
Bruguiera gymnorrhiza	Rhizophoraceae	Oriental mangrove	Kankra
Bunium persicum	Apiaceae	Black cumin	Shahi jeera
Capparis zeylanica	Capparaceae	Ceylon caper	Kalokera
Carica papaya	Caricaceae	Papaya	Penpe
Ceriops decandra	Rhizophoraceae	Flat-leaved spurred mangrove	Goran
Cestrum aurantiacum	Solanaceae	Orange jessamine/ Yellow shrub jessamine	–
Chrozophora rottleri	Euphorbiaceae	Indian chalk plant	Suryavarti
Citrus maxima	Rutaceae	Pomelo	Batabi
Clematis buchananiana	Ranunculaceae	Lemon clematis	Junge laharaa
Cleome viscosa	Cleomaceae	Asian spider flower	Hulhul
Cocos nucifera	Arecaceae	Coconut	Narikel
Commelina diffusa	Commelinaceae	Climbing day flower	Kankana/Kanainala
Coriandrum sativum	Apiaceae	Coriander	Dhone
Croton bonplandianus	Euphorbiaceae	Bonpland's croton	Ban tulsi
Cucurbita moschata	Cucurbitaceae	Pumpkin	Kumro
Cucumis sativus	Cucurbitaceae	Cucumber	Khira/Shosha
Cuminum cyminum	Apiaceae	Cumin	Jeera
Dicliptera bupleuroides	Acanthaceae	Roxburg's foldwing/ Thorowax foldwing	–
Erigeron karvinskianus	Asteraceae	Mexican fleabane	–
Echinochloa frumentacea	Poaceae	Barnyard millet	Sanwa/Shyama
Eucalyptus globulus	Myrtaceae	Blue gum	Eucalyptus
Eucalyptus sp.	Myrtaceae	Eucalyptus	Eucalyptus
Fragaria sp.	Rosaceae	Strawberry	Strawberry
Helianthus annuus	Asteraceae	Common sunflower	Suryamukhi

Table 1. Continued

Scientific name	Family	Common name	Local name*
Impatiens balsamina	Balsaminaceae	Garden balsam	Gil mandi/ Dopati
Kandelia candel	Rhizophoraceae	Narrow-leaved kandelia	Guria/Goria
Lathyrus sativus	Fabaceae	Grass pea, Chickling pea	Khesari
Leucas sp.	Lamiaceae	Thumbai/ Thumba	–
Litchi chinensis	Sapindaceae	Lychee	Litchi/Lichu
Luffa acutangula	Cucurbitaceae	Ridge gourd	Torai/Gilki/Jhinge
Macaranga indica	Euphorbiaceae	Parasol leaf tree/ Heart leaf	Ramalo
Mangifera indica	Anacardiaceae	Mango	Aam
Monochoria hastate	Pontederiaceae	Arrow leaf pondweed	Launkia/ Nukha
Mikania scandens	Asteraceae	Climbing hempvine	Bikash lata
Millettia pulchra	Fabaceae		
Mimosa pudica	Fabaceae	Touch-me-not	Lajwanti/Chui-mui/Lojjaboti
Mimosa rubicaulis	Fabaceae	Himalayan mimosa	Agla/Alral/Shiahkanta/Kuchikanta
Moringa oleifera	Moringaceae	Moringa/ Drumstick tree	Sajina/Sajne
Murraya paniculata	Rutaceae	Orange jasmine	Kamini
Nelumbo nucifera	Nelumbonaceae	Lotus	Kamal/ Padma
Oryza sativa	Poaceae	Paddy	Dhan
Nigella sativa	Ranunculaceae	Black cumin	Kalonji/ Kalojeera
Papaver somniferum	Papaveraceae	Opium poppy	Khuskhus/ Posto
Parthenium hysterophorus	Asteraceae	Santa Maria	Parthenium
Pavetta indica	Rubiaceae	Indian sorrel/ Hill pavetta	Kankra/Jui
Peltophorum pterocarpum	Fabaceae	Copperpod	Radhachura/ Kanakchura
Phoenix sylvestris	Arecaceae	Indian date palm	Khejur
Phyllanthus emblica	Phyllanthaceae	Indian gooseberry	Amla/Amlaki
Pongamia pinnata	Fabaceae	Indian beech tree	Karanja
Potentilla sp.	Rosaceae	Cinquefoils	Jhonukmoni, Bhuijam
Primula sp.	Primulaceae	Primrose	Primrose
Prunus persica	Rosaceae	Peach	Peach
Prunus sp.	Rosaceae	Cherry, Plum	Cherry, Plum
Psidium guajava	Myrtaceae	Guava	Amrut/Peyara
Rosa sp.	Rosaceae	Rose	Gulab/Golap
Rubus ellipticus	Rosaceae	Yellow Himalayan raspberry	Hinsalu
Schima wallichii	Theaceae	Needlewood	Chilauni
Sedum multicaule	Crassulaceae	Stonecrop	–
Sesamum indicum	Pedaliaceae	Sesame	Til
Solanum melongena	Solanaceae	Eggplant	Baigan/Begun
Solanum sisymbriifolium	Solanaceae	Sticky nightshade	Swetarangini, Kanta begun
Sonneratia apetala	Lythraceae	Mangrove apple	Keora
Syzygium cumini	Myrtaceae	Jamun	Jamun/Jam
Tagetes spp.	Asteraceae	Marigold	Ganda
Tectona grandis	Lamiaceae	Teak	Teak
Terminalia arjuna	Combretaceae	Arjun tree	Arjun
Tridax procumbens	Asteraceae	Tridax daisy	Tridhara
Trifolium repens	Fabaceae	White clover	–
Xanthium strumarium	Asteraceae	Rough cocklebur	Arishta, Medhya, Sarpakshi
Zea mays	Poaceae	Corn	Makka/ Vutta
Ziziphus mauritiana	Rhamnaceae	Indian jujube	Ber/ Kul

*The local or vernacular names of the plants are given in Hindi or Bengali or both.

sources from bees yet to be explored. Layek *et al.* (2020b) highlighted that honey collection methods impact the pollen composition detected, affecting the determination of true nectar-foraging plants. Their findings showed that extracted and squeezed honey had significantly more pollen grains compared to pipetted honey. Pollen from nectar-deficient but polleniferous plants, such as *Capparis zeylanica*, *Echinochloa frumentacea*, *Papaver somniferum*, Poaceae type, *Nelumbo nucifera*, *Solanum melongena*, and *Solanum sisymbriifolium* were present in extracted and squeezed honey samples. Employing molecular techniques for plant identification could help uncover these resources (Sun *et al.*, 2024).

2. Seasonal nectar and honey production

Table 2 provides an overview of the key or important plant species that serve as nectar and pollen sources for managed honey bees, detailing their scientific names, vernacular names, and blooming seasons, based on existing studies and the author's experience.

Mustard serves as a principal nectar source for honey bees during the winter months, yielding an abundant nectar flow that supports robust honey production (Personal communication, SG). Das *et al.* (2023) presented an in-depth overview of the frequency of honey harvests and the yield from target crops during migratory periods. Beekeepers typically harvest mustard honey at intervals of 8–10 days during the season, with an impressive yield ranging from 15 to 18 kg per hive. Eucalyptus, another significant source of nectar, sustains honey production with harvests occurring at approximately 15-day intervals. Each hive can produce an average of 15 to 17 kg of honey during this period, contributing to a substantial part of the seasonal yield. Litchi blossoms are notable for their rich nectar, which imparts a distinctive flavor to the honey. The litchi season usually allows for harvesting every 8–10 days, with average yields of 4–6 kg per hive. This type of honey is particularly valued for its unique taste profile. Sundarbans honey, a multifloral variety, is often esteemed as pure honey by consumers, primarily due to its origin in forested regions free from pesticide exposure. Hives placed deep within the forest can produce as much as 40–45 kg of honey per box, whereas those situated near populated areas yield approximately 10–12 kg per hive. The harvest cycle for Sundarbans honey is generally every 10–12 days. Sesame, known locally as *til*, also provides an ample nectar source. Beekeepers typically harvest honey from sesame blossoms every 10–12 days, yielding about 5–6 kg per hive. Coriander and black cumin are additional nectar sources for bees, though their honey yields are lower, producing about 2–3 kg per hive with harvests spaced 15 days apart (Das *et al.*, 2023 and Personal communications of SG with beekeepers).

According to personal communications with beekeepers, it is common practice to expedite harvesting before the optimal period. This practice can shorten the interval between harvests, often preventing sufficient evaporation of moisture from the honey and leading to higher moisture content. This, coupled with the naturally high humidity in the area, contributes to elevated moisture levels in the harvested honey.

Nectar and pollen from Moringa (*drumstick*) trees play a vital role in bolstering colony strength, while consistent high nectar flows from mango, *jamun* (black plum), and other fruit trees are crucial for colony build-up in spring. By April, when many other floral sources diminish, wildflowers such as neem and jujube, as well as crops like sunflower, become key nectar and pollen providers, sustaining bee populations in early summer. Late summer sees the emergence of karanj as a nectar source. During the monsoon, coconut blossoms supply nourishment, and guava trees provide moderate amounts of nectar and pollen, which aid in maintaining colony populations as the dearth season begins - a period marked by limited food resources for bees. Although the tropical climate supports a wide range of flora, plants such as amla, acacia, paddy, maize, pumpkin, cucumber, and various seasonal vegetables offer supplementary nectar and pollen.

3. Migratory beekeeping practices

Due to the honey-centric nature of apiculture, a significant portion of beekeeping in West Bengal involves migratory practices. Beekeepers move their colonies to follow regions with high nectar-yielding crops to optimize honey production. Previous studies identified several migratory routes utilized by beekeepers across the state (Purkait and Basu, 2022; Das *et al.*, 2023) as represented in Table 3. Typically, the migration period begins around October or November and continues until May or June, depending on the routes and nectar sources available.

Table 2. Floral calendar of important bee-flora for beekeeping in West Bengal, India

Sr. No.	Bee flora			Source		Year*											
	Common name	Local name	Scientific name	Nectar (N)	Pollen (P)	11	12	01	02	03	04	05	06	07	08	09	10
1	Amla	Amlaki	*Phyllanthus emblica*	N		■											
2	Eucalyptus	Eucalyptus	*Eucalyptus* spp.	N		■	■										
3	Mustard	Sorshe	*Brassica* spp.	N	P	■	■	■	■								
4	Toria	Sorshe	*Brassica campestris*	N	P	■	■										
5	Coriander	Dhone	*Coriandrum sativum*	N	P		■	■	■								
6	Cumin	Jeera	*Cuminum cyminum*	N				■	■								
7	Black Cumin	Kalojeera	*Nigella sativa*	N				■	■								
8	Khesari	Khesari dal	*Lathyrus sativus*	N	P				■								
9	Litchi	Lichu	*Litchi chinensis*	N					■	■	■	■					
10	Moringa (Drumstick)	Sojne	*Moringa oleifera*	N	P				■								
11	Mango	Aam	*Mangifera indica*	N	P				■	■							
12	Jamun	Jaam	*Syzygium cumini*	N						■							
13	Black Plum	Jaam	*Syzygium* spp.	N							■						
14	Wild flowers	Bonyo ful	–	N	P						■						
15	Sesame	Til	*Sesamum indicum*	N	P						■	■	■				
16	Mangrove	Khalsi	*Aegiceras corniculatum*	N	P				■	■							
		Goran	*Ceriops decandra*	N	P					■	■						
		Keora	*Sonnertia apetala*	N	P					■	■						
		Etc. (Overall)	–	N	P				■	■	■						
17	Neem	Neem	*Azadirachta indica*	N								■					
18	Jujube	Kul	*Ziziphus mauritiana*	N	P							■					
19	Sunflower	Surjomukhi	*Helianthus annuus*	N	P							■					
20	Karanj	Karanja	*Pongamia pinnata/Millettia pinnata*	N									■	■	■		
21	Coconut	Narikel	*Cocos nucifera*	N										■			
22	Guava	Peyara	*Psidium guajava*	N	P									■			
23	Maize	Vutta	*Zea mays*		P										■		
24	Pumpkin	Kumro	*Cucurbita moschata*		P										■		
25	Cucumber	Shosha	*Cucumis sativus*	N											■		
26	Vegetables	Shak-Sabji	–	N	P										■		
27	Gurmi	Gurmi	*Cucumis melo*	N	P										■		
28	Paddy	Dhan	*Oryza sativa*		P											■	
29	Acacia	Acacia/Akashmani	*Acacia* spp.	N												■	
30	Marigold	Ganda	*Tagetes* spp.	N	P												■

*The months of the year are represented numerically as follows: 1 = January, 2 = February, 3 = March, 4 = April, 5 = May, 6 = June, 7 = July, 8 = August, 9 = September, 10 = October, 11 = November, and 12 = December.

Table 3. Important floral resource of migratory beekeeping following different routes of migration in West Bengal, India

Sr. No.		Bee flora	Year												District
			11	12	01	02	03	04	05	06	07	08	09	10	
Path 1	Migratory period	Mustard													Uttar Dinajpur Dakshin Dinajpur
		Cumin													Malda, Murshidabad
		Coriander													Murshidabad, Nadia
		Litchi													Murshidabad, North 24 Pargonas
		Mangrove													South 24 Pargonas (Sundarban)
		Sesame													Paschim Midnapore
	Feeding period														–
Path 2	Migratory period	Mustard													Murshidabad
		Coriander													Murshidabad, Malda
		Mango													
		Litchi													Malda, Murshidabad, Nadia
		Sesame													Nadia, Hooghly
	Feeding period														–
Path 3	Migratory period	Eucalyptus													Purulia, Bankura
		Mustard													Murshidabad Malda, Uttar Dinajpur
		Khesari													
		Coriander													Murshidabad, Nadia
		Litchi													Murshidabad
		Sesame													Burdwan, Hooghly, Paschim Midnapore
	Feeding period														–
Path 4	Migratory period	Eucalyptus													Paschim Midnapore, Bankura
		Mustard													Murshidabad, Hooghly, Nadia, Birbhum, Purba Burdwan, North 24 Pargonas, South 24 Pargonas
		Khesari													Nadia, Birbhum, Purba Burdwan, North 24 Pargonas, South 24 Pargonas
		Coriander													
		Litchi													Murshidabad, Nadia, North 24 Pargonas, South 24 Pargonas
		Sesame													Murshidabad, Nadia, Hooghly, Purba Burdwan, Birbhum
	Feeding period														–

Table 3. Continued

Sr. No.	Bee flora		Year												District
			11	12	01	02	03	04	05	06	07	08	09	10	
Path 5	Migratory period	Mustard													North 24 Pargonas, South 24 Pargonas,
		Coriander													Murshidabad, Nadia
		Cumin													
		Litchi													Murshidabad, North 24 Pargonas
		Mango													
		Mangrove													North 24 Pargonas, South 24 Pargonas (Sundarban)
	Feeding period														–
Path 6	Migratory period	Mustard													Uttar Dinajpur, Dakshin Dinajpur, Malda
															Uttar Dinajpur, Dakshin Dinajpur
		Coriander													Murshidabad
		Cumin													
		Litchi													Murshidabad, Malda
		Mango													
	Feeding period														–
Path 7	Migratory period	Eucalyptus													Bankura, Jhargram, Paschim Midnapore
		Mustard													Nadia, Murshidabad, Malda, Uttar Dinajpur
		Coriander													Nadia, Murshidabad
		Black cumin													
		Litchi													Nadia
		Mangrove													South 24 Pargonas
		Sesame													Hooghly, Purba Burdwan
	Feeding period														–

*The months of the year are represented numerically as follows: 1 = January, 2 = February, 3 = March, 4 = April, 5 = May, 6 = June, 7 = July, 8 = August, 9 = September, 10 = October, 11 = November, and 12 = December.

Beekeepers strategically target specific crops known for their abundant nectar production. Commonly pursued crops include eucalyptus, mustard, coriander, litchi, mango, mangrove forest blooms, and sesame. These crops provide substantial nectar flows that are critical for maximizing honey yields. The rest of the year, particularly the 4−5 months from July to early October, is considered the dearth season, when nectar-rich resources are limited or scarce. However, it is important to note that this period is not entirely devoid of floral resources; some wildflowers and less robust nectar sources still contribute to colony sustenance.

Additionally, there is reluctance among agricultural land and orchard owners to host beekeeping colonies due to perceived inconveniences or incidents of harassment (Baidya and Purkait, 2018; Das *et al*., 2023). Reports indicate that while honey bees are capable of foraging up to 10 km from their hives, positioning colonies far from foraging sites is not ideal.

NUTRITIONAL MANAGEMENT: A PILLAR OF SUSTAINABLE BEEKEEPING

Bees select their foraging resources primarily based on their nutritional requirements, carefully choosing sources that offer optimal nutritional rewards. Vaudo *et al*. (2020) highlighted variations in the protein-to-lipid (P : L) ratio preferences among different bee species, underscoring the diversity in their dietary needs. In an investigation, Ghosh *et al*. (2020) demonstrated that honey bee foraging preferences for pollen are influenced by the nutritional content, specifically the total proteinogenic amino acid content, of the available floral resources. This suggests that the nutritional composition of floral resources significantly influences foraging behavior and preferences.

One of the significant challenges faced today is inadequate nutrition for honey bees, which is a contributing factor to colony declines (Dolezal and Toth, 2018; Branchiccela *et al*., 2019). Although extensive studies on bee health specific to West Bengal are limited, there is evidence correlating poor nutrition with colony weakening in various regions globally (Mull *et al*., 2022). Research has highlighted this issue, emphasizing the need for better nutrition management. Understanding and effectively managing the nutritional status of honey bee colonies is crucial for optimizing the use of the region's abundant floral resources. For instances, the nutritional composition undergoes significant changes as pollen is transformed into bee-pollen, then into pollen patties, and finally into bee bread, which is the form honey bees actually consume (Ghosh and Jung, 2020, 2022). Notably, the protein content, particularly proteinogenic amino acids, varies across these forms, highlighting the dynamic nutritional profile during these transitions (Ghosh *et al*., 2024). During the year, beekeeping in West Bengal rely on seasonal floral resources for nectar and pollen. A dearth period typically occurs from late monsoon to late autumn, though it may vary slightly based on the specific geographical area and floral composition, necessitating supplemental feeding to sustain colony health (Fig. 2). In the state, the dearth period in beekeeping is not characterized by a complete absence of floral resources, as seen in many colder temperate regions. Instead, it is marked by a relatively lower availability of nectar and pollen, which may support some bee activity but in reduced quantities. Providing supplemental feeds, such as pollen patties in addition to the commonly used sugar syrup, can be particularly advantageous during periods of dearth, before the availability of major winter (*rabi*) crops as represented in Fig. 2.

This enhanced nutritional support not only fortifies

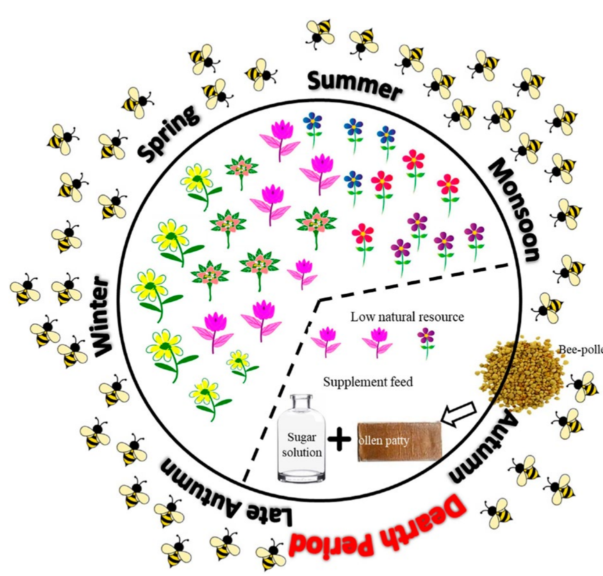

Fig. 2. Annual cycle of floral resources for honey bees in West Bengal, India, highlighting the dearth season which may vary based on specific geographical region and emphasizing the need for supplemental nutrition.

colony strength but also reinforces the long-term sustainability of beekeeping as a reliable livelihood. To ensure optimal bee health, it is essential for beekeepers to monitor both the diversity and quantity of pollen collected by their colonies. This practice helps in identifying any potential nutritional deficiencies and allows for timely corrective measures to be implemented. Additionally, assessing the nutritional quality of the pollen collected can further inform targeted supplementation strategies, ensuring bees receive a balanced diet that promotes robust colony health and productivity.

ADDRESSING KNOWLEDGE GAPS AND CONSTRAINT IN WEST BENGAL'S BEEKEEPING INDUSTRY

The constraints facing beekeeping in West Bengal, particularly when viewed through the lens of honey bee nutrition, highlight a critical gap in the sector's development. One of the fundamental challenges in improving beekeeping practices in the region lies in the limited understanding of what pollen honey bees are consuming, in what quantities, and the nutritional quality of this pollen. This lack of insight creates significant barriers to optimizing colony health, honey production, and the broader growth of the industry. Fig. 3 provides the negative consequences of the inadequate nutrition of the honey bee colony.

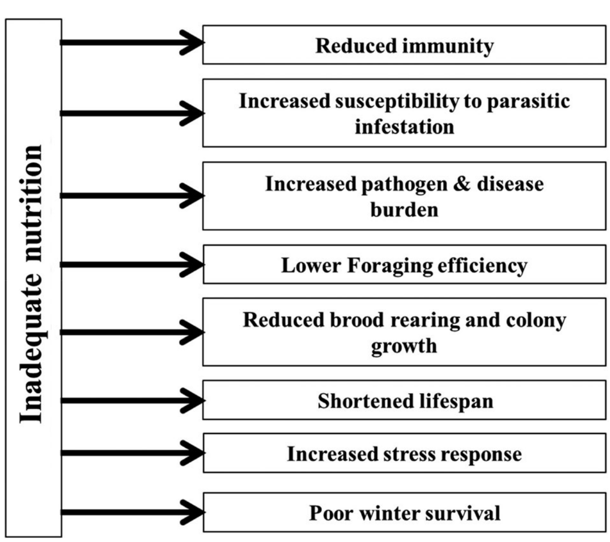

Fig. 3. Negative consequences of poor or inadequate nutrition of honey bee.

1. Monocentric focus on honey production

The prevailing focus on honey production has often overshadowed the importance of other hive products like bee-pollen, which is crucial for bee nutrition.

2. Lack of awareness about pollen quality and quantity

Pollen's nutritional value varies significantly depending on the plant species, geographical and seasonal factors etc. (Manning, 2001; Morgano *et al*., 2012; Ghosh and Jung, 2017; Al-Kahtani and Taha, 2021). Without understanding the nutritional composition of the pollen collected by bees, it is difficult to assess whether colonies are receiving adequate nourishment. If pollen sources are not nutritionally balanced, or if the quantity collected is insufficient, especially in the dearth season, bee health may deteriorate, leading to weaker colonies with other negative consequences (Fig. 3) and to avoid that additional supplementation is necessary to maintain colony strength. Understanding the nutritional value of the pollen can lead to targeted interventions that ensure bees have a balanced diet.

3. Infrastructure and resources

Proper infrastructure could enable beekeepers to gather, store, and analyse pollen samples, helping to address potential nutritional deficiencies and improving overall bee health.

4. Supplementary feeding

Generally, there are two approaches to feeding managed bee colonies: providing pollen supplements, such as pollen patties (Ghosh and Jung, 2015), or using pollen substitute feeds. Understanding the specific nutrient deficiencies of bees allows for targeted interventions, such as fortifying pollen patties with essential vitamins, minerals, and amino acids that bees may be lacking. Pollen patties supplemented with 2% chlorella have been shown to significantly improve honey bee health, resulting in increased food consumption, longevity, gland development, muscle formation, and vitellogenic (Vg) gene expression (Jang *et al*., 2022) and colony health (Jang *et al*., 2023). Treatments with 2.5–5.0% mulberry leaf concentrate supplementation significantly increased acini size and extended life span compared to bees in the control group that were only fed sucrose syrup (Danmek *et al*., 2024).

THE NEED FOR INVESTIGATION

Given these constraints, it is imperative to investigate the nutritional quality of the pollen that honey bees are consuming in West Bengal. Detailed research into the types of pollen available, their nutritional composition, and the quantities that bees are able to collect will provide critical insights into the nutritional status of colonies. Such investigations will enable beekeepers to identify periods of nutritional scarcity, optimize feeding strategies, and ensure that colonies are receiving the proper nutrients needed for optimal growth, health, and productivity.

In addition, understanding the seasonal variability of pollen quality and availability will empower beekeepers to adjust their practices accordingly, either by supplementing with additional nutrients or by moving their colonies to areas with more abundant or higher-quality pollen sources. Addressing the gaps in nutritional knowledge can significantly enhance the sustainability of beekeeping in West Bengal, boosting both the health of bee populations and the economic viability of apiculture.

Furthermore, due to climatic conditions, the blooming periods of plants, including essential bee flora, may vary (Tun *et al*., 2021). Therefore, it is important to investigate if any changes are occurring at present.

CONCLUSION

Beekeeping plays a vital role in sustainable agriculture and economic development. Addressing the constraints of apiculture in West Bengal, such as diversifying hive product use, improving nutrition management, and fostering better cooperation with landowners, can propel the industry toward greater resilience and growth. By expanding beyond honey production and promoting the collection of pollen and other hive products, beekeepers can unlock new opportunities for income generation and contribute to the broader health of honey bee populations, which are essential pollinators for global food security.

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