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Pollen Analysis as a Tool for Understanding Forage Preferences of Rock Bees (*Apis dorsata*) Across Diverse Ecosystems: A Review

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Abstract

Apis dorsata, commonly known as the giant rock bee, is one of the most important wild pollinators in tropical and subtropical ecosystems of South and Southeast Asia. Understanding its foraging behaviour and floral resource utilisation is essential for pollinator conservation, sustainable honey production, and ecosystem management. Melissopalynology, the study of pollen grains present in honey, bee bread, and pollen loads, has emerged as a valuable tool for investigating the forage preferences of honey bees. This review synthesizes current knowledge on the application of pollen analysis in identifying floral sources utilized by *Apis dorsata* across forest, agricultural, and mixed landscapes. Studies reveal that pollen composition varies significantly with habitat type, seasonal flowering patterns, and land-use changes. Natural forests generally support a diverse and multifloral diet consisting of native tree and shrub species, whereas agricultural ecosystems often promote dependence on a limited number of crop plants, resulting in reduced pollen diversity. Pollen analysis also facilitates the development of pollen calendars, enabling the assessment of seasonal forage availability and nutritional gaps. Furthermore, the review highlights standard methodologies, including pollen collection, acetolysis, microscopic identification, and quantitative classification of pollen types. By integrating findings from diverse ecological settings, this review emphasizes the importance of pollen analysis as an effective approach for understanding plant–pollinator interactions, evaluating habitat quality, and developing conservation strategies for sustaining *Apis dorsata* populations in changing environments.

Keywords: *Apis dorsata*; Melissopalynology; Pollen Analysis; Forage Preference; Rock Bees; Pollination Ecology; Floral Resources; Bee Bread; Pollen Calendar; Ecosystem Diversity; Plant–Pollinator Interactions; Conservation Biology.

1. Review of Literature:

Tiwari et al. (2010) conducted a melissopalynological investigation on *Apis dorsata* honey samples collected from the Garhwal Himalaya, India. Analysis of 21 honey samples revealed the presence of pollen from several plant families, including Asteraceae, Brassicaceae, Betulaceae, Myrtaceae, Rosaceae, and Rubiaceae. The study demonstrated that pollen analysis is an effective method for identifying bee forage resources and understanding the floral preferences of rock bees in forest ecosystems.

Raghunandan and Basavarajappa (2014) analyzed multifloral honey produced by *Apis dorsata* in Southern Karnataka. Their study recorded 48 pollen types, representing medicinal, fruit-yielding, vegetable, ornamental, and economically important plant species. The results highlighted the broad foraging range of rock bees and their dependence on diverse floral resources across different habitats.

Gopal (2021) examined 28 honey samples of *Apis dorsata* from Kolar District, Karnataka, and identified 56 pollen types belonging to 27 plant families. The dominant pollen sources included *Syzygium cumini, Pongamia pinnata, Eucalyptus species, Psidium guajava*, and *Coriandrum sativum*. The study concluded that both cultivated crops and wild tree species contribute significantly to the nutritional requirements of rock bees throughout the year.

Gaur et al. (2014) reviewed the bee forage potential of the Garhwal Himalaya and emphasized the region's rich floral diversity as an important source of nectar and pollen for honey bees. Their work highlighted the role of forest vegetation in sustaining wild bee populations and supporting honey production.

Several international studies have demonstrated the importance of pollen analysis in understanding the foraging ecology of giant honey bees. Research conducted in tropical Asian ecosystems revealed that *Apis dorsata* utilizes a wide range of flowering plants and exhibits remarkable adaptability in exploiting available floral resources. Forest ecosystems generally provide greater pollen diversity than agricultural landscapes, thereby supporting better nutritional resources for bee colonies.

Studies from Southeast Asia have shown that habitat alteration and land-use changes can significantly affect pollen diversity and floral resource availability. Reduced plant diversity in monoculture plantations often results in lower pollen diversity in bee-collected samples, potentially affecting colony health and pollination efficiency. These findings underscore the importance of conserving natural habitats and maintaining floral diversity for the long-term sustainability of *Apis dorsata* populations.

2. Introduction

Honey bees are among the most efficient and economically important pollinators in terrestrial ecosystems. They facilitate the reproduction of numerous wild and cultivated plant species, thereby contributing significantly to biodiversity conservation, ecosystem functioning, and agricultural productivity. The foraging activity of honey bees is primarily centred on the collection of nectar and pollen from flowering plants. Nectar serves as the principal source of carbohydrates, providing energy for flight and colony maintenance, whereas pollen supplies proteins, lipids, vitamins, minerals, and other essential nutrients required for brood rearing and colony development (Free, 1993; Crane, 1990).

The giant honey bee, *Apis dorsata* Fabricius, commonly known as the rock bee, is widely distributed throughout South and Southeast Asia. This species is recognised as an important pollinator of both natural vegetation and crops. Unlike managed honey bee species, *A. dorsata* is a wild bee that nests in open environments and exhibits extensive foraging behavior, often covering several kilometres in search of floral resources. Its ecological significance extends beyond honey production, as it plays a crucial role in maintaining plant diversity and ecosystem stability (Oldroyd and Wongsiri, 2006).

The selection of floral resources by honey bees depends on several factors, including nectar concentration, pollen quality, floral abundance, flowering phenology, and environmental conditions. Honey bees often exhibit floral constancy, visiting particular plant species repeatedly during a foraging trip, thereby enhancing pollination efficiency. Understanding the floral preferences of bees is therefore essential for evaluating plant–pollinator interactions and assessing the availability of nutritional resources within different ecosystems (Seeley, 1995).

Melissopalynology, the study of pollen grains contained in honey, bee bread, and pollen loads, has emerged as a valuable tool for investigating the foraging ecology of honey bees. Pollen grains possess distinctive morphological characteristics that enable the identification of their botanical origin. Through microscopic examination and quantitative analysis of pollen assemblages, researchers can determine the plant species visited by bees and assess the relative importance of different floral resources (Erdtman, 1969; Louveaux et al., 1978).

Pollen analysis provides valuable information regarding floral diversity, seasonal forage availability, and habitat quality. The technique has been widely applied to identify nectar and pollen sources, develop pollen calendars, evaluate the effects of habitat modification, and understand bee foraging patterns across forest, agricultural, and urban landscapes. Studies have shown that diverse natural ecosystems generally support a richer spectrum of pollen sources, whereas intensive agricultural systems often limit bees to a narrower range of floral resources. Such changes may influence bee nutrition, colony health, and pollination services (Klein et al., 2007).

In recent decades, growing concerns regarding habitat loss, land-use change, and declining pollinator populations have highlighted the importance of understanding the foraging requirements of wild bee species. In this context, pollen analysis serves as an effective biological indicator for assessing floral resource utilisation and plantpollinator interactions. The present review examines the application of melissopalynological techniques in understanding the forage preferences of Apis dorsata across diverse ecosystems, with particular emphasis on floral resource diversity, ecological significance, and implications for pollinator conservation.

3. Compilation of Palynological Data

Compilation of palynological data is a crucial step in understanding the forage preferences of *Apis dorsata* and the diversity of floral resources available in different ecosystems. This process involves collecting, organising, and analysing information on pollen types identified from honey, bee bread, and pollen loads reported in previous studies. The compiled data provide valuable insights into plant–pollinator interactions, seasonal flowering patterns, and habitat-specific forage resources.

The first step involves gathering published literature, including research articles, books, reports, and databases related to melissopalynological studies of *Apis dorsata*. Information regarding pollen morphology, botanical origin, and floral sources is extracted from these studies. Pollen grains are identified based on their size, shape, apertures, exine ornamentation, and other diagnostic characteristics using standard palynological keys and reference collections.

After identification, pollen types are categorised according to their botanical families, genera, and species whenever possible. The frequency of occurrence of each pollen type is recorded and classified as predominant, secondary, important minor, or minor pollen according to standard melissopalynological procedures. This classification helps determine the relative importance of different plant species as nectar and pollen sources for honey bees.

The geographical distribution of floral resources is then documented by compiling information from different ecological regions such as tropical forests, dry deciduous forests, agricultural landscapes, plantations, grasslands, and urban ecosystems. Comparative analysis of these data reveals regional variations in forage preferences and floral diversity. Forest ecosystems generally exhibit higher pollen diversity due to the presence of numerous native flowering plants, whereas agricultural ecosystems often show dominance of crop-related pollen types.

Seasonal variations in pollen composition are also compiled to identify major flowering periods and periods of forage scarcity. Such information is useful for developing pollen calendars, which indicate the availability of floral resources throughout the year. These calendars help researchers understand seasonal shifts in bee foraging behavior and nutritional resource availability.

The compiled palynological data are subsequently standardised and presented as percentages, frequency distributions, or pollen spectra to facilitate comparisons among studies and ecosystems. This systematic compilation enables researchers to assess floral diversity, identify key forage plants, evaluate habitat quality, and understand the ecological requirements of *Apis dorsata.* Ultimately, the integration of palynological information contributes to pollinator conservation, sustainable beekeeping practices, and the management of floral resources across diverse ecosystems.

4. Analysis of Ecosystem-Based Variations

The foraging behaviour of *Apis dorsata* varies considerably across different ecosystems due to differences in floral diversity, plant composition, seasonal flowering patterns, and land-use practices. Melissopalynological studies have demonstrated that the diversity and abundance of pollen sources directly influence the nutritional ecology and foraging preferences of rock bees.

4.1 Forest Ecosystems

Forest ecosystems generally provide the greatest diversity of floral resources for *Apis dorsata*. Natural forests contain a wide variety of flowering trees, shrubs, climbers, and herbaceous plants that bloom throughout the year. Melissopalynological studies from the Garhwal Himalaya and tropical forests of India have reported pollen from species such as Terminalia, Syzygium, Mangifera, Albizia, Acacia, and various members of Asteraceae and Fabaceae as important forage sources. Forest habitats support multifloral foraging patterns, enabling bees to obtain a balanced diet rich in proteins, amino acids, and micronutrients. The high floral diversity of forest ecosystems contributes significantly to colony health, brood development, and honey production (Tiwari et al., 2010; Oldroyd and Wongsiri, 2006).

4.2 Agricultural Landscapes

Agricultural ecosystems are characterized by extensive cultivation of crop species that provide abundant but often seasonal floral resources. In such habitats, *Apis dorsata* frequently exploits flowering crops such as sunflower (*Helianthus annuus*), mustard (*Brassica juncea*), coriander (*Coriandrum sativum*), sesame (*Sesamum indicum*), pigeon pea (*Cajanus cajan*), and various fruit crops. During peak flowering periods, bees may exhibit floral constancy, resulting in the collection of predominantly unifloral pollen loads. Although crops offer abundant nectar and pollen resources, the overall pollen diversity is generally lower than in natural forests. Intensive agricultural practices, pesticide use, and habitat fragmentation may further reduce forage quality and availability (Free, 1993; Klein et al., 2007).

4.3 Plantation Ecosystems

Plantation ecosystems, including eucalyptus, rubber, coconut, coffee, tea, and oil palm plantations, serve as important forage areas for Apis dorsata. However, these ecosystems are often dominated by a limited number of plant species. Studies conducted in Southeast Asia have shown that pollen samples collected from bees foraging in oil palm plantations contain lower pollen diversity compared to those from natural forests. Similarly, eucalyptus plantations may provide substantial nectar flows but limited pollen diversity. Consequently, bees inhabiting plantation-dominated landscapes often depend on surrounding natural vegetation to supplement their nutritional requirements (Oldroyd and Wongsiri, 2006; Klein et al., 2007).

4.4 Urban Ecosystems

Urban ecosystems are increasingly recognised as important habitats for pollinators. Parks, gardens, roadside plantings, institutional campuses, and ornamental landscapes provide a variety of flowering plants that support bee populations. *Apis dorsata* has been observed foraging on ornamental species, avenue trees, fruit trees, and garden plants in urban areas. Although urban environments are subject to human disturbances, the diversity of ornamental flowering plants can provide continuous floral resources throughout much of the year. However, the availability of forage resources may vary considerably depending on urban planning practices and green space management (Baldock et al., 2015).

4.5 Comparative Assessment

Comparative melissopalynological studies indicate that forest ecosystems support the highest pollen diversity and the most balanced nutritional resources for Apis dorsata. Agricultural and plantation ecosystems often provide abundant but less diverse floral resources, resulting in seasonal dependence on a limited number of plant species. Urban ecosystems offer intermediate levels of floral diversity and may function as supplementary forage habitats. The conservation of diverse flowering plant communities across all ecosystem types is therefore essential for maintaining healthy populations of rock bees and ensuring sustainable pollination services

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5. Evaluation of Seasonal Foraging Patterns

Seasonal variations in flowering phenology strongly influence the foraging behavior of *Apis dorsata.* The availability of nectar and pollen sources changes throughout the year, resulting in corresponding shifts in floral visitation patterns, colony development, brood rearing, and honey production. In tropical and subtropical ecosystems, honey bee colonies depend on a continuous succession of flowering plants that bloom in different seasons, ensuring uninterrupted food resources for survival and growth (Free, 1993; Seeley, 1995).

Pollen calendars derived from melissopalynological studies are important tools for understanding seasonal forage availability. These calendars are developed by analyzing pollen types present in honey, bee bread, and pollen loads collected across different months and seasons. They provide detailed information on dominant floral sources and help identify periods of floral abundance and scarcity (Louveaux et al., 1978).

During spring and early summer, flowering trees such as *Mangifera indica, Syzygium cumini*, Acacia spp., and Terminalia spp. provide rich nectar and pollen resources for *Apis dorsata*. In monsoon and post-monsoon seasons, herbaceous plants and crops dominate pollen spectra, reflecting increased availability of cultivated and wild herb flora. In contrast, winter seasons often exhibit reduced floral diversity, leading to potential forage scarcity and increased dependence on limited plant species.

These seasonal shifts clearly demonstrate the dependence of *Apis dorsata* on temporal floral succession. They also highlight the ecological importance of maintaining diverse, year-round flowering plant communities to ensure colony sustainability, stable honey production, and effective pollination services in both natural and managed ecosystems (Oldroyd & Wongsiri, 2006; Klein et al., 2007).

6. Assessment of Methodological Approaches

Melissopalynological studies rely on a set of standardised laboratory and analytical procedures to investigate the floral origins and foraging behaviour of *Apis dorsata*. The reliability of pollen analysis depends on proper sample collection, preparation, identification, and quantitative evaluation of pollen grains.

The first step involves sample collection, where honey, bee bread, or pollen loads are carefully collected from natural or wild colonies of *Apis dorsata.* These samples represent the actual floral resources utilised by bees across different ecosystems. Proper handling and storage of samples are essential to prevent contamination and ensure accurate results (Louveaux et al., 1978).

The second important step is acetolysis, a widely used chemical preparation technique developed by Erdtman (1969). In this process, samples are treated with a mixture of acetic anhydride and concentrated sulfuric acid to remove organic material, leaving behind the highly resistant pollen exine. This improves the visibility and structural clarity of pollen grains for microscopic examination.

Following preparation, microscopic identification is carried out using light microscopy and sometimes scanning electron microscopy (SEM). Identification is based on diagnostic morphological features such as pollen size, shape, aperture type, and exine ornamentation. Reference pollen slides and published pollen atlases are used for accurate taxonomic classification of pollen types (Moore et al., 1991).

The final step involves pollen quantification, where pollen grains are counted and categorized based on their relative frequency in the sample. Standard classification includes predominant pollen (>45%), secondary pollen (16–45%), important minor pollen (3–15%), and minor pollen (<3%). This quantitative approach helps determine the relative importance of different plant species in the diet of Apis dorsata and allows comparison across ecosystems and seasons (Jones & Bryant, 2014).Overall, these methodological approaches provide a robust framework for analyzing plant–pollinator interactions, assessing floral resource use, and understanding the foraging ecology of *Apis dorsata* in diverse environments.

7. Synthesis of Ecological Implications

Pollen diversity plays a fundamental role in maintaining the nutritional balance, physiological health, and ecological performance of honey bee colonies, particularly *Apis dorsata*. Pollen is the primary source of proteins, essential amino acids, lipids, vitamins, and minerals required for brood development, glandular secretion, immune function, and overall colony growth. A nutritionally diverse pollen diet ensures optimal larval development and enhances adult bee longevity, while also improving resistance to pathogens and environmental stressors (Alaux et al., 2010; Di Pasquale et al., 2013).

Melissopalynological studies across diverse ecosystems have consistently shown that forest habitats provide a higher richness of pollen types compared to agricultural and plantation systems. This floral diversity directly contributes to better colony nutrition by offering a more balanced and continuous supply of essential nutrients. In contrast, monoculture-dominated agricultural landscapes often result in pollen diets dominated by a few crop species, which may lead to nutritional imbalances and reduced colony performance (Klein et al., 2007).

The ecological implications of pollen diversity extend beyond bee nutrition to broader ecosystem functioning. Healthy *Apis dorsata* colonies play a crucial role in the pollination of wild flora and cultivated crops, thereby supporting plant reproduction, genetic diversity, and ecosystem stability. Reduced floral diversity can negatively affect pollination services, leading to decreased crop yields and disruption of natural plant regeneration processes.

Furthermore, pollen analysis provides valuable insights into habitat quality and environmental change. High pollen diversity in bee-collected samples generally reflects healthy ecosystems with abundant floral resources, while low diversity indicates habitat degradation or land-use intensification. Therefore, melissopalynological data serve as an effective bioindicator for assessing ecosystem health and guiding conservation strategies.

In the context of global pollinator decline, maintaining diverse flowering plant communities is essential for sustaining *Apis dorsata* populations. Conservation of natural habitats, integration of bee-friendly crops, and establishment of flowering corridors can significantly enhance pollen availability and ensure long-term stability of pollination services.

Conclusion

This review highlights the significance of pollen analysis (melissopalynology) as a powerful tool for understanding the foraging ecology *of Apis dorsata* across diverse ecosystems. The compiled evidence clearly demonstrates that rock bees utilize a wide range of floral resources, and their foraging preferences are strongly influenced by ecosystem type, seasonal flowering patterns, and landscape composition.

Forest ecosystems generally provide the highest pollen diversity, supporting nutritionally balanced diets and healthier colonies, whereas agricultural and plantation systems often contribute limited and seasonally dependent floral resources. Urban ecosystems, though variable, can serve as supplementary forage habitats when diverse ornamental and cultivated plants are available. These variations directly influence colony health, brood development, and pollination efficiency.

Melissopalynological techniques, including sample collection, acetolysis, microscopic identification, and pollen quantification, provide a reliable scientific framework for identifying plant–pollinator interactions and evaluating floral resource use. The development of pollen calendars further enhances understanding of seasonal forage availability and helps identify critical periods of nutritional stress.

Overall, pollen analysis serves not only as a diagnostic tool for studying bee foraging behavior but also as an important ecological indicator for assessing habitat quality and environmental change. In the context of declining pollinator populations and habitat degradation, conserving floral diversity and maintaining continuous flowering resources are essential for sustaining *Apis dorsata* populations and ensuring ecosystem stability and agricultural productivity.

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