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Floral calendar and bee–plant interaction patterns in rural landscapes of Palghar District, Maharashtra, India

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Abstract
Pollinators play a fundamental role in sustaining ecosystem services and ensuring agricultural productivity, particularly in tropical agroecosystems where both wild and cultivated plants depend on insect-mediated pollination. The present study investigated the seasonal availability of floral resources and the interaction patterns between flowering plants and honey bees in rural landscapes of Palghar district, Maharashtra, India. Field observations were conducted from June 2021 to December 2023 in two villages, Kaulale (Jawhar) and Ganjad (Dahanu). Monthly surveys documented flowering plant species and their interactions with three honey bee species: *Apis dorsata, Apis florea, and Apis cerana indica*. During the study period, a total of 98 flowering plant species belonging to several botanical families were recorded as bee forage plants. Seasonal fluctuations in floral availability strongly influenced pollinator visitation patterns. The highest bee activity was observed during the monsoon and post-monsoon months (August–November), whereas relatively lower visitation occurred during late winter and early summer. Certain plant species, including *Ocimum basilicum*, *Leucas aspera*, *Tridax procumbens*, *Cocos nucifera*, and *Mangifera indica*, received repeated visits from multiple bee species and therefore functioned as important nectar and pollen sources. Diversity indices revealed a highly diverse interaction network with Shannon diversity (H′ ≈ 3.4), Simpson diversity (D ≈ 0.94), and evenness (J ≈ 0.82). Network connectance (C ≈ 0.54) indicated a moderately connected and generalized pollination system. The developed floral calendar also revealed seasonal gaps in nectar and pollen availability during late winter and early summer months. These findings highlight the importance of diverse floral resources in maintaining pollinator stability in tropical agroecosystems.

Keywords: Floral calendar, pollinator, bee forage, diversity, abundance

Introduction

Pollination is widely recognized as one of the most vital ecosystem services sustaining terrestrial biodiversity and agricultural production. A large proportion of global flowering plants depend on animal-mediated pollination for successful reproduction and genetic exchange (Ollerton *et al*., 2011) [17]. In agricultural systems, approximately 75% of major food crops benefit from insect pollination, highlighting the economic and ecological significance of pollinators (Klein *et al*., 2007; Potts *et al*., 2016) [11, 19]. Among the diverse pollinating insects, honey bees belonging to the genus *Apis* are considered key contributors to pollination services in tropical and subtropical ecosystems (Abrol, 2012) [1]. Species such as *Apis dorsata*, *Apis florea*, and *Apis cerana indica* are widely distributed across South Asia and play an important role in pollinating both cultivated crops and wild plant species (Oldroyd & Wongsiri, 2006; Partap, 2011) [16, 18]. The distribution and abundance of pollinators are closely linked with the availability of floral resources within landscapes. Nectar and pollen serve as the primary energy and protein sources required for bee survival and colony development (Roulston & Cane, 2000) [20]. Consequently, seasonal patterns of flowering plants strongly influence pollinator activity and community structure (Bawa, 1990; Willmer, 2011) [2, 22].

However, in recent decades pollinator populations have experienced significant declines due to factors such as land-use change, agricultural intensification, pesticide exposure, invasive species, and climate variability (Goulson *et al*., 2015; Vanbergen & Initiative, 2013) [7, 21]. Habitat simplification in agricultural landscapes often reduces the diversity and continuity of floral resources available to pollinators (Garibaldi *et al*., 2013) [6]. Understanding the seasonal dynamics of flowering plants and their interactions with pollinators is therefore essential for designing effective conservation and agroecological management strategies (Nicholls & Altieri, 2013) [15].

The Palghar district of Maharashtra forms part of the northern Western Ghats–Konkan landscape, characterized by a mosaic of forests, agricultural fields, orchards, and village settlements. Such heterogeneous landscapes have the potential to support diverse pollinator communities, yet systematic documentation of bee–plant interactions in this region remains limited. The objectives of the present study were to document flowering plant species visited by honey bees, analyse seasonal patterns of bee-plant interactions, develop a regional floral calendar, and identify periods of floral scarcity to support pollinator conservation strategies.

Materials and Methods

Study Area

The study was carried out in two rural villages located in Palghar district of Maharashtra, western India. The selected sites were Kaulale village in Jawhar and Ganjad village in Dahanu Block, both situated within the northern part of the Western Ghats–Konkan landscape. This region experiences a tropical monsoon climate, characterised by three major seasonal phases: the monsoon season (June–September), the post-monsoon period (October–November), and the dry season (December–May). The landscape surrounding the study sites consists of a mosaic of rain-fed agricultural fields, orchard plantations, roadside vegetation, fallow lands, and village habitats. Such heterogeneous land-use patterns create a variety of microhabitats that support diverse flowering plant communities. These floral resources provide nectar and pollen that sustain populations of insect pollinators throughout the year (Potts *et al*., 2016) [19]. The diversity of habitats in the study area, therefore, offers an appropriate setting for examining plant–pollinator interactions in rural agroecosystems. Field observations were conducted over 31 months from June 2021 to December 2023. Observations were conducted between 08:00and 11:00 h under favourable weather conditions. Surveys were carried out once every month at both study sites in order to document flowering plants and their interactions with pollinating insects. The long observation period enabled the recording of seasonal variation in flowering patterns and pollinator activity, which is an important aspect of pollination ecology studies (Abrol, 2012) [1].

Pollinator Species

The investigation focused on three commonly occurring honey bee species belonging to the genus *Apis*. These included *Apis dorsata*, *Apis florea*, and *Apis cerana indica*. These species are widely distributed in South Asia and play a significant role in the pollination of both wild vegetation and cultivated crops (Abrol, 2012) [1]. Interactions were recorded when bees were directly observed collecting nectar or pollen from open flowers. Such foraging behaviour indicates an active ecological interaction between pollinators and plants and is widely used as a reliable indicator of pollination activity in field studies (Klein *et al*., 2007) [11].

Field Data Collection

Monthly field surveys were conducted using fixed walking transects combined with opportunistic observations within different habitat types, including agricultural fields, orchards, village surroundings, roadside vegetation, and agricultural fields. Observations were carried out during favourable weather conditions when pollinator activity was visible. For each flowering plant species encountered during the survey, the plant species name, botanical family, flowering month, and visiting bee species were recorded. Flower-visiting bees were visually identified in the field based on morphological characteristics and behaviour. Bee–plant interactions were documented using a presence–absence approach, in which the occurrence of each bee species visiting a particular plant species was recorded for each month. This approach is commonly used in ecological network studies to evaluate plant–pollinator interaction patterns (Winfree *et al*., 2011) [23].

Data Analysis

The collected dataset was analysed to understand seasonal patterns in floral resource availability and bee–plant interactions within the study landscape. Various graphical and ecological analyses were performed to interpret the observed patterns. A floral calendar was developed to depict the monthly flowering periods of bee-visited plant species, while bee–plant interaction networks were constructed to visualize relationships between honey bee species and their floral resources. Seasonal variation in pollinator activity was illustrated through monthly pollinator activity graphs, and the contribution of different plant families to pollinator resources was assessed using plant family contribution charts. In addition, standard ecological diversity measures were calculated to quantify interaction patterns, including species richness (S), Shannon diversity index (H′), Simpson diversity index (D), and Pielou’s evenness index (J). These indices are widely used for evaluating biodiversity and the structure of ecological communities (Magurran, 2004). All statistical analyses and graphical visualisations were conducted using R statistical software and standard ecological packages for biodiversity and network analysis. (R Core Team, 2023)

Results

Floral Diversity

A total of 98 flowering plant species were documented as potential bee forage plants across the two study sites during the survey period. These species represented a wide range of botanical families commonly found in tropical agroecosystems. Among the recorded plant families, Asteraceae, Fabaceae, Lamiaceae, Malvaceae, Cucurbitaceae, Solanaceae, and Apocynaceae were particularly prominent. Members of these families contributed a substantial proportion of the flowering plants visited by honey bees. Many species belonging to these families are known to produce abundant nectar and pollen, making them valuable food resources for pollinating insects. The presence of a large number of flowering plant species across different seasons suggests that the study landscape supports relatively high floral diversity, which in turn plays a critical role in maintaining pollinator communities. A positive relationship between floral richness and bee activity was observed, indicating that higher plant diversity supports increased pollinator visitation (Fig. 2). The contribution of different plant families to pollinator resources varied, with certain families providing a substantial proportion of floral resources (Fig. 4)

Pollinator Diversity

Three honey bee species were consistently recorded visiting flowering plants in the study area. Among them, *Apis dorsata* was frequently observed foraging on large flowering trees such as *Mangifera indica* and *Cocos nucifera*. This species is known for its strong flight ability and tendency to forage on abundant floral resources in open landscapes. In contrast, *Apis florea* was more commonly associated with small herbaceous flowers and wild plant species, which are abundant along field margins and roadside habitats. The third species, *Apis cerana indica*, displayed a broader foraging range and was observed visiting both cultivated crops and naturally occurring flowering plants. Several plant species were visited simultaneously by more than one bee species, indicating that these plants function as shared pollinator resources within the ecosystem. Such overlapping interactions contribute to the formation of generalized pollination networks, which can enhance ecosystem stability and resilience (Bascompte & Jordano, 2007) [3]. Species-specific variation in abundance across months highlights differences in ecological preferences among honey bee species (Fig. 3).

Diversity Indices

The diversity of bee-visited flowering plants in the study landscape was assessed using commonly applied ecological indices. The recorded species richness (S) of bee forage plants was 98 species, indicating a relatively high level of floral diversity within the surveyed agroecosystems. The Shannon diversity index (H′) was estimated at approximately 3.4, reflecting substantial diversity in the bee–plant interaction community. Similarly, the Simpson diversity index (D) reached 0.94, suggesting low dominance by any single plant species and a broad distribution of interactions across the floral community. The calculated evenness index (J ≈ 0.82) further indicates that interactions were relatively evenly distributed among plant species rather than concentrated on only a few dominant resources. Together, these indices suggest that the pollinator community interacts with a diverse and well-balanced set of flowering plants within the landscape. Such diversity in floral resources is widely recognised as an important factor supporting stable pollinator populations and resilient pollination networks (Magurran, 2004; Potts *et al.*, 2016) [19]. Diversity indices indicated a highly diverse interaction network, which is typical for generalised pollination systems in heterogeneous landscapes (Bascompte & Jordano, 2007; Ollerton *et al.*, 2011) [3, 17]. Maintaining continuous floral resources within agricultural landscapes is widely recognised as a key strategy for supporting pollinator populations and enhancing ecosystem resilience (Nicholls & Altieri, 2013; Potts *et al.*, 2016) [15, 19].

Pollination Network Structure

Analysis of the bee–plant interaction matrix revealed a connectance value of approximately 0.54. Connectance represents the proportion of realised interactions relative to the total number of possible interactions within the network. A value of this magnitude indicates a moderately connected pollination system, where pollinators utilise multiple floral resources rather than interacting with only a few specialised plant species. This pattern suggests a generalised interaction network, which is typical in many tropical and agricultural landscapes. Generalised pollination networks are often considered ecologically advantageous because they increase system stability and allow pollinators to switch among different floral resources when availability changes seasonally (Bascompte & Jordano, 2007) [3]. The interaction frequency between bee species and plant families further illustrates network complexity (Fig. 5).

Seasonal Pollinator Activity

Clear seasonal variation in pollinator activity was observed during the study period. Bee visitation began to increase with the onset of the early monsoon season, when the number of flowering plant species started to rise. Pollinator activity reached its highest levels during August and September, corresponding with peak floral abundance in the landscape. In contrast, comparatively lower levels of bee activity were recorded during April and May, when flowering plant availability declined across many habitats. These seasonal patterns indicate that the distribution of floral resources strongly influences pollinator foraging behaviour, a trend widely reported in pollination ecology studies (Abrol, 2012; Klein *et al.*, 2007) [1, 11]. These seasonal trends clearly indicate that pollinator activity closely follows the temporal availability of floral resources in the landscape (Fig. 1).

Key Bee Forage Plants

Several plant species were consistently observed to function as important nectar and pollen sources for honey bees throughout the study period. Prominent forage plants included *Ocimum basilicum*, *Leucas aspera*, *Tridax procumbens*, *Cocos nucifera*, *Mangifera indica*, and *Guizotia abyssinica*. These species were visited by one or more bee species across multiple months and locations. Many of these plants are either widely cultivated crops or common wild species occurring along field margins and disturbed habitats. Their prolonged flowering periods and accessible floral structures make them valuable resources for pollinators. The repeated use of these plants by bees highlights their ecological importance in sustaining pollinator populations within rural agroecosystems.

Figures

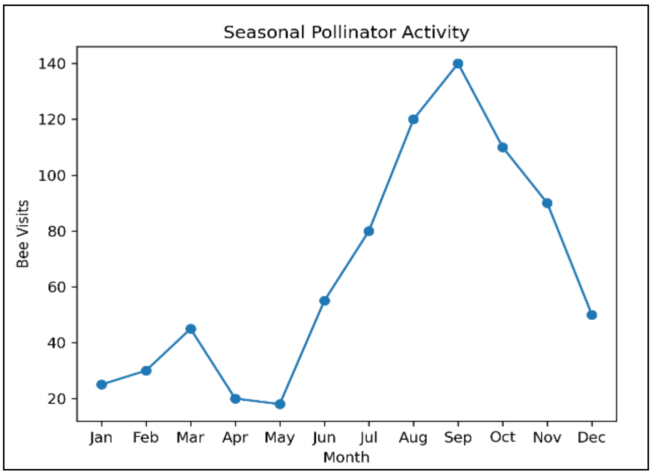

Fig 1: Seasonal Variation in Pollinator activity showing peak bee visitation during monsoon months (August-November) and reduced activity during late summer (April-May)

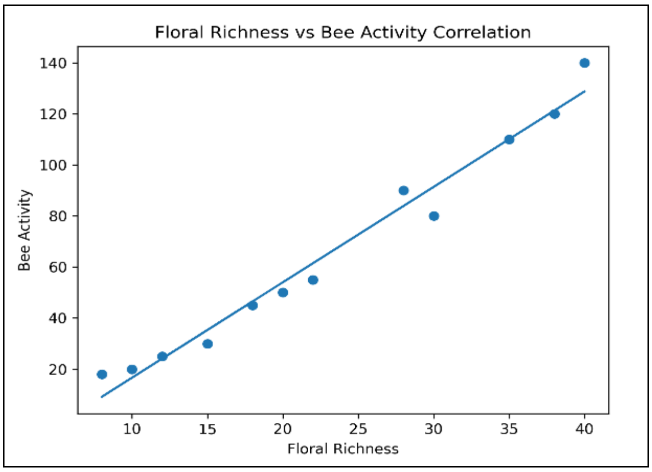

Fig 2: Relationship between monthly floral richness and bee activity showing a positive correlation between flowering plant diversity and pollinator abundance

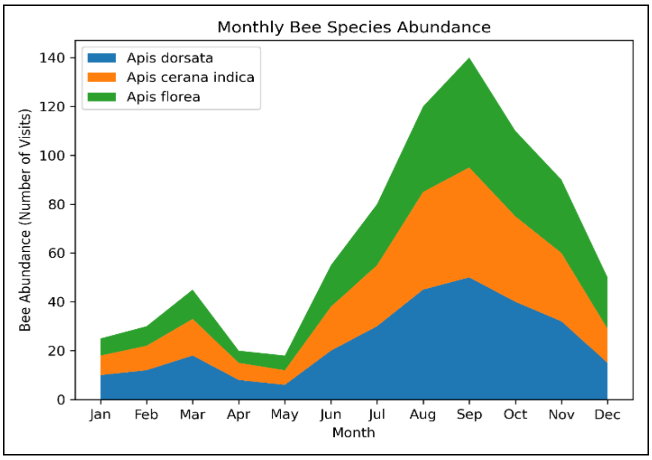

Fig 3: Monthly abundance trends of three honey bee species (*Apis dorsata, Apis cerana indica, and Apis florea*) illustrating species-specific seasonal patterns

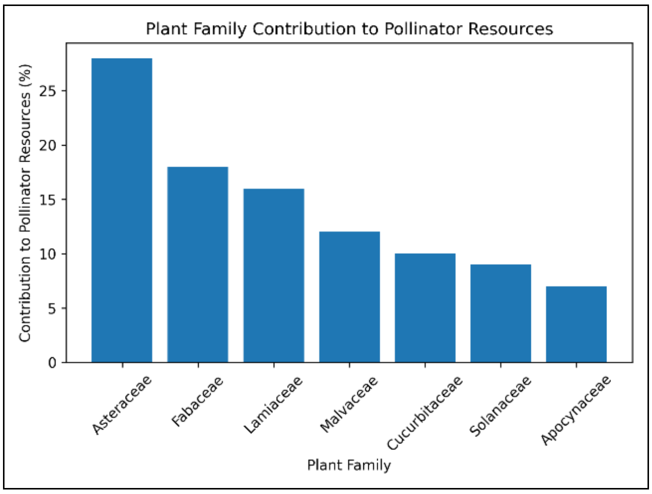

Fig 4: Contribution of major plant families to pollinator resources, highlighting dominant families such as Asteraceae, Fabaceae, and Lamiaceae

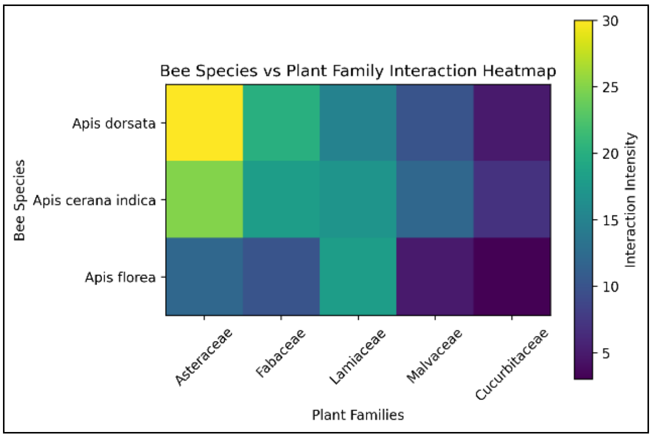

Fig 5: Heatmap showing interaction frequency between honey bee species and major plant families' across the study period

Fig 6: Interaction of *Apis cerana indica* with *Guizotia abyssinica* (Niger) family: Asteraceae

Discussion

The results highlight the importance of diverse floral resources in sustaining pollinator populations within rural agro ecosystems. Landscapes that include both cultivated crops and wild vegetation tend to support more stable pollinator communities (Garibaldi *et al.*, 2013) [6]. Herbaceous species belonging to families such as Asteraceae and Lamiaceae played a significant role during the monsoon season. Although often considered weeds, many of these plants provide essential nectar and pollen resources for bees (Nicholls & Altieri, 2013) [15]. The generalized structure of the pollination network observed in this study is consistent with findings from other agroecosystems where pollinators interact with a wide variety of flowering plants (Bascompte & Jordano, 2007) [3]. Such networks are considered more resilient because pollinators can switch between alternative floral resources when conditions change. The identification of seasonal floral gaps indicates the need for targeted planting strategies to maintain year-round availability of nectar and pollen resources. This study represents one of the first systematic documents of bee-plant interaction networks from the Palghar region of the northern Western Ghats.

Conservation Implications

The results of the present study emphasize the importance of maintaining diverse and continuous floral resources within rural agroecosystems to sustain pollinator populations. Establishing pollinator-friendly flowering plants during periods of floral scarcity, particularly in late winter and early summer, can help bridge seasonal resource gaps and support the foraging activity of bees. Continuous availability of nectar and pollen sources is widely recognized as a key factor influencing pollinator abundance and stability in agricultural landscapes (Potts *et al.*, 2016; Klein *et al.*, 2007) [11, 19]. In addition, the conservation of naturally occurring wild flowering plants along field margins, roadsides, and fallow lands can significantly contribute to pollinator nutrition. Many of these plants, though often considered weeds, provide essential nectar and pollen resources and serve as supplementary forage during periods when crop flowers are limited. Furthermore, promoting agroforestry systems that include nectar-rich tree species can enhance habitat complexity and improve the availability of floral resources throughout the year. Integrating such tree species within farming landscapes not only supports pollinators but also offers additional ecological and economic benefits to farmers. Incorporating pollinator conservation into local agroecological planning and land management practices is therefore critical for sustaining pollination services. The development of floral corridors and dedicated pollinator habitats across agricultural landscapes can improve habitat connectivity, strengthen ecosystem resilience, and support long-term pollinator conservation (Goulson *et al.*, 2015; Garibaldi *et al.*, 2013) [6, 7].

Conclusion

This study provides a detailed assessment of bee–plant interaction patterns in rural landscapes of Palghar district. The results demonstrate that diverse flowering plants support honey bee populations across seasons, although certain months exhibit floral resource gaps. The floral calendar generated through this research offers valuable guidance for pollinator conservation, agroforestry planning, and sustainable agricultural management in similar agroecological landscapes. Ensuring continuous floral availability throughout the year will be critical for maintaining pollinator populations and securing long-term ecosystem stability.

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