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Assessment of pollinator diversity and foraging dynamics in the drumstick (*Moringa oleifera* Lam.) ecosystem of Chhatrapati Sambhaji Nagar district, Maharashtra, India

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Abstract
A comprehensive field investigation was undertaken to document and analyse the diversity, abundance, and foraging behaviour of pollinators in a drumstick (*Moringa oleifera* Lam.) orchard located in Itkheda village, Chhatrapati Sambhaji Nagar district, Maharashtra, during the peak flowering season of January-December 2020. The study employed systematic visual counts, timed observations, and specimen collection across diurnal cycles. A total of 17 distinct pollinator species were recorded, systematically classified into the orders Hymenoptera (9 species), Lepidoptera (5 species), Diptera (1 species), and the avian order Passeriformes (2 species). The family Apidae within Hymenoptera was the most species-rich and abundant, with key pollinators including the giant honey bee (Apis dorsata), the little honey bee (Apis florea), and three species of carpenter bees (Xylocopa pubescens, X. violacea, and X. fenestrata). Foraging activity exhibited distinct temporal patterns, with hymenopterans dominating the forenoon and lepidopterans and avian visitors peaking during midday. Qualitative assessment of pollen loads identified Xylocopa species as the most efficient pollinators, followed by Apis dorsata. The study also notes the significant presence of the stingless bee Meliponula ferruginea and two species of sunbirds (Leptocoma zeylonica and Cinnyris asiaticus). These results emphasize the essential function of a diverse pollinator guild in the reproductive success of this economically significant "Miracle Tree" and underscore the imperative for conservation-focused agricultural practices in the area.

Keywords: *Moringa oleifera*, pollinator diversity, foraging ecology, Xylocopa, Apis Dorsata, Hymenoptera, agro-ecosystem

Introduction

Moringa oleifera Lam., commonly known as the drumstick tree or horseradish tree, is a multipurpose perennial softwood tree belonging to the monogenetic family Marantaceae. Indigenous to the sub-Himalayan tracts of North India, it is now extensively cultivated across tropical and subtropical regions worldwide due to its remarkable adaptability to arid conditions (Ramachandran *et al*., 1980) [15]. Every part of the tree—leaves, pods, flowers, and seeds—is replete with high nutritional and medicinal value, justifying its epithet as the "Miracle Tree" (Fuglie, 2001) [6]. In India, drumstick is a staple vegetable, particularly in South Indian cuisine, with cultivation spanning approximately 40,000 hectares, predominantly in states like Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, and Gujarat.

The flowering phenology of M. oleifera generally extends from January to April, reaching a zenith in February. The tree yields abundant inflorescences of creamy-white, bisexual, slightly zygomorphic, and weakly scented flowers (Jyothi *et al*., 1990) [8]. As a highly cross-pollinated and entomophilous species, it is entirely dependent on biotic agents for pollen transfer. The floral structure, with its exerted stamens and pistil, is particularly suited for pollination by large-bodied insects (Olson & Razafimandimbison, 2000) [12]. A diverse array of pollinators, including bees (Apidae), wasps (Vespidae), butterflies (Lepidoptera), flies (Diptera), and nectar-feeding birds (Nectariniidae), have been reported to forage on its flowers for nectar and pollen (Srinivasan *et al*., 2018) [16]. Among these, carpenter bees (Xylocopa spp.) are often cited as the most effective and reliable pollinators due to their size, buzzing behaviour, and flower-handling proficiency (Abrol, 2012) [1].

Pollinators are indispensable keystone species in terrestrial ecosystems, providing a critical ecosystem service that ensures the genetic diversity and reproductive success of nearly 90% of flowering plants (Ollerton *et al*., 2011) [11]. In agriculture, they play a huge role in global food production, with an estimated 35% of crop volume depending directly on animal pollination (Klein *et al*., 2007) [9]. However, global pollinator populations are facing severe threats from habitat fragmentation, pesticide use, and climate change (Potts *et al*., 2010) [13], making localized biodiversity assessments more critical than ever.

This study was, therefore, conceptualized to document the pollinator diversity systematically, composition, and temporal foraging patterns within the drumstick agro-ecosystem of Chhatrapati Sambhaji Nagar district, Maharashtra. The findings aim to establish a baseline for sustainable pollinator management strategies to enhance drumstick productivity in the region.

Materials and Methods

1. Study Site and Period

The research was conducted over one year (January-December 2020) in a commercially managed drumstick orchard in Itkheda village (19° 53' 47" N, 75° 23' 54" E), Chhatrapati Sambhaji Nagar district, Maharashtra. The district lies on the Deccan Plateau, with an average altitude of 513 meters above mean sea level. The region experiences a semi-arid climate, characterized by an average annual rainfall of 734 mm, concentrated from June to September. The temperature exhibits significant seasonal variation,

ranging from a winter minimum of 8°C to a summer maximum of 46°C.

Photo of Drumstick Orchard located in Itkheda Village, to side of Aurangabad - Paithan Road.

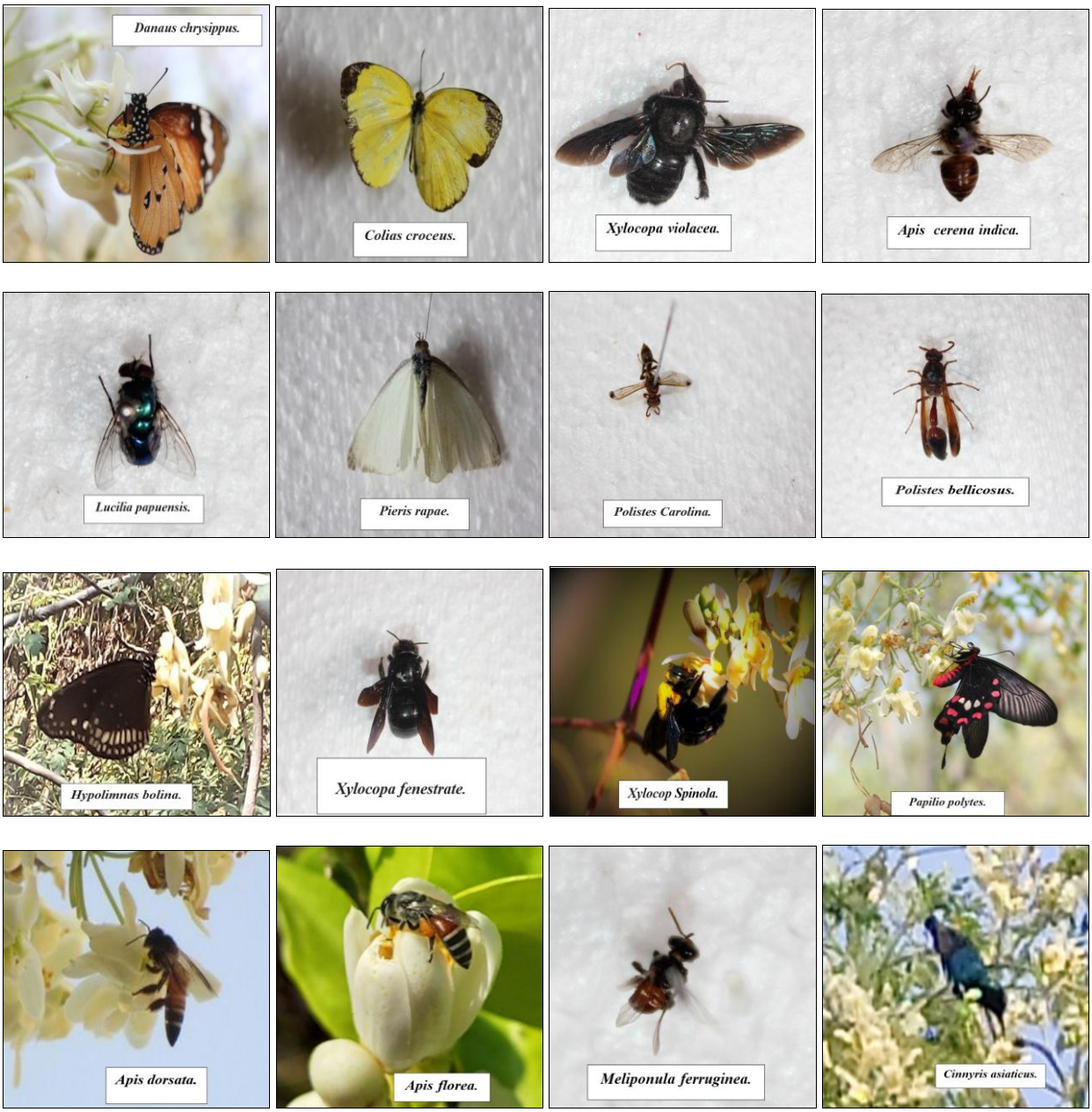
2. Data Collection and Pollinator Sampling

Observations were initiated when approximately 20% of the trees in the orchard were in bloom. Pollinator surveillance was conducted on clear, sunny days from 07:00 to 17:00 hours. On each visit, the orchard was surveyed for one hour, during which all pollinators visiting randomly selected inflorescences from five different trees were counted visually. This process was repeated at hourly intervals throughout the day to capture temporal variations in foraging activity.

Insect pollinators were collected using a standard aerial sweep net (45 cm diameter). For each captured insect, the time and date were recorded. Bees and other fragile insects were humanely euthanized using ethyl acetate vapor in a killing jar and subsequently transferred to 70% ethanol for preservation. Avian visitors were identified and counted visually using binoculars without capture. All specimens were photographed in their natural habitat and in a laboratory setting post-preservation.

3. Specimen Processing and Identification

In the laboratory, insect specimens were carefully pinned, posture-set, and dried in a dedicated insect drying chamber maintained at 40°C for 24 hours. Fully dried specimens were then curated in entomological storage boxes lined with foam sheets, with paradichlorobenzene crystals used as a pest repellent. The identification was carried out to the species level wherever possible using standard taxonomic keys (Bingham, 1897; Borror *et al*., 1989) [4, 5]. The foraging nature (nectar only, pollen only, or both) of each species was noted during field observations.



Observations and Results

The systematic survey led to the identification of 17 distinct species of floral visitors in the drumstick ecosystem, as catalogued in Table 1.

Table 1: Inventory of Floral Visitors in the Drumstick (*Moringa oleifera*) Ecosystem

Sr. No.	Name of Species / Pollinators	Order	Family	Foraging Nature (N/P/N+P)
1	*Apis dorsata* Fabricius	Hymenoptera	Apidae	N+P
2	*Apis florea* Fabricius	Hymenoptera	Apidae	N+P
3	*Apis cerana indica* Fabricius	Hymenoptera	Apidae	N+P
4	*Meliponula ferruginea* Lepeletier	Hymenoptera	Apidae	N+P
5	*Xylocopa pubescens* Spinola	Hymenoptera	Apidae	N+P
6	*Xylocopa violacea* Linnaeus	Hymenoptera	Apidae	N+P
7	*Xylocopa fenestrata* Fabricius	Hymenoptera	Apidae	N+P
8	*Polistes bellicosus* Cresson	Hymenoptera	Vespidae	N
9	*Polistes carolina* Linnaeus	Hymenoptera	Vespidae	N
10	*Papilio polytes* Linnaeus	Lepidoptera	Papilionidae	N
11	*Danaus chrysippus* Linnaeus	Lepidoptera	Nymphalidae	N
12	*Hypolimnas bolina* Linnaeus	Lepidoptera	Nymphalidae	N
13	*Pieris rapae* Linnaeus	Lepidoptera	Pieridae	N
14	*Colias croceus* Geoffroy	Lepidoptera	Pieridae	N
15	*Lucilia papuensis* Macquart	Diptera	Calliphoridae	N
16	*Leptocoma zeylonica* Linnaeus	Passeriformes	Nectarinidae	N
17	*Cinnyris asiaticus* Latham	Passeriformes	Nectarinidae	N

N= Nectar, P= Pollen, N+P= Nectar and Pollen

1. Taxonomic Composition and Abundance

The pollinator guild was dominated by Hymenoptera, which constituted 52.9% (9 species) of the total diversity. Within this order, the family Apidae was preeminent, represented by seven species, including honey bees and carpenter bees. The Vespidae family contributed two wasp species. Lepidoptera was the second most diverse order, with five species from families Papilionidae, Nymphalidae, and Pieridae. Diptera was represented by a single calliphorid fly, and two species of sunbirds (Passeriformes: Nectarinidae) completed the visitor spectrum.

2. Foraging Dynamics and Temporal Activity

A clear temporal succession in pollinator activity was observed:

- **Hymenoptera (Bees):** The giant honey bee, *Apis dorsata*, exhibited peak foraging activity between 09:00 and 11:00 hours. The little honeybee, *Apis florea*, showed a slightly delayed peak from 11:00 to 12:00 hours. The carpenter bees (*Xylocopa* spp.), the most conspicuous visitors, were highly active from 09:00 to 13:00 hours, their loud buzzing marking their presence. The wasps (*Polistes* spp.) were primarily early morning foragers (09:00–10:00 h).

- **Lepidoptera (Butterflies):** Butterfly activity intensified around midday, with peak visits recorded between 12:00 and 14:00 hours, coinciding with higher temperatures and sunlight.

- **Sunbirds**, such as the Purple-rumped Sunbird (Leptocoma zeylonica) and the Purple Sunbird (Cinnyris asiaticus), were seen making quick, frequent visits all day, with a small increase in the late morning.

3. Qualitative Pollination Efficiency

Through visual inspection, we qualitatively assessed the number of pollen grains adhering to the bodies of individual foragers. Carpenter bees (*Xylocopa* spp.) were unequivocally the most efficient, with their large, hairy thoraxes and ventral scope laden with thousands of pollen grains. They were followed by *Apis dorsata*, which also carried substantial pollen loads in their corbiculae. The other bees carried moderate amounts, while lepidopterans, dipterans, and birds, being exclusive nectar feeders, carried comparatively negligible pollen, acting as occasional or secondary pollinators.

Discussion

The findings of this study illuminate a complex and diverse pollinator community associated with *Moringa oleifera* in the semi-arid region of Chhatrapati Sambhaji Nagar. The recorded diversity of 17 species corresponds with the established generalist pollination system of the drumstick

tree, which provides open and accessible floral resources (Srinivasan *et al*., 2018) [16]. The dominance of Hymenoptera, particularly bees, is consistent with global studies on *Moringa* pollination, which identify bees as the principal pollinators (Jyothi *et al*., 1990; Krieg *et al*., 2015) [8, 10].

The superior pollination efficiency of *Xylocopa* species can be attributed to their "buzz-pollination" behaviour and large body size, which ensures effective contact with anthers and stigma during nectar foraging (Abrol, 2012) [1]. Their long foraging duration further enhances their role as keystone pollinators in this system. The high abundance of *Apis dorsata* demonstrates the value of wild honey bees in agricultural pollination, a service often overlooked in favor of managed *Apis mellifera* colonies (Basu *et al*., 2011) [3].

The significant visitation by *Meliponula ferruginea*, a stingless bee, is an important finding. Stingless bees are increasingly recognized as effective pollinators in various cropping systems (Heard, 1999) [7], and their role in drumstick pollination warrants further quantitative study. The presence of sunbirds adds another layer to this interaction, showing that the flowers are attractive to birds, probably because they make a lot of nectar, which Jyothi *et al*. (1990) [8] also noted.

The temporal partitioning of foraging activity reduces interspecific competition and potentially extends the effective pollination window throughout the day, a phenomenon that can contribute to a higher fruit set (Rajasri *et al*., 2012) [14]. This study's results are in broad agreement with the pollinator diversity reported in other parts of India (Srinivasan *et al*., 2018) [16] and West Africa (Krieg *et al*., 2015) [10], confirming the pan-tropical nature of the drumstick's pollinator guild.

Conclusion

This study provides a detailed account of the rich pollinator assemblage in the drumstick ecosystem of Chhatrapati Sambhaji Nagar district. It conclusively identifies the guild's composition, with Hymenopterans, specifically *Xylocopa* carpenter bees and *Apis dorsata*, as the primary and most efficient pollinators. The complementary roles played by stingless bees, butterflies, and sunbirds highlight the ecological complexity and resilience of this agro-ecosystem. The findings carry serious implications for local agricultural practices. To safeguard this natural capital, it is imperative to promote pollinator-friendly farming, including the reduced application of broad-spectrum insecticides during flowering, the maintenance of native flowering plants as hedgerows to provide alternative forage, and the potential installation of artificial nesting sites for carpenter bees. Future research should focus on quantifying the individual contribution of each pollinator species to the fruit set and yield, providing a more robust basis for conservation management.

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