CoFTI
Coalition for Food-Systems Transforma(c)tion in India

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WORKING PAPER

POLLINATOR-FRIENDLY CROPPING PATTERN FOR NUTRITION GARDENS AND FARMS IN HUMID REGIONS OF WEST BENGAL

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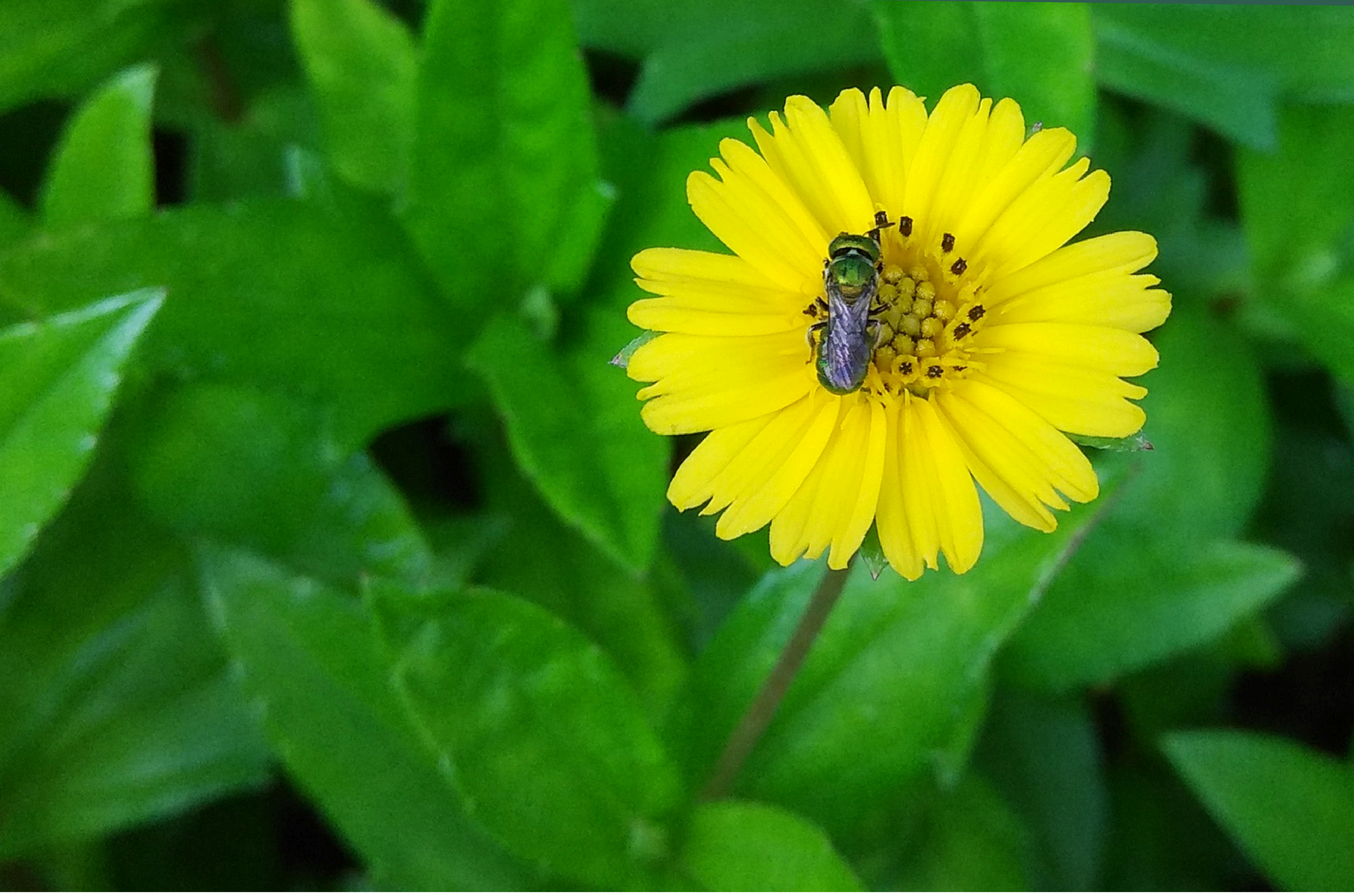

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Cover photo: *Ceratina sp.* sitting on Bhringaraj (*Eclipta prostrata*) flower, Narendrapur Ramkrishna Mission, Belur Math, West Bengal

Photo credit: Dr. Aditi Dutta

Designed by: Nemani Chandrasekhar, Watershed Support Services and Activities Network (WASSAN)

About CoFTI

The **Coalition for Food-Systems Transforma(c)tion in India (CoFTI)** was born out of the United Nations (UN) Food Systems Summit 2021 with a commitment to reshaping India's food system so that safe and nutritious food is accessible to all. Its mission addresses hunger and malnutrition while championing biodiversity, climate resilience, and the protection of livelihoods. By bringing together diverse stakeholders, CoFTI works to create sustainable and equitable solutions that balance the needs of people, planet, and economy. Grounded in the Sustainable Development Goals (SDGs), the Coalition drives positive change across seven key areas of work, ensuring that India's food systems remain resilient for both present and future generations.

CoFTI's approach is anchored in **three core objectives**.

1	THOUGHT LEADERSHIP	USING RESEARCH, INNOVATION, AND EVIDENCE-BASED INSIGHTS TO SHAPE EFFECTIVE POLICIES AND GUIDE THEIR IMPLEMENTATION.
2	COLLECTIVE ACTION	OFFERING A COLLABORATIVE SPACE WHERE STAKEHOLDERS CAN UNITE, SHARE RESOURCES, AND WORK TOGETHER ACROSS ITS AREAS OF FOCUS.
3	BUILDING CONNECTIONS	FOSTERING STRONG LOCAL AND INTERNATIONAL NETWORKS TO ENABLE THE EXCHANGE OF KNOWLEDGE AND STRENGTHEN PARTNERSHIPS

Through these objectives, CoFTI serves as both a catalyst and a convener, ensuring that India's journey towards a just, sustainable, and nourishing food future is grounded in shared purpose and actionable solutions.

CoFTI Core Group comprises of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Welthungerhilfe India (WHH), Food Future Foundation (FFF), and Watershed Support Services and Activities Network (WASSAN), which hosts the Secretariat of CoFTI.

The Core Group has evolved to CoFTI's Transformation Council (2025–26), a strategic advisory body driving high-potential initiatives through a cross-sector cohort. It unites civil society, government, academia, and private sector stakeholders to advance collaborative food systems transformation in India.

The CoFTI Fellowship Programme

The CoFTI Fellowship Programme (2025) was conceptualized to nurture early-career researchers in India by supporting them to explore and generate evidence on critical food systems issues. Designed as a structured three-month fellowship, it combined rigorous selection, thematic focus, and a mentorship model curated, hosted and implemented by CoFTI Secretariat with support from WASSAN and Welthungerhilfe (WHH) India. Through guided research and collaborative knowledge creation, the programme culminated in the Fellows producing six working papers, an Issue Brief, and a detailed survey-based analytical report.

The CoFTI Fellowship Programme was carried out from August to November 2025 followed by a rigorous process of review and finalisation of the outputs. Applications were invited from early career researchers for specific thematic areas identified through consultations with CoFTI members. The programme received nearly 500 applications from which eight fellows were selected by a panel including the CoFTI Core group members and other subject experts who are also members of the Coalition. A team of subject experts was invited to mentor the Fellows. The CoFTI Fellows received an honorarium to support their research during the Fellowship, and the final topics were decided jointly by the Fellows and their assigned mentors.

Of the eight fellows selected, seven successfully completed the CoFTI Fellowship programme. Five Fellows undertook original research projects from conceptualisation to manuscript preparation, while two contributed to the development of a CoFTI Issue Brief and a survey-based analytical report.

Voluntary mentorship by CoFTI members: A defining feature of the fellowship was its mentorship model. Members of CoFTI, Core Group, and the Secretariat have voluntarily mentored the fellows throughout the programme.

The fellowship culminated in the presentation of findings, followed by review, revision, and publication as part of the CoFTI Working Paper Series, with opportunities for further research collaboration and publication.

The CoFTI Secretariat was responsible for the overall design and coordination of the Fellowship programme. This included developing the fellowship framework, managing the selection process, facilitating mentor–fellow engagement, and coordinating the review, editing, design, publication, and communication of the Fellows' outputs. As the institutional anchor of the Secretariat, WASSAN also played a significant role in the operational management and smooth implementation of the fellowship programme by providing administrative, human resource, and design support, which was instrumental in ensuring the effective delivery of the programme.

Acknowledgements

This working paper was developed as part of the CoFTI Fellowship Program (August–November 2025). Through mentorship, financial support, and opportunities to undertake primary research, the Fellowship provided the foundation for the conceptualisation, fieldwork, and development of this paper. We would like to express our heartfelt gratitude to the CoFTI Fellowship Program for providing us with this valuable opportunity to learn and engage with diverse stakeholders working towards sustainable and inclusive agricultural development. The fellowship has significantly enhanced the understanding of the first Author for field-based research, community engagement, and participatory approaches to development.

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Dr. Aditi Dutta
Anshuman Das

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LIST OF ABBREVIATIONS

ABBREVIATION	FULL FORM
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
FAO	Food and Agriculture Organization of the United Nations
IPCC	Intergovernmental Panel on Climate Change
MOEFCC	Ministry of Environment, Forest and Climate Change (Government of India)
ISHS	International Society for Horticultural Science
NCBI	National Center for Biotechnology Information
DRCSC	Development Research Communication and Services Centre
JGVK	Jaygopalpur Gram Vikash Kendra
BTS	Baikunthapur Tarun Sangha
NEWS	Nature Environment and Wildlife Society

Photo Credit: Dona Roy
Lassioglosum sp. sitting on Bringaraj flower

Executive Summary

Pollinators play a key role in agricultural productivity, biodiversity conservation, and food and nutrition security. However, pollinator populations are declining globally due to habitat loss, pesticide overuse, monocropping, environmental pollution, and climate change. These challenges are particularly significant in the humid agroecosystems of West Bengal, where agricultural intensification and high pest pressure threaten pollinator diversity and the ecosystem services they provide.

This study aimed to evaluate the role of seasonal cropping patterns, intercropping practices, and non-crop vegetation in sustaining pollinator diversity and floral resource availability in humid agroecosystems, and to develop a pollinator-friendly cropping framework for small farms and nutrition gardens. The research sought to understand how existing farming practices support pollinators and identify practical interventions for improving pollination services.

A mixed-methods approach was adopted, combining a literature review with field-based surveys. Data were collected through interviews with 25 farmers from South 24 Parganas and 13 pollination researchers from West Bengal and Bangalore. Information on cropping systems, non-crop vegetation, pollinator diversity, and pollinator-friendly practices was documented and analyzed.

The study revealed that diverse seasonal crops and naturally occurring non-crop vegetation, including *Ocimum sanctum, Calotropis gigantea, Hibiscus rosa-sinensis*, and *Mikania micrantha*, provide continuous floral resources for pollinators throughout the year. Bees, particularly *Apis* and *Xylocopa* species, were identified as the dominant pollinators. Major challenges included excessive pesticide use, monocropping, habitat fragmentation, and humidity-related impacts on crop reproductive biology. Researchers recommended intercropping, reduced pesticide application during flowering, and the incorporation of nectar-rich plants such as *Sesamum indicum*, *Turnera subulata*, and *Hamelia patens*.

The study highlights the importance of integrating traditional farmer knowledge with scientific recommendations to develop sustainable pollinator management strategies. Future efforts could focus on promoting diversified cropping systems, conserving non-crop vegetation, enhancing farmer awareness, and implementing pollinator-friendly agricultural practices to improve ecosystem resilience, biodiversity conservation, and long-term food security in humid regions of West Bengal.

1

INTRODUCTION

1.1. IMPORTANCE OF POLLINATORS IN FOOD AND NUTRITION SECURITY

Pollination is one of the most vital ecological services that sustains agriculture, biodiversity, and ecosystem resilience. Pollination plays an important role in supporting biodiversity and food production in agricultural landscapes (IPBES 2016), with an estimated 30% of the global food crop production volume depending on pollinators (Klein et al. 2007). By depending more on natural ecosystem services than industrial inputs (Timberlake et al. 2022), small farms rely on pollination services for crop yields and nutrition, with pollinator-dependent crops providing essential micronutrients that prevent malnutrition (Chaplin-Kramer et al. 2014, Tibesigwa et al. 2019, Mulungu et al. 2023).

In addition to their direct contribution to agricultural productivity, pollinators play a crucial role in maintaining ecosystem stability by sustaining plant biodiversity and enhancing ecological resilience. Pollination supports the reproduction of wild plant species that form the structural and functional foundation of terrestrial ecosystems, providing habitat and resources for numerous other organisms (IPBES, 2016; FAO, 2019). These interactions strengthen ecological networks and contribute to the stability of food webs and ecosystem services. The global decline in pollinator populations is driven by habitat loss, excessive pesticide use (Das et al., 2024), environmental pollution, introduction of invasive species, and climate change leading to significant loss of both biodiversity and food systems (Potts et al., 2016; IPCC, 2022). The loss of pollinators has been linked to reduced crop yields, lower fruit and seed quality, and diminished nutritional diversity in human diets (Klein et al., 2007; Garibaldi et al., 2013). Among the pollinators bees are the most efficient pollinators and the decline of bees in the agricultural landscape is due to agricultural intensification mainly due to loss of seminatural vegetation and pesticide use (Basu et al.,2016). Therefore, the conservation of pollinators and their habitats may play a significant role in sustaining agricultural productivity and rural livelihoods but also for ensuring long-term food and nutrition security (Gallai et al., 2009; Potts et al., 2016). The decline of pollinators could have major socio-economic impacts in countries like India, where many small and marginal farmers depend on stable crop yields for their livelihood (Basu et al., 2011).

1.2. ROLE OF DIVERSIFIED AND POLLINATOR-FRIENDLY CROPPING SYSTEMS

Agricultural diversification and pollinator-friendly cropping systems play a vital role in enhancing ecosystem services, improving crop productivity, and ensuring the resilience of agroecosystems. Traditional monoculture farming systems lead to simplification of the surrounding landscape which further leads to loss of floral resources, and decline in pollinator diversity and abundance (Tscharntke et al., 2012; Kennedy et al., 2013). In contrast, diversified farming systems that include multiple crop species, other flowering plants, and semi-natural habitats provide continuous and diverse sources of nectar and pollen to the pollinators throughout the cropping season. (Garibaldi et al., 2014; Dainese et al., 2019).

Pollinator-friendly practices like intercropping, maintaining field margins with wildflowers, and reducing pesticide usage not only sustain pollinator communities but also enhance pollination services to crops (Blaauw and Isaacs, 2014; Woodcock et al., 2019). These systems contribute to greater yield stability, improved fruit and seed set, and higher nutritional quality of produce (Garibaldi et al., 2013). Moreover, diversified cropping systems enhance landscape connectivity, facilitating pollinator movement and gene flow between habitats, which is crucial for long-term agricultural sustainability (Kremen et al., 2018).

In the context of smallholder and resource-limited farms, such approaches are particularly valuable as they promote ecological intensification—using biodiversity-based ecosystem functions rather than external chemical inputs to sustain productivity (Bommarco et al., 2013). Thus, promoting diversified and pollinator-friendly cropping systems is a potential key strategy for reconciling agricultural production with biodiversity conservation and food security goals in the face of global environmental change.

1.3. CHALLENGES IN HUMID REGIONS OF WEST BENGAL

The humid and subtropical agro-climatic conditions of West Bengal present a unique set of challenges for sustainable crop production. These are characterized by high relative humidity, prolonged monsoon rainfall, and elevated temperatures for most of the year. This provides a favourable condition for pests to proliferate, crop disease outbreaks, and physiological stress in crops (Kumar et al., 2021; Anil Kumar et al., 2020). High humidity and persistent leaf wetness support the rapid multiplication of fungal and bacterial pathogens, particularly in rice, vegetables, and horticultural crops, leading to significant loss of yield (MOEFCC, 2012). In rice-based systems, pest attacks, like stem borers and leaf folders, are mainly caused due to high relative humidity, excessive rainfall, and longer sunshine hours (Kumar et al., 2021).

Agricultural intensification in humid zones of West Bengal has historically been associated with monocropping, particularly the dominance of paddy cultivation, which occupies over half of the gross cropped area (Roy et al., 2019). Although high-yielding varieties and irrigation expansion have improved productivity, the lack of crop diversification has reduced agroecosystem resilience, depleted soil nutrients, and increased vulnerability to pest outbreaks and market instability (Tscharntke et al., 2012). Studies from the Ganga delta and North 24 Parganas districts indicate that over the past three decades, paddy, potato, and oilseed have expanded at the expense of pulses and other legumes, leading to decreased biodiversity and ecological stability within the cropping system (Roy et al., 2019).

High atmospheric humidity also influences plant reproductive processes by affecting pollen hydration, viability, and stigma receptivity. High humidity during the flowering season reduces pollen longevity and germination efficiency, which ultimately impair fruit set and seed formation (Iovane et al., 2021; Harrap et al., 2020). Crops with open or exposed floral structures, such as many vegetables and fruit species, are particularly sensitive to these effects, which leads to fungal infections under moist conditions (ISHS, 2018).

Overall, the convergence of pest pressure, monocropping, and high humidity-induced reproductive stress poses a substantial threat- to make it neutral, possible alternatives: may pose significant challenges to crop productivity and sustainability in humid regions of West Bengal. The agricultural intensification in India, particularly in the humid regions of West Bengal has been associated with landscape changes that may reduce habitat suitability for pollinators. The widespread adoption of monocultures, coupled with rising pesticide dependency, has sharply reduced both the abundance and diversity of pollinators. Addressing these challenges may benefit from integrated management strategies that combine crop diversification, pollinator-friendly farming, and climate-resilient practices to strengthen the ecological and economic stability of smallholder farming systems in the region.

This study is designed with the aim of addressing these challenges by focusing on cropping practices in humid agroecosystems of West Bengal. The first objective is to evaluate how seasonal cropping patterns, intercropping strategies, and non-crop vegetation can sustain pollinator diversity, abundance, and floral resource availability. The second is to develop a practical, locally relevant, and low-cost framework for pollinator-friendly cropping that can be adopted in nutrition gardens and small farms across the region. By combining a systematic review of existing literature with field-based surveys, the research will attempt to bridge current knowledge gaps and provide actionable insights for both farmers and policymakers.

1.4 OBJECTIVES

1. To evaluate seasonal cropping patterns, intercropping practices, and non-crop vegetation in relation to their role in sustaining pollinator diversity, abundance, and floral resource availability in humid agroecosystems.
2. To develop a pollinator-friendly cropping framework for nutrition gardens and small farms in West Bengal based on the findings.

2

LITERATURE REVIEW

2.1. INTRODUCTION

More than three-quarters of the world's leading food crops depend, at least in part, on animal pollination. Bees, butterflies, flies, beetles, birds, and bats transfer pollen from one flower to another, ensuring fruit and seed formation, enhancing crop yield, and improving the quality of produce (Potts et al. 2016). Maintaining and enhancing pollinator populations and diversity in small farms is thus a conservation and food security priority (United Nations 2015), especially in the face of ongoing land-use change and habitat fragmentation, increasing pesticide application, environmental pollution, and decreasing resource diversity (Potts et al. 2010, Dicks et al. 2021). One effective approach to sustaining pollination services in agricultural landscapes is the adoption of pollinator-friendly management and design practices (IPBES 2016; Potts et al. 2016). In particular, preserving semi-natural and natural habitats near the farms can be beneficial, as these areas provide significant resources for pollinators, including foraging and nesting opportunities (Ricketts et al. 2008, Garibaldi et al. 2011, Cole et al. 2017, Tscharntke et al. 2021). Farmers have limited control over the surrounding environment, but they can make improvements within their own farms. However, it is not well understood whether such on-farm restoration efforts actually enhance production. Hence, it is important to study these practices directly at the farm level.

2.2. POLLINATOR DECLINE AND ITS IMPACTS

Pollinator decline has been identified as a significant global concern, particularly in countries where agriculture plays an important role. Pollinators form the backbone of crop yield, fruit and seed set, and food quality. Their disappearance not only reduces harvests for farmers but also signals broader ecological consequences, including reduced reproduction of wild plants and disruption of ecosystem stability (Potts et al. 2010; IPBES 2016). In Indian agroecosystems dominated by smallholder farmers, pollinator loss has even more implications for food security and rural livelihoods (FAO 2018).

Pollinator decline is driven by multiple interlinked factors. Widespread habitat loss has fragmented landscapes, removing essential foraging and nesting spaces (Kennedy et al. 2013). Heavy pesticide and herbicide use has been associated with adverse effects on pollinator health (Sánchez-Bayo & Wyckhuys 2019), while monoculture-based farming systems reduce floral diversity critical for survival (Goulson et al. 2015). Invasive species, climate variability, and the spread of pathogens further worsen these stresses (Brown & Paxton 2009; Kerr et al. 2015). Rapid urbanization and industrial agriculture have transformed heterogeneous farmlands into simplified, resource-poor landscapes, placing both managed and wild pollinator populations under severe pressure (Dicks et al. 2021).

2.3. CAUSES FOR POLLINAR DECLINE

Agricultural intensification has created simplified landscapes less favorable for pollinators. High pesticide dependency and monocropping reduce pollinator abundance and diversity (Potts et al. 2010). Declines in natural pollination increase reliance on artificial pollination services or rented bee colonies, raising production costs. The major causes are listed below:

2.3.1 Habitat loss and fragmentation: The expansion of agriculture, urbanization, deforestation, has led to extensive destruction and fragmentation of natural habitats (Kennedy et al. 2013). Pollinators such as wild bees and butterflies depend on diverse vegetation for foraging and nesting. Fragmentation reduces floral availability, prevents movement between patches, and decreases gene flow, increasing extinction risk (Harrison et al. 2012). Loss of hedgerows, field margins, and fallow lands further reduces habitat quality in agricultural landscapes.

2.3.2 Pesticide use: Widespread pesticide use is one of the most significant threats to pollinators and other insects as well. Neonicotinoid insecticides cause both acute mortality and chronic sub-lethal effects, including impaired navigation, memory, and foraging (Woodcock et al. 2017; Stanley et al. 2015). Fungicides and herbicides indirectly affect pollinators by reducing floral diversity and altering pollen and nectar microbiomes (Mullin et al. 2010). Chronic exposure weakens immunity, increasing susceptibility to pathogens (Sánchez-Bayo & Wyckhuys 2019).

2.3.3 Monoculture farming: Another cause of pollinator decline is extensive use of monoculture systems, where large areas are planted with a single crop, drastically reducing floral diversity and seasonal continuity of food resources (Goulson et al. 2015). Pollinators dependent on diverse flowers suffer nutritional stress during non-blooming periods. Monocultures also eliminate wild vegetation that offers nesting substrates and alternative forage, and they intensify reliance on pesticides, compounding pollinator decline.

2.3.4 Climate change: Climate change is another major factor influencing pollinator decline, which impacts pollinators through altered temperature and rainfall, increased heat extremes, and shifts in seasonality (IPCC 2014). Many pollinators are temperature-sensitive; extreme heat or unexpected cold spells disrupt activity and survival (Kerr et al. 2015). Changes in plant phenology cause mismatches between flowering times and pollinator emergence (Memmott et al. 2007). Altered climate patterns also shift geographical ranges, resulting in habitat mismatch or local extinctions.

2.3.5 Pathogens and parasites: Pathogens such as viruses, fungi, and bacteria, and parasites like Varroa destructor mites and Nosema spp., have caused severe declines in managed and wild pollinator populations (Brown & Paxton 2009; Fürst et al. 2014). Stress from pesticides, habitat loss, and inadequate nutrition further increases vulnerability to disease. The global movement of managed bees accelerates the spread of pathogens to wild species.

Scientific name: *Senna tora*
Common name: Chakunda
Visting pollinators: Bees, butterfly

Scientific name: *Lantana Camera*
Common name: Putus
Visting pollinators: Bees (blue banded bee), butterfly, moth.

2.3.6 Invasive species: Non-native species disrupt local ecological balances. Invasive plants can dominate ecosystems and reduce native floral diversity, limiting forage for native pollinators (Stout & Morales 2009). Invasive pollinators such as *Apis mellifera* in certain regions outcompete native bees and can transmit diseases (Russo 2016). Alien predators and parasites can create cascading negative effects on pollinator populations.

2.4 CURRENT STATE OF POLLINATOR-FRIENDLY FARMING IN INDIA

Pollinator-friendly farming is yet to receive wide consideration and integration into the Indian agricultural policy landscape. Although traditional mixed farming and organic practices indirectly support pollinators, these approaches are rarely recognized as formal conservation strategies (Sharma et al. 2019). In regions like humid West Bengal, agricultural intensification has sharply reduced pollinator abundance and diversity (Bhattacharya et al. 2020). This leads to unstable crop yields and increased dependence on chemical inputs or artificial pollination.
The widespread adoption of monocultures and increased pesticide use in humid regions of West Bengal has significantly disrupted plant–pollinator interactions, making yields less reliable and increasing vulnerability to ecological and economic shocks (Bhattacharya et al. 2020).

Scientific name- *Ocimum basilicum*
Common name- ভোগ Tulsi
Visting pollinators: Honeybees (*Apis cerana, A. dorsata*), stingless bees (*Tetragonula*), hoverflies

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METHODOLOGY

Academic databases such as NCBI Pubmed and Google Scholar were searched using keywords including “pollination”, “pollinator-friendly cropping”, and “pollination in humid regions” for a comprehensive review of existing research on pollination and cropping practices, with particular emphasis on studies relevant to humid and subtropical environments. This allows the identification of patterns, gaps, and opportunities in the current body of knowledge. In parallel, field surveys are being carried out across selected sites in West Bengal. These surveys documented cropping practices, seasonal flowering patterns, the extent of intercropping, and the presence of non-crop vegetation such as weeds, hedgerows, and wild flowering plants that act as supplementary resources for pollinators. Observations on the diversity and abundance of pollinator species in different cropping systems will be recorded, providing empirical insights into the links between agricultural practices and pollinator health.

Scientific name: *Leucas aspera*
Common name: Shwetdron, dronpushpi
Visting pollinators: Leaf cutter bee (*Megachilidae*), *Apis cerana, Apis dorsata*

Farmer survey

Most of the surveys were conducted in the South 24 Parganas district, covering areas such as Basanti, Baikunthapur, Sagardeep, Patharpratima, and Namkhana. Organizations including Runners and Madhuban, BTS, JGVK Sundarbans, DRCSC and NEWS assisted us in conducting these surveys with various farmers.

Scientist survey

A total of thirteen scientists and pollination researchers were surveyed, primarily from West Bengal and Bangalore. The survey outcome is listed in the results section.

Scientific name: *Hygrophilla auriculata*
Common name: Kulekhara, swetfulka
Visting pollinators: Leaf cutter bees (Megachilidae), Carpenter bee (*Xylocopa* sp.), *Apis dorsata.*

Scientific name: *Tridax procumbens*
Common name: Tridhara, kot botam
Visting pollinators: Bees, butterfly, moth

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RESULTS

Results of the Farmer Survey

A total of 25 farmers, primarily from South 24 Parganas, West Bengal, were surveyed to document existing cropping patterns, non-crop vegetation, pollinator diversity, and constraints to adopting pollinator-friendly farming practices. The survey reports are listed below:

MAJOR NON-CROP PLANTS FOUND IN FARMERS' FIELDS

TABLE 1. COMMON NON-CROP AND WILD PLANTS REPORTED BY FARMERS

Ipomoea *(Morning glory)*	**Telakochu** *(Trichosanthes dioica / Coccinia indica* type creeper)
Berachampa / Bera champa *(Plumeria rubra)*	**Tulsi (***Ocimum sanctum)*
Akanda *(Calotropis gigantea)*	**Croton** *(Codiaeum variegatum)*
Mikania sp. *(Climbing weed, Mikania micrantha)*	**Crape jasmine** *(Tabernaemontana divaricata)*
Datura *(Datura metel)*	**Green milkweed** *(Asclepias curassavica)*
Chiana rose / China rose *(Hibiscus rosa-sinensis)*	**Bunophol** *(*local climber/shrub – possibly *Clerodendrum* sp.*)*
Ivy gourd *(Coccinia grandis)*	**Germany pata** (local ornamental foliage plant)

Farmers reported a diverse assemblage of non-crop and wild flowering plants growing naturally along field margins, homesteads, and uncultivated areas. Frequently reported species included Tulsi (*Ocimum sanctum*), Akanda (*Calotropis gigantea*), *Ipomoea* spp., *Mikania micrantha*, *Datura metel*, *Hibiscus rosa-sinensis*, *Coccinia grandis*, and *Plumeria rubra*. Several ornamental and naturally occurring species were also commonly present. These plants provide continuous floral resources outside the cropping season and are likely to support pollinator populations by supplying nectar and pollen when cultivated crops are not flowering.

TABLE 2. MAJOR POLLINATORS OF DOMINANT NON-CROP PLANTS

Non-Crop Plant	Major Pollinators Observed
Tulsi *(Ocimum sanctum)*	Honeybees *(Apis cerana, A. dorsata),* stingless bees *(Tetragonula),* hoverflies
Akanda *(Calotropis gigantea)*	Carpenter bees (*Xylocopa spp.*), honeybees, butterflies (*Danaus* spp.)
Ipomoea	Carpenter bees, leafcutter bees, butterflies, hawkmoths
Crape jasmine *(Tabernaemontana divaricata)*	Bees, butterflies, moths (especially sphinx moths)
Datura *(Datura metel)*	Hawkmoths (*Sphingidae*), carpenter bees
Croton / *Mikania* sp.	Honeybees, hoverflies, small solitary bees
China rose (*Hibiscus rosa-sinensis*)	Carpenter bees, bumblebees, butterflies
Ivy gourd *(Coccinia grandis)*	Honeybees, leafcutter bees, flies
Bera champa *(Plumeria rubra)*	Large bees, butterflies, and nocturnal moths
Green milkweed *(Asclepias* sp.*)*	Monarch butterflies, honeybees, wasps

The survey indicated that non-crop plants attracted a wide range of pollinators. Honey bees (*Apis* spp.) were the most frequently observed visitors, followed by carpenter bees (*Xylocopa* spp.), stingless bees (*Tetragonula* spp.), leafcutter bees, hoverflies, butterflies, hawkmoths, and occasionally wasps. Species such as Tulsi and Akanda supported multiple pollinator groups, while Datura was mainly visited by hawkmoths. Similarly, Ipomoea and China rose attracted large bees and butterflies, highlighting the ecological importance of maintaining diverse non-crop vegetation within agricultural landscapes.

TABLE 3A. SEASONAL CROPS REPORTED BY THE FARMERS AND THE NON-CROPS IN THEIR FIELDS: PRE-KHARIF CROPS.

Pollinator attractant crops and non-crops are in **bold**.

Category	Major Crops
Leafy Vegetable	Jute, Drumstick, **Water spinach**, Malabar spinach
Fruit Vegetables	Ladies finger
Fruits	**Banana, Guava,** Papaya, Custard apple, **Lemon,** Sugar plum, Date plum, Coconut
Legumes	**Green gram, Beans, Pigeon pea, Grass pea**
Tubers	Elephant foot yam, Taro, Dioscorea
Spices	Ginger, Turmeric (haldi)
Non crop plants	**Ocimum, Senna alata, Akanda, Cyanthelium cenereum, Rungia, Sida, Datura, Ivy gourd, Sponge gourd, Crotalaria sp.**
Timber Trees	Sirish, Sugar plum, Date plum, Coconut

During the pre-Kharif season, farmers cultivated a mixture of leafy vegetables, legumes, fruit crops, tubers, and spices. Banana, guava, papaya, green gram, pigeon pea, elephant foot yam, ginger, and turmeric were among the dominant crops. Several flowering non-crop species including *Ocimum, Akanda, Cyanthelium cinereum, Datura, Sida, Crotalaria*, and Ivy gourd were commonly found around fields. These flowering plants likely serve as important nectar and pollen sources during periods when crop flowering is limited.

TABLE 3B. SEASONAL CROPS REPORTED BY THE FARMERS AND THE NON-CROPS IN THEIR FIELDS: KHARIF CROPS.

Pollinator attractant crops and non-crops are in **bold**.

Category	Major Crops
Cereals	**Paddy, Maize**
Leafy Vegetable	**Water spinach,** Malarbar spinach
Fruit Vegetables	**Ridge gourd, Cucumber, Bitter gourd**
Fruit	**Banana, Mango,** Black plum, Coconut, **Guava**
Legumes	**Beans, Black gram, Yardlong beans, Lentil, Flat bean**
Tubers	Elephantfoot yam, Taro
Spices	**Chilli,** Ginger
Non crop plants	***Datura, Tridax procumbens, Senna alata, Senna tora, Senna occidentalis, Lantana camera, Ocimum, Leucus aspera, Hygrophilla ringes, Hygrophilla auriculata, Cyanthelium cinereum, Rungia, Sida, Crotalaria, Ipomoea, Datura,*** **Ivy gourd, Sponge gourd.**
Timber trees	**Mango,** Black plum, Coconut, **Guava**

The Kharif season was dominated by paddy and maize, together with cucurbits such as ridge gourd, cucumber, and bitter gourd. Farmers also cultivated banana, mango, black plum, beans, chilli, ginger, and elephant foot yam. Field margins contained abundant flowering weeds including *Tridax procumbens, Ocimum, Leucas aspera, Hygrophila* spp., *Senna* spp., *Lantana camara, Ipomoea,* and *Crotalaria*. The diversity of flowering weeds during this season provides important forage for bees and other insect pollinators.

TABLE 3C. SEASONAL CROPS REPORTED BY THE FARMERS AND THE NON-CROPS IN THEIR FIELDS: RABI CROPS.

Pollinator attractant crops and non-crops are in **bold**.

Category	Major Crops
Leafy Vegetable	**Coriander,** Spinach
Fruit Vegetables	**Pumpkin,** Tomato
Fruit	**Guava, Java apple, Banana**
Legumes	**Beans, Yardlong beans, Pea, Chick pea, Grass pea**
Tubers	**Radish,** Carrot, Beetroot, Sweet potato, Potato, Elephant foot yam
Spices	**Chilli,** Onion, Garlic
Medicinal plants	**Ocimum, Vasaka, Leucas aspera, Senna alata, Senna tora, Senna occidentalis, Sponge gourd**
Timber Trees	Wood apple, **Indian jujube, Mango, Lemon, Java apple**

Rabi cultivation consisted mainly of vegetables, legumes, tubers, and spices. Pumpkin, tomato, beans, peas, chickpea, radish, carrot, potato, onion, garlic, and chilli were commonly grown. Farmers also maintained medicinal and flowering plants such as *Ocimum, Leucas aspera, Senna* spp*.,* and *Vasaka*, which continue to provide floral resources during the dry season. Fruit trees including mango, lemon, wood apple, and Indian jujube further contributed to seasonal nectar availability.

TABLE 4. MAJOR CROPS AND MAIN POLLINATORS OBSERVED IN THE SURVEY

Crop	Main Pollinators Observed
Yardlong beans *(Vigna unguiculata)*	Bees, butterflies, *Xylocopa* spp., wasps
Pumpkin *(Cucurbita moschata)*	Bees, butterflies, *Xylocopa* spp., wasps, ants, spiders
Cucumber *(Cucumis sativus)*	Bees, butterflies, *Xylocopa* spp., wasps
Jamrul *(Syzygium samarangense)*	Bees, wasps, *Xylocopa* spp.
Mango *(Mangifera indica)*	Bees, butterflies, *Xylocopa* spp., wasps
Pineapple *(Ananas comosus)*	Bees, wasps, *Xylocopa* spp.
Sojne / Drumstick *(Moringa oleifera)*	Bees, Xylocopa, butterflies
Mocha / Banana inflorescence *(Musa* spp.*)*	*Bees, Xylocopa* spp.
Pomegranate *(Punica granatum)*	Bees, *Xylocopa* spp.
Lime *(Citrus aurantifolia)*	Bees, *Xylocopa* spp.
Ladies finger *(Abelmoschus esculentus)*	Bees, *Xylocopa* spp.
Java apple *(Syzygium samarangense)*	Bees, *Xylocopa* spp.
Banana blossom *(Musa* spp.*)*	Bees, *Xylocopa* spp.
Corn *(Zea mays)*	Bees, *Xylocopa* spp., butterflies, wasps
Sunflower *(Helianthus annuus)*	Bees, *Xylocopa* spp., butterflies, wasps
Ridge gourd *(Luffa acutangula)*	Bees, butterflies, *Xylocopa* spp., wasps
Ivy gourd *(Coccinia grandis)*	Bees, butterflies, *Xylocopa* spp., wasps
Bottle gourd *(Lagenaria siceraria)*	Bees, butterflies, *Xylocopa* spp., wasps
Mustard *(Brassica juncea)*	Bees, butterflies, *Xylocopa* spp., wasps
Ash gourd *(Benincasa hispida)*	Bees, butterflies, *Xylocopa* spp., wasps, ants, spiders
Beans *(Phaseolus* spp.*)*	Bees, butterflies, *Xylocopa* spp., wasps

Crop	Main Pollinators Observed
Bitter gourd *(Momordica charantia)*	Bees, butterflies, *Xylocopa* spp., wasps
Guava *(Psidium guajava)*	Bees, butterflies, flies
Neem *(Azadirachta indica)*	Butterflies
Tomato *(Solanum lycopersicum)*	Butterflies
Paddy *(Oryza sativa)*	Bees, butterflies
Green gram *(Vigna radiata)*	Bees, butterflies
Black gram / Lentil *(Vigna mungo / Lens culinaris)*	Bees, butterflies
Brinjal *(Solanum melongena)*	Bees, butterflies, *Xylocopa* spp.
Chilli *(Capsicum annuum)*	Bees, butterflies
Grass pea *(Lathyrus sativus)*	Butterflies
Coconut *(Cocos nucifera)*	Bees
Drum stick *(Moringa oleifera)*	Bees, butterflies
Radish *(Raphanus sativus)*	Bees, butterflies
Potato *(Solanum tuberosum)*	No pollinators reported

Farmers identified bees as the most important pollinators across nearly all crop species. Carpenter bees (*Xylocopa* spp.) were frequently associated with large-flowered crops such as pumpkin, ridge gourd, bottle gourd, cucumber, bitter gourd, beans, drumstick, and brinjal. Butterflies and wasps were also commonly observed visiting cucurbits, mango, mustard, sunflower, and several legume crops. Flies were mainly reported on guava flowers, while ants and spiders were occasionally seen on pumpkin and ash gourd flowers. Potato was the only crop for which farmers reported no noticeable pollinator visits, reflecting its predominantly vegetative propagation.

Scientific name: *Rungia pectinata*
Common name: Dhupjhora, Pindi
Visting pollinators: Small bees

Scientific name: *Cyanthellium cinereum*
Common name: Kuksima
Visting pollinators: Bees, butterfly, moth

Scientific name: *Crotalaria retusa*
Common name: Atasi, jhunjhuni
Visting pollinators: Leaf cutter bee (Megachilidae), Carpenter bee (*Xylocopa* spp.), Apis dorsata, Butterfly.

Scientific name: *Luffa aegyptiaca*
Common name: Dhundul
Visting pollinators: Bees, butterfly, moth

Scientific name: *Mikania micrantha*
Common name: Germany lata, asam lata
Visting pollinators: Honey bees, small solitary bees, flies, butterflies, moths

Scientific name: *Oxalis corniculate*
Common name: Amrul, Toksushuni
Visting pollinators: Small solitary bees, honey bees, flies, butterflies, moths

FIGURE 1. MAJOR CHALLENGES IN ADOPTING POLLINATOR-FRIENDLY PRACTICES IN HUMID ZONES

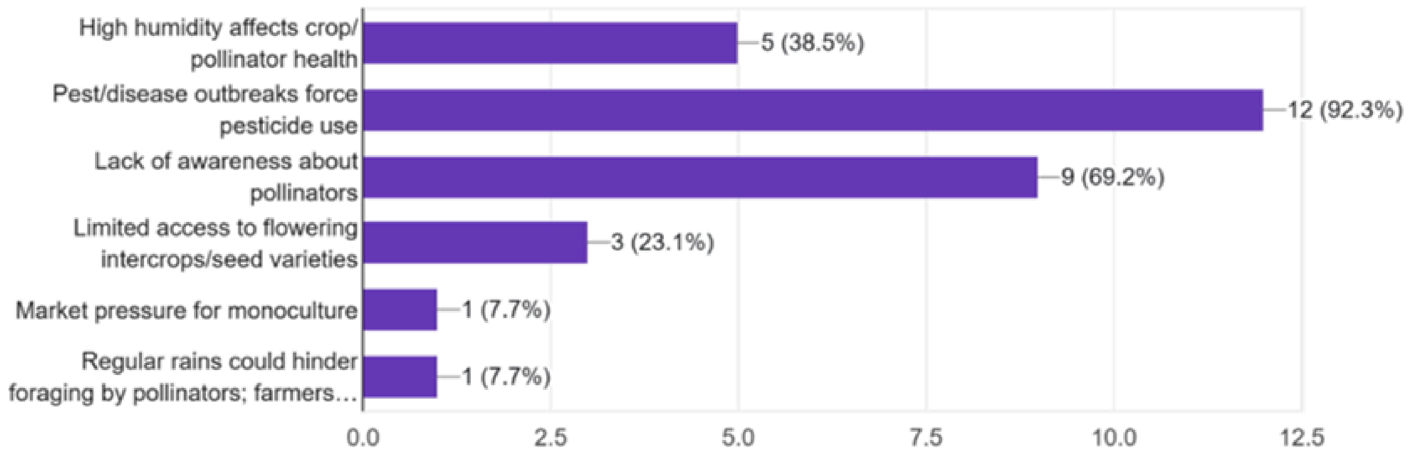

Figure 1 summarizes the major constraints reported by farmers in adopting pollinator-friendly farming practices. The most frequently identified challenges included high pest incidence leading to pesticide dependence, limited awareness regarding pollinator conservation, shortage of quality planting materials for flowering plants, small landholdings, and economic limitations. Climatic factors such as high humidity and seasonal flooding also affected the establishment of flowering vegetation and pollinator habitats.

FIGURE 2. MAJOR CROPS COMMONLY FOUND IN THE AREA

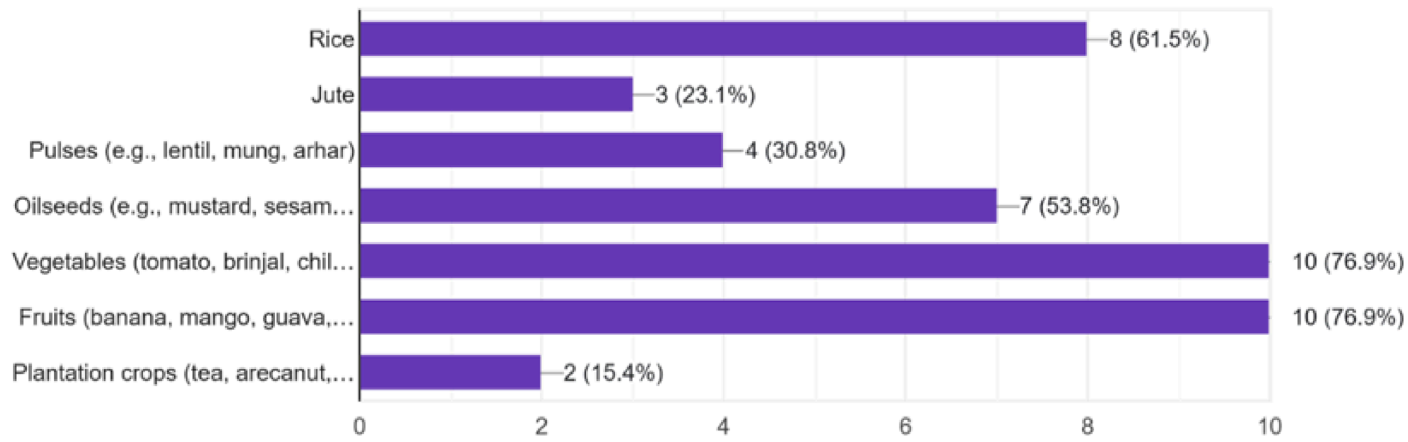

Figure 2 illustrates the major crops cultivated by farmers across the surveyed villages. Vegetable crops, legumes, fruit trees, cereals, and cucurbits dominated the farming systems, indicating a highly diversified agricultural landscape. Such crop diversity has the potential to provide floral resources over much of the year, particularly when combined with flowering non-crop vegetation.

FIGURE 3. COMBINATION OF INTERCROPPING SUGGESTED BY THE RESEARCHERS

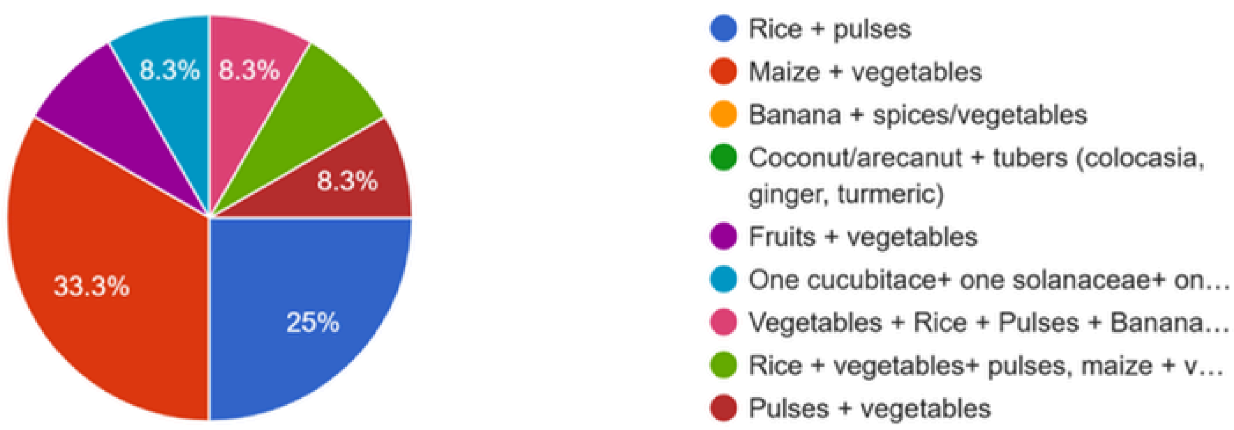

Figure 3 presents the recommended intercropping combinations proposed by researchers to improve pollinator diversity and ecosystem services. The suggested combinations integrate flowering legumes, vegetables, medicinal plants, and nectar-rich flowering species with major crops to ensure continuous floral availability throughout the growing season. These systems are expected to enhance pollinator abundance while simultaneously improving crop productivity and biodiversity conservation.

FIGURE 4. COMMON POLLINATORS IDENTIFIED DURING THE FIELDWORK BY RESEARCHERS

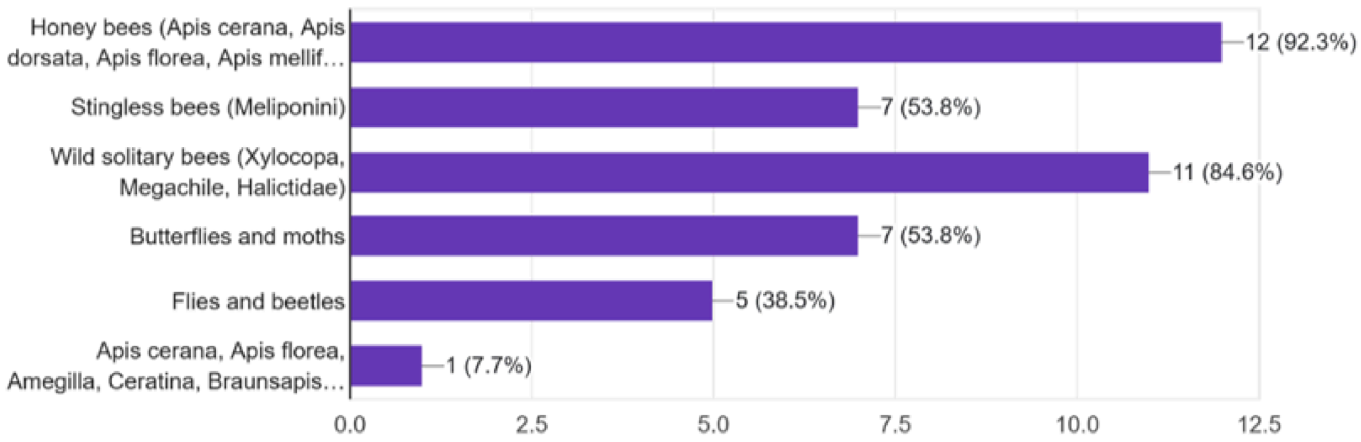

Figure 4 shows the major pollinator groups recorded during field visits by researchers. Bees represented the dominant pollinator group, particularly honey bees, carpenter bees, stingless bees, and leafcutter bees. Butterflies, hoverflies, moths, and wasps were also frequently observed visiting flowering crops and non-crop vegetation. The diversity of pollinator taxa indicates that agricultural landscapes in South 24 Parganas support a rich assemblage of pollinating insects.

TABLE 5. LIST OF MAJOR POLLINATOR FRIENDLY PLANTS ACCORDING TO THE SCIENTISTS

Tridax procumbens	*Mimosa pudica*	*Crotalaria pallida*
Cassia sp.	*Heliotropium indicum*	*Coleus strobilifer*
Lantana camara	*Mikania micrantha*	*Tecoma stans*
Ociumum sp.	*Scoparia dulcis*	*Grona triflora*
Leucas aspera	*Borassus flabellifer*	*Alternanthera sessilis*
Hygrophila auriculata	*Phoenix sylvestris*	*Cipadessa baccifera*
Cyanthillium cinereum	*Senna occidentalis*	*Calotropis* sp. *(Akanda)*
Rungia pectinata	*Senna alata*	*Amaranthus viridis (*Green amaranath*)*
Sida sp.	*Senna tora*	*Ageratum conyzoides (*Goat weed*)*
Commelina sp.	*Tephrosia purpurea*	*Cynodon dactylon (*Bermuda grass*)*
Glycosmis pentaphylla	*Mesosphaerum suaveolens*	*Tagetes* sp. *(*Marigold / Ganda*)*

Scientists identified a range of flowering plant species that are highly beneficial for sustaining pollinators throughout the year. These species were selected based on their flowering duration, nectar and pollen production, attractiveness to multiple pollinator groups, and adaptability to local climatic conditions. The recommended plants can be incorporated into field margins, homestead gardens, and bunds to strengthen pollinator habitats within agricultural landscapes.

TABLE 6. LIST OF MAJOR FLOWERING PLANTS

Hygrophila (Hygrophila auriculata)	*Mikania (Mikania micrantha)*	*Cynathillium (Cyanthillium cinereum)*
Convolvulus (Convolvulus arvensis)	*Murraya koenigii*	*Turnera subulata*
Hamelia patens	*Cinnamomum tamala*	*Citrus* sp.
Brassica juncea (Mustard)	*Helianthus annuus* (Sunflower)	*Sesamum indicum* (Sesame)
Vigna unguiculata (Cowpea)	*Coriandrum sativum* (Coriander)	*Tagetes* sp. (Marigold/Ganda)
Cajanus cajan (Pigeonpea)	*Tridax procumbens*	*Ocimum* sp.
Ruellia tuberosa	*Antigonon leptopus*	*Moringa oleifera* (Drumstick)
Syzygium cumini	*Eclipta prostrata* (False daisy)	

Table 6 lists flowering plant species recommended for enhancing pollinator resources in humid agroecosystems. The selected species provide staggered flowering periods across seasons, ensuring continuous nectar and pollen availability. Inclusion of these plants in farming systems is expected to improve pollinator diversity, support beneficial insects, and contribute to stable crop pollination services.

FIGURE 5. PRACTICES THAT ARE MOST EFFECTIVE TO SUPPORT POLLINATORS ACCORDING TO THE RESEARCHERS

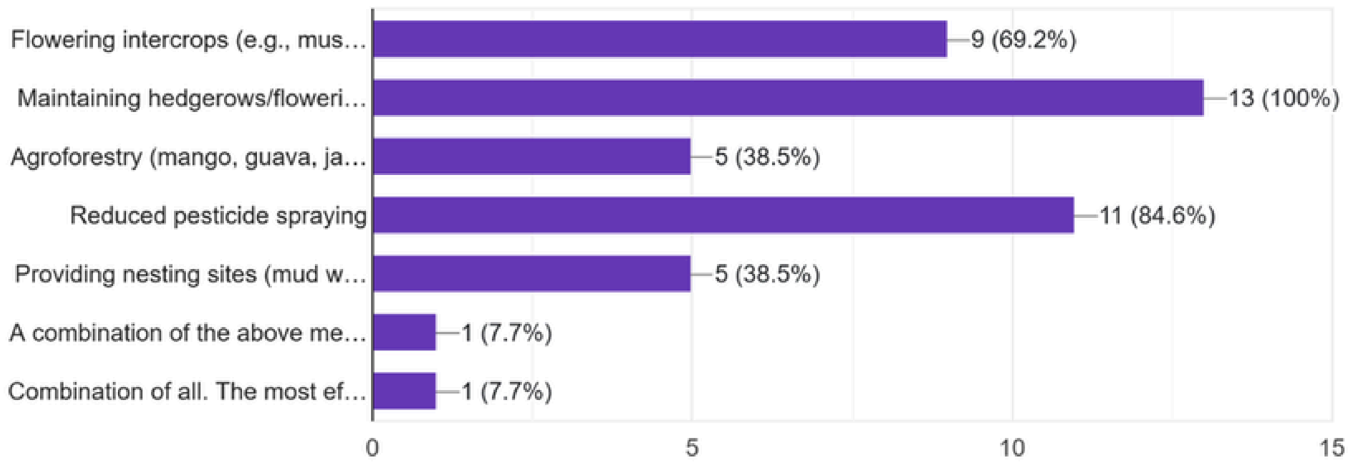

Figure 5 summarizes researchers' opinions on the most effective practices for pollinator conservation in agricultural landscapes. The highest-ranked practices included reducing pesticide use, maintaining flowering field margins, preserving natural vegetation, adopting intercropping systems, planting pollinator-friendly flowering species, and providing year-round floral resources. Collectively, these management strategies were considered essential for sustaining pollinator populations and improving ecosystem resilience in humid farming systems.

Scientific name: *Senna alata*
Common name: dadmari, boro chakunda
Visting pollinators: Bees (*Xylocopa* spp.)

Scientific name: *Sida acuta*
Common name: Kureta, berela
Visting pollinators: Honey bees, solitary bees, flies, butterflies.

Scientific name: *Calotropis gigantea*
Common name: Akanda, arok
Visting pollinators: Carpenter bees (*Xylocopa* spp.), honeybees, butterflies.

Scientific name: *Datura wrightii*
Common name: Dhutura
Visting pollinators: Hawkmoths (*Sphingidae*), carpenter bees

Scientific name: *Alternanthera sessilis*
Common name: Sanchi sak
Visting pollinators: Bees (Solitary bees) *Apis cerana, Apis dorsata, Apis florae*

Scientific name: *Coccinia grandis*
Common name: Telakucho, Tolli
Visting pollinators: Honeybees, leafcutter bees (*Megachilidae*), flies

5
DISCUSSION

The combined results from the farmer surveys and researcher surveys provide a comprehensive understanding of plant–pollinator dynamics in humid agroecosystems of South 24 Parganas and adjoining regions. The findings illustrate a complex mosaic of cultivated crops, non-crop vegetation, and diverse pollinator assemblages that jointly shape pollination services in these areas.

5.1. DIVERSITY OF NON-CROP FLORA AND ITS ECOLOGICAL IMPLICATIONS

Farmers reported a substantial presence of non-crop and wild plants within or surrounding their fields, including *Ipomoea, Tulsi (Ocimum sanctum), Calotropis gigantea, Hibiscus rosa-sinensis, Mikania micrantha, Coccinia grandis*, and several shrubs and ornamentals. These plant species provide a continuous source of nectar and pollen resources to the pollinators throughout the year, which acts as an alternative nectar and pollen source to the pollinators when primary crops are not flowering.

The presence of species such as *Mikania, Calotropis, Ocimum,* and *Hibiscus* indicates that farmers unintentionally maintain semi-natural foraging patches. Which provides critical nectar and pollen resources that help sustain pollinator populations in disturbed or intensively managed landscapes.

5.2. POLLINATOR ASSEMBLAGES REFLECT A GENERALIST-DOMINATED SYSTEM

Farmers documented a rich set of pollinators mainly bees (*Apis* spp., *Xylocopa* spp.), butterflies, hoverflies, and wasps. The dominance of generalist foragers, particularly *Apis cerana*, *A. dorsata*, and *Xylocopa* species, is consistent with humid and heterogenous landscapes where flowering resources are abundant but fragmented.

Scientists also reported overlap in pollinator groups, reinforcing the reliability of farmer observations. The presence of carpenter bees (*Xylocopa* spp.) as major visitors highlights their importance for large-flowered crop species such as Cucurbita, brinjal, Ladies finger and Moringa, which require powerful pollinators capable of handling complex floral structures.

5.3. CROP–POLLINATOR INTERACTIONS ACROSS SEASONS

The crop list reported by farmers illustrates a year-round availability of floral resources due to the diversity of Pre-Kharif, Kharif, and Rabi crops. Across seasons, pollinator-dependent crops such as pumpkin, cucurbits (*Luffa, Coccinia, Cucumis*), brinjal, mustard, legumes, and fruit trees (guava, mango, jamrul) ensure continuous foraging opportunities.

Several crops particularly legumes (yardlong bean, green gram), cucurbits, mustard, and fruit trees showed repeated observation of bees and butterflies, reflecting moderate to high pollination dependence. Whereas crops like potatoes reported no pollinator activity. The seasonal crops with diverse flowering periods act as a buffer to pollinators during periods of food shortage.

5.4. CONVERGENCE AND DIVERGENCE BETWEEN FARMERS AND SCIENTISTS

A key convergence between both groups lies in identifying bees, especially *Apis* and *Xylocopa*, as the most critical pollinators across cultivated and wild plants. Scientists additionally highlighted the importance of syrphid flies and solitary bees, the group of bees less frequently recognized by farmers, mainly due to small size and lack of knowledge.

Scientists emphasized on some specific intercropping systems, such as mustard with vegetables, sesame with legumes, sunflower with brinjal, which enhance floral resource diversity and potentially increase in yield through better by increases in pollinators pollination service. These combinations were unknown to farmers, indicating a knowledge gap that can be addressed through targeted extension programs.

5.5. CHALLENGES IN HUMID AGROECOSYSTEMS

According to researchers, humid regions of South Bengal face several problems, like high pest attack that encourages frequent pesticide use, which leads to pollinator decline as well. Another problem is the fragmentation of semi-natural habitats due to dense village settlements & small landholdings further limits available resources for pollinators. Farmers indirectly reflected these issues in their responses, reporting declining pollinator numbers, heavy reliance on pesticides, and a noticeable reduction in non-crop vegetation around their fields.

5.6. CONSERVATION AND MANAGEMENT OPPORTUNITIES

Researchers identified several highly beneficial plant species for supporting pollinators, including *Sesamum indicum, Turnera subulata, Murraya koenigii, Cyanthillium cinereum, Hamelia patens, Citrus* spp., *Brassica juncea,* and *Helianthus annuus*. These species provide staggered nectar–pollen availability and can be incorporated into field bunds, homestead gardens, and intercrop strips.

Both farmers and scientists agreed that maintaining some level of non-crop vegetation supports pollinators, but scientists emphasized structured practices, such as:

- Reducing pesticide use during peak flowering season
- Maintaining year-round flowering plant strips
- Promoting crop diversification and intercropping
- Conserving nesting substrates for wild bees
- Protecting semi-natural hedgerows and field margins

5.7. IMPLICATIONS FOR SUSTAINABLE FARMING IN SOUTH 24 PARGANAS

The combined results of the two surveys strongly suggest that humid region agroecosystems with mixed cropping and diverse non-crop vegetation can sustain robust pollinator communities. However, pollinator services remain vulnerable to pesticide use, habitat simplification, and the spread of invasive plants.

The study highlights the key considerations for a farm for a farm-level pollinator management framework, including:

1. Pollinator-friendly intercropping (like mustard–vegetable, sesame–legume systems).
2. Planting recommended nectar-rich plant
3. species identified by scientists.
4. Controlled management of invasive weeds like Mikania while retaining beneficial non-crops.
5. Awareness and capacity-building for farmers on pollinator identification and pollinator friendly agricultural practices.

Such interventions can help stabilize yields, increase biodiversity, and reinforce ecological resilience in these humid agricultural landscapes.

5.8 KEY TAKE AWAY FROM THE COMBINED SURVEY AND REVIEW:

1. **Pollinators are critical for food security in humid regions of West Bengal**, where diverse cropping patterns and non-crop vegetation provide year-round floral resources essential for bees, butterflies, flies, and other pollinators.
2. **Agricultural fields host rich non-crop vegetation**, including *Ocimum sanctum, Calotropis gigantea, Senna* species*, Leucas aspera, Mikania micrantha,* and many others, which unintentionally serve as a, naturally occurring foraging habitat for the pollinators between and during the cropping seasons. The observation and various reports suggest that maintaining a patch of natural vegetation (approximately 6-37% depending on the targeted pollinator) may support pollinator presence (Bishop, 2025).
3. **Seasonal crop calendars strongly influence pollinator activity**, with cucurbits, legumes, leafy vegetables, fruit vegetables, and tuber crops providing major floral resources at different times of the year. Alongside these, non-crop species like *Ocimum, Senna* spp.*, Crotalaria, Leucas, Datura, Tridax procumbens,* ivy gourd, and sponge gourd ensure a near-continuous nectar and pollen supply to the pollinators.
4. **Generalist pollinators like** *Apis* **and** *Xylocopa* **species** dominate the fields visiting both crop and non-crop plants in turn plays a major role in pollinating a variety of plants like cucurbits, legumes, fruit trees, and other key regional crops across all seasons.
5. Some of the major **humid-region challenges** include, high pest pressure, monocropping, excessive pesticide use, habitat fragmentation, and high humidity affecting floral biology which directly threaten pollinator stability and reduce natural pollination services.

6. **Researchers emphasize the effectiveness of pollinator-friendly practices** such as intercropping, reducing use of pesticide during flowering seasons, and advice to incorporate nectar-rich plants like *Sesamum indicum, Turnera subulata*, and *Hamelia patens*.
7. **There is strong convergence between farmer observations and scientific insight**, especially regarding the importance of bees and mixed vegetation; however, farmers have limited awareness of solitary bees, syrphid flies, and structured pollinator-supportive practices.
8. **The findings recommend an integrated pollinator management framework** that combines traditional knowledge with scientific recommendations, focusing on diversified cropping, year-round flowering resources, and sustainable pesticide management.
9. **The combined survey and seasonal crop analysis suggests that diversified cropping systems supported by naturally occurring non-crop plants may function as a low-cost pollinator support network**. Maintaining this crop–non-crop mosaic may contribute to improve yield stability, ecological resilience, and long-term sustainability for smallholder farms in humid West Bengal.
10. A suggestive **crop combination** keeping pollinator friendly crop in mind for Sundarban region is following:

- **Pre-Kharif Crops**
  - Main crop patch: Pumpkin + Brinjal or Chili + Okra + Basil + Cowpea + Sweet Jute or Amaranthus or Malabar spinach or Ipomoea
  - Trellis (North/West/North-West): Ridge Gourd or Cucumber, Malabar spinach
  - Under Trellis: Ginger, Turmeric, Elephant foot yam
  - Boundary: Sunflower, Marigold
  - Hedge row (side): Papaya, Lemon
  - Herbs patch: Mint
- **Kharif Crops**
  - Main crop patch: Pumpkin + Okra + Brinjal + Marigold + Tulsi + Cowpea (lobia) + Amaranth or Malabar Spinach or Ipomea+ Sweet potato as live mulching
  - Trellis (North/West/North-West): Bottle Gourd + Ridge Gourd + Bitter gourd
  - Under Trellis: Elephant foot yam, Taro, Ginger
  - Boundary: Pigeon pea
  - Hedge row: Papaya, Broad bin on tall trees
  - Herbs patch: Mint
- **Rabi Crops**
  - Main crop patch: Tomato or Chili or Brinjal + Fenugreek or Amaranthus or Chenopodium + Carrot or Coriander + Spinach or Beet Root + Sweet Pea or Bean or Grass Pea + Turnip or Radish + Onion or Garlic + Basil
  - Trellis (North/West/North-West): Bottle gourd, Pumpkin
  - Under Trellis: Elephant foot yam
  - Flower patch: Cosmos, Zinnia, Calendula
  - Boundary: Mustard, Marigold
  - Hedge row – Flat/broad bean on the tree

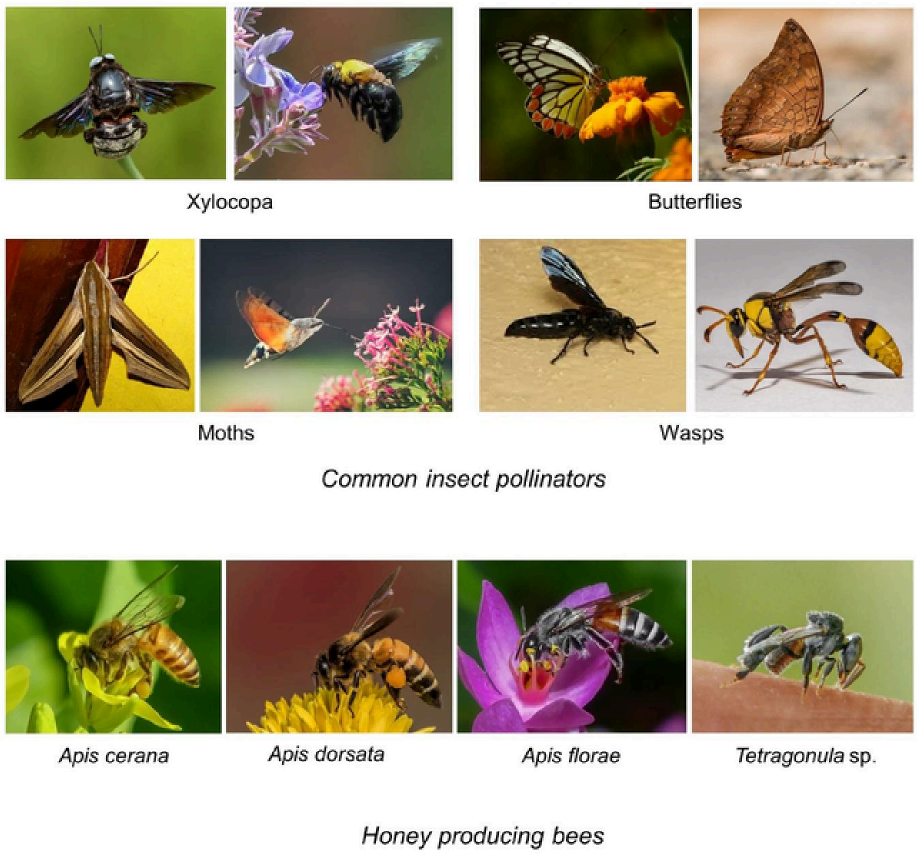

Figure 6: Some important pollinators.

6
CONCLUSION

The combined surveys of farmers and scientists provide valuable insights into the role of pollinators and pollinator-friendly farming practices in the humid agroecosystems of South 24 Parganas, West Bengal. The findings reveal that these agricultural landscapes consist of a diverse mosaic of seasonal crops, fruit trees, vegetables, legumes, and naturally occurring non-crop vegetation that collectively support a rich community of pollinators. Farmers identified key pollinator groups, particularly honey bees (*Apis* spp.) and carpenter bees (*Xylocopa* spp.), as frequent visitors to major crops such as cucurbits, legumes, mustard, fruit trees, and vegetables. These pollinators play a critical role in maintaining crop productivity and ensuring food security in the region.

The study highlights the significant contribution of non-crop vegetation, including species such as *Ocimum sanctum, Calotropis gigantea, Hibiscus rosa-sinensis*, and *Mikania micrantha*, which provide nectar and pollen resources throughout the year. Together with diverse seasonal cropping patterns across the Pre-Kharif, Kharif, and Rabi seasons, these plants create a continuous supply of floral resources that sustain pollinator populations even during periods when major crops are not flowering. Such crops–non-crop mosaics function as low-cost ecological support systems that enhance pollinator abundance and resilience.

Despite the presence of diverse plant and pollinator communities, several challenges threaten the long-term stability of pollination services in humid regions. High pest pressure often results in excessive pesticide application, which negatively affects pollinator health and abundance. Habitat fragmentation, agricultural intensification, and the gradual loss of semi-natural vegetation further reduce the availability of nesting and foraging resources. Additionally, high humidity and changing climatic conditions may influence floral biology and pollinator activity, creating additional pressures on plant–pollinator interactions.

The findings emphasize the importance for integrated pollinator management strategies that combine farmers' traditional knowledge with scientific recommendations. Promoting pollinator-friendly intercropping systems, reducing pesticide use during flowering periods, conserving non-crop vegetation, and incorporating nectar- and pollen-rich species such as *Sesamum indicum, Turnera subulata,* and *Hamelia patens* can significantly improve pollinator diversity and ecosystem resilience. Continued collaboration among farmers, researchers, extension agencies, and other relevant actors will be essential for developing sustainable, pollinator-inclusive agricultural systems that enhance biodiversity, stabilize crop yields, and strengthen long-term food and nutrition security in the humid agroecosystems of West Bengal.


Photo Credit: Dona Roy

7
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WORKING PAPER

POLLINATOR-FRIENDLY CROPPING PATTERN FOR NUTRITION GARDENS AND FARMS IN HUMID REGIONS OF WEST BENGAL

Photo Credit: Dona Roy
Hoplonomia sp. visiting *Solanum* sp. flower

COALITION FOR FOOD SYSTEMS TRANSFORMA(C)TION IN INDIA

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