

INDIAN ENTOMOLOGIST

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FEATURING:

- Pioneering Contribution of Hermann August Hagen to Termite Taxonomy
- Insect Vectors as Bio-sentinels
- Inspiring women entomologist: Dr. M. Shanthi
- TÊTE-À-TÊTE with Dr. D. P. Abrol
- Obituary: Prof. Mahadevan Raghuraman

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Cover page image: Tiger moth caterpillar (*Lepidoptera: Geometroidea: Geometridae*) by Arvind Prajapat from Kerala, India.

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EDITORIAL

Celebrating the Uniqueness of Insects



Insects have long served as elegant models for fundamental research, offering insights that transcend disciplinary boundaries and often yield impacts beyond imagination. This editorial is a continuation of that conviction: insects are exceptional creatures of nature, and their activities have no parallel among other organisms. Many of their life fundamentals are original, thought-provoking, and yet too often overlooked. As entomologists, we sometimes fail to give due cognisance to these extraordinary attributes. Recognizing and exploring them is of paramount importance. Today's technological advancements—whether in molecular biology or digital tracking—provide unprecedented avenues to do so, with cascading benefits across science and society.

Recently, I came across two striking examples that illuminate this uniqueness:

Snow Flies on Ice: A recent *Current Biology* publication highlights wingless snow flies (genus *Chionea*), remarkable insects adapted to extreme cold. Active throughout winter, they traverse snow even at sub-freezing temperatures. Molecular studies now reveal antifreeze proteins, sensory signalling adaptations, and bursts of endogenous heat that enable survival in such hostile conditions. These findings not only deepen our understanding of insect thermogenesis but also hold promise for broader biological applications in extreme environments.

Honey Bees in Flight: Equally fascinating are new insights into honey bee navigation. Using a multicopter drone-based tracking system, researchers have mapped bee flight with unprecedented precision in agricultural landscapes. These studies unravel the cognitive maps bees construct, their fine-scale behavioural strategies, and the remarkable accuracy of their navigation. Emerging tools like drone-assisted tracking exemplify how modern technology can illuminate the hidden dimensions of insect ecology and cognition.

Is it not invigorating to witness such discoveries? They remind us that insects embody a universe of uniqueness waiting to be explored. My purpose in sharing these examples is to provoke thought and inspire our fraternity—especially young entomologists in India—to embrace these marvels with curiosity and creativity.

Let us celebrate insects not only as models of research but as unparalleled wonders of nature. May this spirit echo across our community, in conferences, classrooms, and conversations, and may it find resonance in the vibrant networks of the Entomological Society of India.

Dr. V. V. Ramamurthy
Editor in Chief

FEATURED ARTICLE

Pioneering Contribution of Hermann August Hagen (1817-1893) to Termite Taxonomy

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Abstract

Hermann August Hagen (1817–1893), a German entomologist and physician, played a foundational role in 19th-century insect taxonomy. His systematic research on dragonflies, lacewings, and termites—then grouped under Linnaean Neuroptera—established essential principles for comparative morphology and species classification. Hagen's *Monographie der Termiten* (1855–1860) provided the first comprehensive taxonomic framework for termites, emphasizing wing venation, morphology, and biogeographical distribution. His later works, including *Synopsis of the Neuroptera of North America* (1861) and *Bibliotheca entomologica* (1862–1863), reflected an unprecedented integration of descriptive and bibliographic scholarship. As the first Professor of Entomology at Harvard University, Hagen advanced entomology as a professional discipline in the United States. This article highlights his life, scientific career, and enduring significant contributions on termite systematics, illustrating how his rigorous methods continue to underpin modern taxonomic and phylogenetic research.



Hermann August Hagen (1817–1893)
(Photograph reproduced from Krishna et al., 2013)

Introduction

Hermann August Hagen (1817–1893), a German Entomologist is recognized for his novel taxonomic studies on dragonflies, termites and lacewings- groups then classified under **Linnaean Neuroptera**. These insects were likely chosen for his studies due to their complex wing venation and the unclear phylogenetic relationships of the time. For instance, In Linnaeus' 10th edition of *Systema naturae* (1758), only three species of termites were known,

placed in two different orders, Neuroptera and Apterata, highlighting the need for systematic study. Although trained as a surgeon, Hagen developed a deep interest in insects, producing extensive catalogues, comparative analyses, and innovative classifications that laid the foundation for modern Entomology.

Born on May 30, 1817, in Königsberg, East Prussia, to Anna Dorothea Linck and Carl Heinrich Hagen, he was influenced by his grandfather Carl Gottfried Hagen, a Professor of Natural history, and by mentors such as Rathke, von Baer, and von Siebold. Hagen enrolled in medicine at the University of Königsberg in 1836, where his fascination with natural history flourished. His interest in Odonata, was sparked when his first collected specimen proved to be a previously undescribed species (Henshaw, 1894).

In 1839, Hagen accompanied Professor Rathke on a scientific journey through Sweden, Norway, and Denmark, focusing on entomological collections and libraries. As part of his medical training, he prepared a dissertation entitled "**Synonymia Libellularum Europaeorum**," earning his Doctor of Medicine degree in 1840 (Henshaw, 1894).

Like many German naturalists of his time, Hagen pursued entomology, especially the Linnaean Neuroptera alongside medical practice and civic responsibilities. His first published work, "**A list of dragonflies of East Prussia**" (1839), marked the beginning of his scholarly career. His collaboration with Baron de Selys-Longchamps resulted in a series of important monographs, including **Revue des odonates d'Europe (1850)**, **Monographie des Calopterygines (1854)**, and **Monographie des Gomphines (1857)**. Their scientific partnership continued for four decades,

during which they exchanged notes, specimens, and illustrations.

Major Scientific Contributions

Hagen's studies extended beyond extant species to the fossil record. His monograph **Neuroptera der Bernsteinfauna (1854)** compared fossilized species preserved in amber with modern taxa, providing one of the earliest comprehensive analyses of paleoentomology (Psyche, 1894). His **Monographie der Termiten (1855–1860)**, regarded as a "masterpiece of original research", synthesized prior work on termites and emphasized their complex social organization (Hagen, 1858).

In 1861, the Smithsonian Institution published Hagen's **Synopsis of the Neuroptera of North America**, a landmark reference in American entomology. This work distinguished species of Chrysopidae based on wing venation and morphology, indicating the limited knowledge of their diversity at the time. Hagen also produced **Bibliotheca entomologica (1862–1863)**, a monumental two-volume bibliography that catalogued global entomological literature up to 1862. This compilation, often described as the "Entomologist's bible," was based on his exhaustive examinations of library collections across Germany, France, Belgium, Holland and England.

Hagen and the Taxonomy of Termites

Hagen's termite studies represented the first comprehensive taxonomic framework for the group. He placed termites under **Pseudoneuroptera** (Family: Termitinae) and classified them based on alate morphology, particularly wing venation, head and thorax shape, and antennae (Hagen, 1861), which differs from usual termite identification based on soldiers. He recognized four principal lineages

- *Termopsis*, *Hodotermes*, *Kalotermes*, and *Termes* and published detailed descriptions in **Catalogue of the Specimens of Neuropterous Insects in the Collection of the British Museum: Part I – Termitina (1858)**. Hagen described six genera of termites, namely *Calotermes*, *Hodotermes*, *Porotermes*, *Stolotermes*, *Rhinotermes* and *Kalotermes*. In addition, he also described several species of termites, including *Zootermopsis angusticollis*, *Hodotermes mossambicus*, *Stolotermes brunneicornis*, *Electrotermes affinis*, *Postelectrotermes praecox*, *Comatermes perfectus*, *Rugitermes nodulosus*, *Termitogen umbilicatus*, *Pseudocanthotermes militaris*, *Tenuirostritermes strenuus*, and, along with Bates, he described *Serritermes serrifer*.

His works also included descriptions of termite diversity in Ceylon (Synopsis der Neuroptera Ceylons, 1858) and the Mozambique region (Hagen, 1862). His description of *Hodotermes japonicus*, a wingless termite expanded knowledge of termite biogeography in East Asia (Hagen, 1868). Hagen's writings also addressed the economic importance of termites, describing of their destructive potential: "Nothing is more dangerous than underrating or overlooking the power of even the feeblest enemy"

(Hagen, 1876, p.408). He emphasized their role as pests in warmer climates and foreshadowed the study of termites as agricultural threats.

Beyond termites, Hagen explored biological control methods. He mistakenly attributed insect mortality to *Saccharomyces cerevisiae* (beer yeast fungus), believing it is pathogenic to insects (Hagen, 1884). Later, Metschnikoff demonstrated that the true pathogen was *Isaria destructor* (green muscardine). Despite this error, his interest in microbial control anticipated modern entomopathology.

Later Career in America

In 1867, Hagen accepted Louis Agassiz's invitation to lead the entomological department at Harvard's Museum of Comparative Zoology in Cambridge at United States of America. By 1870, he became **Professor of Entomology**, the first such appointment in the United States. Hagen emphasized the importance of specimen collection, remarking that "the study of natural history consists chiefly in comparison" (Hagen, 1876).

In 1882, he joined Raphael Pumpelly's Northern Transcontinental Survey, studying insects

Table.01. List of insects named in honour of Hagen

Sl.No.	Scientific name	Insect	Family
1.	<i>Eucryptotermes hagenii</i> (Muller, 1873)	Termite	Kalotermitidae
2.	<i>Reticulitermes hageni</i> Banks, 1920	Termite	Heterotermitidae
3.	<i>Tanypteryx hageni</i> (Selys, 1879)	Dragonfly	Petaluridae
4.	<i>Enallagma hageni</i> (Walsh, 1863)	Damselfly	Coenagrionidae
5.	<i>Microthyria hageni</i> (Selys, 1889)	Dragonfly	Libellulidae
6.	<i>Dipheter hageni</i> (Eaton, 1885)	Mayfly	Baetidae
7.	<i>Ceratonia hageni</i> Grote, 1874	Moth	Sphingidae
8.	<i>Atrophaneura priapus hageni</i> (Rogenhofer, 1889)	Butterfly sub-species	Papilionidae
9.	<i>Hagenius</i> Selys, 1854	Dragonfly genus	Gomphidae

harmful to agriculture and forestry across the western United States. His contributions included taxonomic revisions of *Colias* butterflies (Hagen, 1883). Throughout his career, Hagen authored over 400 works, demonstrating his remarkable productivity and influence.

Honors and Legacy

Hagen's scientific achievements were widely recognized. He received honorary doctorate from the University of Königsberg (1863) and Doctor of Science from Harvard University (1887). In 1868, he was elected a fellow of the American Academy of Arts and Sciences and later served on its council. He was an active member of numerous scientific and entomological societies worldwide and helped to reverse the traditional flow of insect collections from America to Europe. His students, including John Henry Comstock, Herbert Osborn, Henry G. Hubbard, and Charles W. Woodworth became leading figures in American entomology.

After a distinguished career, Hagen passed away in Cambridge on November 9, 1893, following several years of illness. His systematic approach, exhaustive bibliographies, and taxonomic rigor firmly established him as one of the most important entomologists of the 19th century.

Conclusion

Hermann August Hagen's careful observation, systematic classification, and dedicated research provided a solid foundation for termite taxonomy and modern insect systematics. His studies on Odonata, Neuroptera, and termites, along with his bibliographic compilations, bridged European and American entomological traditions. By emphasizing collection-based research and mentoring future scientists, Hagen shaped generations of entomologists. His pioneering

frameworks continue to guide contemporary taxonomy, phylogenetic studies, and museum curation, cementing his enduring legacy as a cornerstone of entomological science.

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FEATURED ARTICLE

Insect Vectors as Bio-sentinels: Expanding the Frontiers of Xenosurveillance in Public Health for Pathogen Detection and Disease Monitoring

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Abstract

Arthropod xenosurveillance is an emerging, non-invasive approach that leverages the blood-feeding behavior of insects to monitor circulating pathogens across human, livestock, and wildlife populations. Blood-fed arthropods such as mosquitoes, tsetse flies, and sand flies act as natural biosentinels, preserving genetic traces of viruses, bacteria, parasites, and host DNA within their blood meals. This review highlights the expanding frontiers of xenosurveillance in public health, emphasizing its application for early detection of arboviruses, retroviruses, and other zoonotic pathogens in complex ecological settings. By integrating metagenomic sequencing with targeted molecular assays, xenosurveillance overcomes limitations of conventional surveillance, including low sensitivity, invasiveness, and high logistical costs. Recent success stories demonstrate its effectiveness in detecting both known and unexpected pathogens at wildlife–livestock–human interfaces. Despite challenges such as nucleic acid degradation and data interpretation, xenosurveillance represents a scalable, cost-effective, and ethically sound One Health tool with strong potential for early warning systems and pandemic preparedness.

Introduction

What if the key to stopping the next big pathogen outbreak wasn't hidden in a lab or a high-tech surveillance system, but buzzing right in front of us? Around us, countless insects are constantly feeding, flying, and interacting with humans and animals unknowingly acting as tiny couriers of biological information. Every bite from a mosquito, tick, or fly is more than an irritating nuisance; it's a moment of sampling from the living library of their hosts' genetic and microbial worlds. Scientists are now realizing that these very tiny insects, often labeled as villains, could become our greatest allies in disease detection. This emerging idea, known as

"*Arthropod Xenosurveillance*", turns blood-feeding insects into natural biosensors, flying syringe or bio-sentinels capable of revealing which viruses or pathogens like human bacteria, parasites, and viruses in mosquito blood meals are silently circulating in an ecosystem long before they reach humans. As we know that current methodologies for vector or parasite identification have limitations in comparison to arthropod xenosurveillance. Conventional surveillance methods tend to be limited by low sensitivity, especially during early and/or low-density infections, more so when sampling involves individual hosts or vectors

directly. Such approaches can be labor-intensive and are more complex from a logistical aspect (McLure et al., 2025; Okorie and de Souza, 2016). Importantly, they mostly sample one pathogen at the time, which affects the cost requirement and throughput. Ethical concerns also arise from sampling from humans or other wildlife, and cryptic or elusive reservoir hosts are also likely to be missed.

The concept of arthropod xenosurveillance came to life in an experiment by researchers from Montpellier University, France, who explored how tsetse flies, notorious for spreading sleeping sickness, might instead help in tracking emerging diseases, which can utilize blood-feeding arthropods for natural sampling and has the capacity for broader, non-invasive, and more spatially and temporally integrated, multi-pathogen surveillance. The *Glossina fuscipes fuscipes* fed with rabbit blood spiked with six viruses such as Zika, Dengue, Chikungunya, African swine fever, Bluetongue, Peste des Petits Ruminants (PPR) and found that traces of these viral genetic material persisted in the flies' guts for up to six days. For dengue-endemic nations like Bangladesh, integrating Molecular Xenosurveillance (MX) or Molecular xenomonitoring into existing health systems could transform early outbreak detection and empower communities to act swiftly before diseases spread unchecked. These results were astonishing: the same insects once feared for transmitting illness could now act like "flying syringes or bio-sentinels," preserving snapshots of the invisible viral world around us. In a broader sense, this approach represents a revolution in how we monitor diseases, especially in regions with limited infrastructure.

This study aims to expand the scope of molecular xenosurveillance by evaluating

the ability of blood-fed mosquitoes to detect a broad range of circulating viruses, including arboviruses and non-arbovirus retroviruses, within complex ecological settings. The objective is to determine whether mosquito-derived viral and host genetic material can reliably reflect pathogen presence, host exposure, and livestock–vector–environment interactions. By integrating metagenomic sequencing with targeted molecular assays, this work contributes to advancing non-invasive One Health surveillance approaches. The expected outcome is a more sensitive, scalable, and ecologically informative framework for early detection of emerging pathogens in high-risk interfaces.

What is Arthropod Xenosurveillance?

Xenosurveillance is an emerging technique that harnesses the blood-feeding (hematophagous) behavior of certain arthropods to monitor vertebrate hosts for infectious disease agents (Brinkmann *et al.*, 2016). It derived from two Greek words xeno (foreign) and surveillance (watching); xenosurveillance involves using blood-feeding arthropods such as mosquitoes, tsetse flies, sand flies, leeches, and even carrion beetles as natural collectors of host DNA or RNA. Instead of bleeding animals or capturing wildlife, researchers can simply collect these insects, which already contain within them a snapshot of the genetic and microbial world of their hosts. Arthropod xenosurveillance evolved from classical mosquito surveillance during the 1950s–1980s, when entomologists like Rosen (1987) and Reeves et al. (1994) studied mosquitoes as indicators of arbovirus circulation. In the 2000s, molecular tools enabled the detection of vertebrate DNA in mosquito blood meals (Ngo and Kramer, 2003; Kent and Norris, 2005), revealing their potential as biological samplers. In 2013, Grubaugh and team introduced

the concept of “xenosurveillance,” formalizing the idea of using mosquitoes to monitor human pathogens non-invasively (Grubaugh *et al.*, 2015). In 2015, Grubaugh’s study validated this concept, demonstrating that blood-fed mosquitoes can detect human viral, bacterial, and parasitic infections, revolutionizing biosurveillance approaches. In earlier studies, including those involving *Anopheles gambiae* mosquitoes, researchers have successfully detected viral genetic material from mosquito blood meals under both laboratory and field conditions.

A sound understanding of the biology and ecology of these arthropods along with pathogens they transmit is crucial for applying this method effectively. *Anopheles gambiae*, the main malaria vector in sub-Saharan Africa, is highly anthropophilic (prefers feeding on humans), endophilic (rests indoors), and endophagic (feeds indoors) that make it not only an efficient malaria vector but also a non-invasive and easily collected sampler of human blood for disease surveillance. Each blood-fed arthropod acts as a microscopic time capsule containing viral, bacterial, and host genetic material. This innovative approach marks a paradigm shift in epidemiology field. It is non-invasive, cost-effective, and highly informative which turn pest species into allies for detecting emerging pathogens. In essence, arthropod xenosurveillance transforms mosquitoes and other vectors into biological detectives, providing a simple yet powerful way to detect pathogens before disease outbreaks occur (Figure 1).

Workflow of Arthropod Xenosurveillance

The basic road map of arthropod Xenosurveillance (Ndione *et al.*, 2025) as follows:

1. Field Collection of Arthropods

- Deploy CO₂-baited CDC light traps near

villages, livestock enclosures, water bodies, and wildlife interfaces.

- Collect predominantly **blood-fed female mosquitoes** and identify them morphologically.

2. Pooling and Sample Preparation

- Group mosquitoes into pools based on species, location, or feeding status.
- Homogenize whole mosquitoes and extract **total nucleic acids** from each pool.

3. RNA Extraction & Enrichment

- Perform RNA extraction using viral/pathogen nucleic acid kits.
- Remove host ribosomal RNA to enrich viral and microbial sequences.

4. cDNA Synthesis & Library Preparation

- Convert enriched RNA into first-strand and then double-stranded cDNA.
- Prepare sequencing libraries (e.g., **Nextera XT**) for high-throughput sequencing.

5. Metagenomic Sequencing

- Sequence prepared libraries on Illumina platforms (e.g., **NextSeq550**) for unbiased detection of pathogens.

6. Bioinformatic Processing

- Conduct quality filtering, adapter trimming, and removal of host reads.
- Use pipelines such as **CZ-ID, Bowtie2, RAPSearch2, SPAdes, and BLAST** for classification and assembly.
- Identify viral, bacterial, or host-derived sequences present in the bloodmeal.

7. Molecular Confirmation (If Needed)

- Validate metagenomic detections using **RT-qPCR or hemi-nested PCR**, designed from

detected viral fragments.

8. Phylogenetic Analysis

- Align sequences using **MAFFT** and infer evolutionary relationships with **IQ-TREE**.
- Confirm taxonomic identity and determine relatedness to known global strains.

9. Interpretation & Surveillance Output

- Integrate viral detections with ecological and host-interaction data.
- Use findings to infer pathogen circulation, host exposure, and spillover potential.
- Apply results to **early-warning systems** and One Health surveillance planning.

When should we go for it?

Timing is everything. If the goal is to catch pathogens early, we need to know both the vector's habits and the disease's seasonality.

1. Follow the mosquito calendar: Mosquitoes and other vectors are highly seasonal in nature. In tropical countries like India, their populations surge during and after the monsoon, when puddles and stagnant water create ideal breeding sites. Therefore, collecting mosquitoes before and during this period greatly enhances the chances of early detection of infections, including those present in asymptomatic individuals.

2. Catch them when they're full: Only blood-fed mosquitoes carry pathogens acquired from their human hosts. Since these tiny vampires primarily feed during dawn and dusk, collecting samples at these times yields the most effective results.

3. Keep an eye on pathogen activity: Viruses such as dengue, chikungunya, and Zika circulate in human blood for only a few days after infection. By targeting mosquitoes during this viremic window, scientists can identify these pathogens early,

Importance of Molecular Xenosurveillance (MX)



Early detection saves lives

You can predict outbreaks before hospitals overflow



It's non-invasive

No needles, no hospital visits — just clever use of mosquitoes



Multi-pathogen detection

A single mosquito can reveal multiple diseases



Insight into disease ecology

You understand not just the pathogen, but also how it moves between humans, animals, and vectors

Figure 1: Significance of molecular Xenosurveillance (Valente et al., 2023)

enabling the detection of diseases before they spread widely and cause outbreaks.

4. Routine vs. Reactive surveillance: In endemic regions, xenosurveillance can be conducted regularly through weekly or biweekly collections, providing a real-time snapshot of circulating pathogens. During sudden increases in disease risk, it can also serve a reactive role, functioning as an early warning system for public health authorities.

The next time a mosquito lands on your arm, it should be viewed not merely as a nuisance but as a potential tool for disease surveillance. In the hands of scientists, mosquitoes act as miniature bio-samplers capable of providing valuable insights into circulating pathogens. Understanding the

optimal timing and location for their collection is crucial, as it can determine whether an impending outbreak is detected early or allowed to spread undetected.

Success stories

Over the past decade, several successful studies have demonstrated the power and versatility of xenosurveillance (Table 1). From Ndione *et al.* (2025) identifying retroviruses and arboviruses in Senegalese mosquitoes to Valente *et al.* (2023) proving tsetse flies can retain viral RNA for enzootic virus screening, these works highlight the method's expanding scope. Likewise, Anvari *et al.* (2025) developed scalable techniques for detecting *Plasmodium falciparum* from mosquito blood meals, while McMinn *et al.* (2023) validated field-based vector surveillance in Guatemala. Together, these studies feature the xenosurveillance's growing promise for real-world disease monitoring across diverse ecological settings.

Why it matters?

The COVID-19 pandemic revealed how swiftly animal viruses can cross species barriers and trigger global crisis. Around 60% of emerging infectious diseases are zoonotic, with most originating in tropical regions that lack robust surveillance systems. Traditional wildlife monitoring requires the capture and bleeding of animals, which is laborious, costly, ethically complex, and sometimes risky. Xenosurveillance provides a more practical and humane alternative. Blood-feeding insects naturally sample a wide range of hosts daily including humans and livestock. Strategically placed traps in villages or forests can generate vital data about circulating viruses. With portable sequencing technologies, field teams could soon analyze these insect-derived samples on-site and in real time. Additionally, the

potential of using this technique near bat caves or bat-dwelling areas is particularly significant, as bats serve as intermediate hosts for many zoonotic viruses. Although bats commonly feed on mosquitoes, some studies have detected bat blood in mosquitoes, indicating natural blood exchange between these species. Additionally, applying xenosurveillance approaches using ectoparasitic bat flies or blood-fed mosquitoes around bat roosts located close to human settlements can provide an early warning system for emerging pathogens. This strategy enhances early detection of vector-borne microorganisms and may help identify future pandemic threats before they spill over into human populations (Szentiványi *et al.*, 2020; Fagre and Kading, 2019).

Challenges on the horizon

Xenosurveillance is a novel method for passive monitoring of circulating pathogens from blood-fed arthropods using nucleic acid analyses, but complex biological, technical, logistical, and interpretational challenges limit its adoption. Biologically, the process of digestion can quickly degrade viral nucleic acids within the insect gut, restricting the window of detection to a few days after the blood-meal and possibly missing low-titer infections. Furthermore, viral fragments do not necessarily confirm ongoing active infections in the vertebrate host, nor do they indicate viable virus infection in the vertebrate host. Environmental contamination (in housing or sampling vessels), mixed blood-meals, and inconsistency in host availability for blood consumption can further pose logistical and ecological challenges and caused complexity in interpretation.

Technically, identifying an insect-associated virus from a vertebrate-derived virus will require complete metagenomics, taking care

to remove background sequences, and confirming the presences of viral RNA from the insect vector host using RT-qPCR or similar assays. Maintaining high-quality preservation of nucleic acids in the field continues to be difficult, but it appears that use of FTA cards and RNAlater may offer better alternatives. Logistically, regular blood-feeding insect capture is difficult, especially at remote wildlife interfaces where no routine trapping may take place, and where personnel and resources may limit repeat sampling and transport of field samples. Policy-related barriers include limited integration

into national surveillance systems, lack of standard operating procedures, biosafety concerns, and unclear frameworks for sharing genetic data, especially those linked to wildlife or livestock. Despite these challenges, xenosurveillance offers significant advantages as reported by Ndione et al. (2025) that even partial viral sequences provide valuable ecological insights into host exposure, viral diversity, and regional circulation patterns. High-throughput metagenomics enhances this potential by enabling unbiased detection of known and novel viruses. Moreover, expanding surveillance beyond

Table 1. Historical timeline highlighting major milestones in the development of arthropod Xenosurveillance

Category	Insect Vector	Associated Pathogen(s)	Disease / Host Application	Key Reference
Lab-fed	Mosquito, <i>Anopheles gambiae</i>	<i>Trypanosoma brucei gambiense</i> , <i>Bacillus anthracis</i> , MERS-CoV, Zika virus	Demonstrated multi-taxa detection: trypanosomiasis, anthrax, MERS, Zika	Fauver et al., 2017
	<i>Glossina</i> spp. (tsetse)	Zika, DENV-2, Chikungunya, ASFV, Bluetongue, PPRV	Wildlife/livestock viral surveillance “flying syringe” concept	Valente et al., 2023
Field-collected	Mosquito, <i>Aedes aegypti</i>	Dengue virus serotype-2	Dengue fever: first MX report from Bangladesh	Ghosh et al., 2025
	Mosquito, <i>Culex / Aedes</i> sp.	West Nile, Usutu, Bagaza, Sindbis, Barkedji viruses	Arbovirus surveillance in humans and birds	Ndione et al., 2025
	Mosquitoes (blood-fed)	Retroviruses: JSRV, ENTV-2	Livestock surveillance on sheep/goats	Ndione et al., 2025
	Mosquito, <i>Anopheles / Culex</i>	<i>Plasmodium falciparum</i> and other <i>Plasmodium</i> spp.	Malaria surveillance on parasite detection + drug-resistance markers	Anvari et al., 2023
	Sand flies (<i>Phlebotomine</i> spp.)	<i>Leishmania</i> spp.	Cutaneous/visceral leishmaniasis vector surveillance	Nikookar et al., 2024
	Mosquitoes (bloodmeal analysis)	<i>Toxoplasma gondii</i> ; SARS-CoV-2 antibodies	Xeno-serosurveillance on protozoa & host immune exposure	Štefanić et al., 2022
	House / biting flies (<i>Musca, Stomoxys</i>)	Ebola virus (exposure models)	Tested mechanical detection potential (low)	Haddow et al., 2017
	Mosquitoes (rural habitats)	Broad pathogen panel: arboviruses, veterinary viruses, parasite DNA	Validated practical feasibility in rural public health settings	McMinn et al., 2023; Grubaugh et al., 2019

mosquitoes to include vectors such as tsetse flies, as proposed by Valente et al. (2023), extends monitoring deeper into wildlife systems that are otherwise difficult to sample. Together, these advancements strengthen One Health surveillance across human, livestock, and wildlife interfaces.

Future directions of Xenosurveillance

Envision networks of “insect observatories” spread across Africa’s national parks and rural landscapes solar-powered smart traps passively capturing mosquitoes, midges, and tsetse flies, with weekly screening for viral signatures. Uploaded to global databases, these data streams could generate early outbreak alerts well before symptoms appear in livestock or humans. This scenario is increasingly realistic: recent studies demonstrate that blood-feeding insects function as natural biosentinels, their bodies preserving molecular snapshots of ecosystems that reveal hidden host–pathogen interactions and the silent movement of viruses. From Senegal’s savannas to Gabon’s forests, scientists are learning to interpret these subtle “insect whispers” embedded in blood meals.

Portable Field Diagnostics:

Develop compact, battery-operated molecular tools for rapid on-site detection of viral fragments in insect blood meals to minimize nucleic-acid degradation and strengthen sensitivity.

AI-Assisted Monitoring:

Incorporate machine-learning pipelines to enhance detection of low-abundance viral sequences, distinguish true signals from background noise, identify novel pathogens, automate host-blood profiling, and forecast spillover hotspots.

Standardized Protocols:

Establish harmonized guidelines for vector

collection, blood-meal preservation (e.g., FTA cards vs. RNAlater), optimal detection windows, sequencing thresholds, and data-reporting standards to ensure comparability across studies and regions.

Expanded Wildlife-Interface Surveillance:

Deploy xenosurveillance near bat caves, livestock corridors, forest-edge habitats, and peri-urban settlements to intercept viral circulation at high-risk wildlife–livestock–human interfaces without disturbing host animals.

Global Data-Sharing Networks:

Create interoperable genomic databases and real-time One-Health information pipelines to share viral signatures, host profiles, and ecological metadata, enabling coordinated, cross-border early-warning systems for emerging zoonotic threats.

Implications for one health

Xenosurveillance embodies the principles of the One Health framework by integrating human, animal, and environmental health monitoring. This approach enables the early detection of zoonotic spillover events before they develop into widespread outbreaks. It also provides a cost-effective and non-invasive method for monitoring wildlife in remote or inaccessible regions, while offering deeper insights into the complex interactions among hosts, pathogens, and ecosystems.

Conclusion

Blood-feeding insects long viewed simply as pests, but now they are increasingly recognized as powerful sentinels of pathogen circulation. Their blood meals preserve genetic traces of the often-hidden viral world that surrounds humans, livestock, and wildlife. Xenosurveillance, strengthened by metagenomic sequencing,

shows that even partial viral fragments recovered from mosquitoes, sand flies, or tsetse flies can yield valuable insights into host exposure, viral diversity, and regional transmission patterns. Findings of past researches demonstrate how mosquito-derived sequences can reveal both arboviruses and unexpected retroviruses and highlight tsetse flies as reliable “flying syringes” capable of detecting multiple medically important viruses several days after feeding. Despite challenges such as nucleic acid degradation, short detection windows, environmental contamination, and the need for robust analytical pipelines, xenosurveillance remains a promising One Health tool. These limitations outline clear priorities for future improvement, including standardized protocols, better field preservation, and stronger integration into public and veterinary health surveillance systems. Ultimately, insect sentinels offer a remarkable, noninvasive pathway for early detection of enzootic and emerging viruses. By harnessing the natural feeding habits of these small yet influential organisms, we move closer to anticipating spillover events and strengthening global health security proving that even the tiniest creatures can play a transformative role in preventing future pandemics.

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TÊTE-À-TÊTE

In Conversation with Dr. D. P. Abrol: A Life Dedicated to Entomology, Apiculture, and Pollination Biology

In this edition of *Tête-à-tête*, we feature **Dr. D. P. Abrol**, an eminent entomologist and academician whose contributions to pest management, apiculture, and pollination biology have significantly enriched agricultural science in India. Dr. Abrol served the **Sher-e-Kashmir University of Agricultural Sciences and Technology** for over three and a half decades, holding several key academic and administrative positions. During his distinguished career, he served as Head of the Division of Entomology (August 2008–February 2015), and also held important administrative responsibilities as Controller of Examinations and Director of Education in 2012. His long association with the university reflects a remarkable commitment to teaching, research, and academic leadership.



Dr. D. P. Abrol

Ex-Dean, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences

Dr. Abrol's research interests span pest management, honeybee management, and pollination biology—areas that are increasingly critical for sustainable agriculture and food security. Over the course of his career, he has authored **22 books, 12 manuals, and 60 book chapters**, and published **more than 300 research papers** in national and international journals. He has successfully led **over nine externally funded research projects** and participated in **international collaborative projects with institutions in Poland and Switzerland**, contributing significantly to global research partnerships.

An active participant in the international scientific community, Dr. Abrol has visited several countries—including Switzerland, Poland, South

Korea, Malaysia, Saudi Arabia, and Thailand—as a special invitee for academic engagements and scientific collaborations. His contributions to entomology and agricultural sciences have been widely recognized through numerous prestigious honours and awards.

Notably, Dr. Abrol became the **first scientist from Jammu & Kashmir** to be elected as a Fellow of the **National Academy of Agricultural Sciences, India**, and a Fellow of the **Royal Entomological Society, London**. Among his many accolades are the **Young Scientist Award (1992)** from the Jammu and Kashmir State Council for Science and Technology, the **Pran Vohra Award (1993)** from the **Indian Science Congress Association**, and the **Prof. T. N. Ananthkrishnan Award (1997–1998)** for outstanding contributions to

entomology. He also received the **Dr. Rajendra Prasad Puruskar (1999–2000)** from the **Indian Council of Agricultural Research** for his Hindi book on beekeeping titled *Madhmakhi Palan—Sidhant Evam Vidhian*.

Further recognition includes the **11th Apicultural Association Award (2010)** for outstanding contributions to apiculture, and a **Gold Medal from King Saud University** for his contributions to the development of apiculture in Asia. In recent years, Dr. Abrol has also been listed among the **top 2% of scientists worldwide (2022–2025)** in the ranking compiled by **Stanford University**.

Even after retirement from active university service, Dr. Abrol continues to contribute to the scientific community in multiple advisory and evaluative roles. He currently serves as a member of **Peer Review Teams for accreditation of universities**, a member of **QRT teams for evaluation of AICRP projects**, an expert member of the **Neonicotinoids Group for Asian countries**, and a **core member of SERB–DST, Government of India**. He is also associated with the Asian chapter of **Apimondia** and frequently serves as an expert on various academic and research selection committees.

Through his extensive research, academic leadership, and continued engagement with the scientific community, Dr. Abrol remains an inspiring figure in Indian entomology. In this conversation, he shares insights from his long and distinguished journey in science, research, and academic service.

The following interview was conducted by Dr. P. R. Shashank (PRS), Managing Editor, Indian Entomologist. In this engaging conversation, Prof. Abrol reflects on his long and distinguished career in entomology, shares insights from his

research on pest management, apiculture, and pollination biology, and discusses the evolving role of entomological research in ensuring sustainable agriculture and food security. The interview also highlights his experiences in academia, international collaborations, and his perspectives on the future directions of entomological sciences

PRS: You were born in a rural village in Jammu & Kashmir and rose to become a leading authority in apiculture. What early experiences shaped your interest in Agriculture and Entomology?

Dr. D. P. Abrol (DPA): I was born on 6th February 1959 in Kangri village of District Rajouri, Jammu & Kashmir, India, located about 90 km from Jammu. Growing up in a farming family with a rural background, I gained practical knowledge of agriculture through lived experience, even before receiving any formal education. The village school was nearly 4 km from our home, requiring daily travel on foot across hilly terrain. We lived in a mud house, and until 1980, electricity was unavailable; kerosene lamps were our sole source of light for studying. Grain was milled in traditional water mills, and drinking water had to be carried from village wells almost 1 km away. Life was simple and self-reliant—fire was carefully preserved to relight the hearth, as matchsticks were not in use at that time. I received my early education at Government High School, Baja Bain (District Rajouri, J&K) from 1965 to 1975. I completed my B.Sc. at Government Gandhi Memorial Science College, Jammu (1975–1979), followed by an M.Sc. from the University of Jammu (1979–1981), and earned my Ph.D. from Haryana Agricultural University, Hisar (1981–1986).

PRS: From your schooling in Rajouri to earning a Ph.D. from Haryana Agricultural

University, what key experiences shaped your decision to specialize in honeybee research?

DPA: From my undergraduate and postgraduate days, I developed a keen interest in the collection and identification of plants and in observing visiting insects. The buzzing and melodious sounds of insects always fascinated me. Honey, the miraculous gift of honeybees to humankind, particularly captured my imagination, and I became deeply curious about the life, behaviour, and organization of honeybees, as well as their vital role in sustaining global food security and maintaining ecological balance. After completing my M.Sc., I had the opportunity to join the Department of Zoology, Haryana Agricultural University, Hisar, as a Ph.D. student. My long-cherished dream of working on insects—especially honeybees and other pollinators—became a reality under the guidance of the eminent scientist Prof. Dr. R. P. Kapil. Prof. Kapil was an outstanding scientist, a dedicated teacher, and an innovative researcher. Along with his team, he developed pioneering technologies for the domestication and conservation of non-*Apis* bee pollinators. Working under his mentorship was truly a dream come true. Students trained by Prof. Kapil went on to occupy prestigious positions in science, with each making significant contributions and earning national and international recognition. Notably, one of my seniors, Prof. R. C. Sihag, was recently awarded the Padma Shri for his outstanding contributions to beekeeping.

PRS: As a young scientist, what challenges did you face in shifting focus from general entomology to pollination biology and honeybee management in the 1980s?

DPA: Most entomologists prefer to work on diverse entomological disciplines and often avoid honeybee

research due to the fear of stings and the challenges associated with handling live colonies. During my undergraduate years, I was fascinated by observing insects moving from one flower to another, and their gentle, melodious sounds deeply attracted me. The sweetness of honey—traditionally used in earlier times alongside Ayurvedic medicines, including remedies for eye ailments—left a lasting impression on my mind and sparked my curiosity to understand its production and the biology behind it. Working with honeybees, their remarkable social organization, tireless labour, and fascinating behavioural patterns has continually inspired me to explore their life processes in greater depth.

PRS: As former Dean of the Faculty of Agriculture at Sher-e-Kashmir University and Head of the Division of Entomology, what were the most significant reforms you implemented to advance agricultural education and research in Jammu & Kashmir?

DPA: Under my leadership as Head (2008-2015), the Division of Entomology not only attained national prominence but also achieved international recognition as a centre of excellence in research and development. This is reflected in the establishment of international research collaborations with the Department of Behavioural Ecology, Institute of Environmental Sciences, Jagiellonian University,



Kraków, Poland, and the ETH Laboratory, Zurich, Switzerland. Scientists from both Jagiellonian University and ETH Zurich have visited the Division of Entomology, strengthening academic exchange and collaborative research.

In addition, a new international collaboration focusing on the global decline of pollinator biodiversity was initiated, with the Division serving as an Indian co-partner in collaboration with the British Natural History Society, UK, under the international coordination of Dr. P. H. Williams.

As Dean, Faculty of Agriculture (2016-2021), I introduced several innovative academic and administrative reforms aimed at enhancing the quality of education and governance.

Attendance System: Upon assuming office as Dean, Faculty of Agriculture, low student attendance was identified as a major concern. To address this, undertakings were obtained from students at the time of admission, duly endorsed by their parents, committing to regular attendance and acknowledging that they would not be eligible for examinations without fulfilling the mandatory 75% attendance requirement. Faculty members were instructed to submit monthly attendance records by the 5th of each month, duly signed by the Head of Department, with copies forwarded to the Dean and Director of Education. This initiative effectively resolved the issue, resulting in a marked improvement in student attendance and classroom discipline.

Modified Synopsis Presentation System: The existing system of conducting M.Sc. and Ph.D. synopsis seminars within individual divisions was restructured. Pre-synopsis discussions were first held at the divisional level, followed by presentations before the entire faculty, including advisory committee members and Heads of Departments, in the presence of the Dean (Faculty

of Agriculture) as Chairperson and the Director of Research and Director of Education as members. This comprehensive review process significantly strengthened research quality by incorporating multidisciplinary feedback. Faculty-wide seminars were institutionalized during the third week of every month.

Viva Voce Under CCTV Surveillance: To ensure transparency and maintain the highest standards of examination, Ph.D., M.Sc., and comprehensive viva voce examinations were introduced under CCTV surveillance. Students were also required to undergo a pre-viva voce examination before their advisory committees prior to the final viva.

Wi-Fi System: A campus-wide Wi-Fi facility was introduced for the benefit of students, faculty, and staff, significantly improving access to academic and research resources.

Green Graduation Programme: A Green Graduation initiative was launched, under which each student was encouraged to nurture and maintain a plant throughout their four-year stay at the university, promoting environmental responsibility and sustainability.

Swachhta Abhiyan: A cleanliness drive (Swachhta Abhiyan) was initiated to instil a sense of hygiene and civic responsibility among students and to maintain a clean and healthy campus environment.

Photography and Media Cell: A Photography and Media Cell was established to document university activities and showcase the institution's technological and academic achievements.

Technology Cell: A dedicated Technology Cell was created to facilitate the regular dissemination of new technologies among students, teachers, and farmers, strengthening extension and outreach activities.

Agri-Fest: An Agri-Fest was organized to provide

students with a platform to demonstrate their technical knowledge, creativity, and practical skills.

Seminars and Debates: Regular seminars and debates were organized to foster academic discourse, critical thinking, and communication skills among students.

PRS: You've received prestigious awards like the Young Scientist Award (1992), Pran Vohra Award (1993), and Dr. Rajendra Prasad Puruskar (1999–2000). Which achievement are you most proud of, and how did it impact your work in Apiculture?

DPA: In recognition of outstanding host plant relationship of bees, understanding environmental factors influencing flight and pollination activities of bees, pollination efficiency, diseases and management of honeybees which have great bearing in enhancing agricultural, horticultural productivity and beekeeping industry. Besides, research, I am very proud of Dr. Rajendra Prasad Puruskar (1999–2000) was conferred for Hindi book on beekeeping which has revolutionized beekeeping industry all over the country for the beekeepers to learn and practice beekeeping.

PRS: How has pollination research in India evolved over the last three decades, and what role did your work play in this progress?

DPA: During last three decades much strides has been made in the pollination research in India. Government of India has given due thrust to pollination research and recognised beekeeping as input in agriculture. AICRP on honeybee and pollinators training has been reframed as honeybee and pollinators to give more thrust on pollination. AICRP centres on honeybee and pollinators has increased and almost every state of the country has got AICRP centres to boast pollination studies. At

present there are 18 regular centres and 6 voluntary centres working on honeybees and pollinators. Multilocational Network project on biosystematics of insects under the esteemed patronage of Prof V Ramamurthy has played a key role in exploring the non-*Apis* bee pollinators. In our centre, we Identified seven species of bumblebees and sixteen distinct species of Megachilids belonging to three tribes within the Megachilinae subfamily: Megachilini, Anthidini and Osmiini from various landscapes of this Jammu and Kashmir. Given the significant role of wild populations of bee pollinators in crop pollination, conservation with mitigating the stress factors are imperative. Prioritizing their conservation efforts would greatly contribute to ecosystem sustainability and enhance food security. Pioneer in developing management techniques of wild bee pollinators which play tremendous role in pollination of field and fruit crops for enhancing crop productivity. Most efficient pollinators of wide variety of crop plants in natural and agricultural systems have been identified. Evaluated the optimum number of colonies for different crops which shall increase yield manifold ranging from 20-100%. Recommendations popularized and adopted by farmers in pollination of crops in an area of at least 3.97 lakh ha. of Jammu region. Pioneer in developing low-cost management technology for honeybee diseases, mites and other bee enemies. It has become popular as an economically viable and popular technology for resource poor farmers. Books on bees and beekeeping, non - *Apis* pollinators and pollination biology are recognized as a standard reference in pollination biology, particularly in relation to pollinator diversity and ecology, crop pollination and agricultural productivity, pollinator–plant interactions and conservation of pollinators in agro-ecosystems. In universities and research institutions, they are

being commonly used as supplementary or core reading for postgraduate courses in entomology, apiculture, ecology, and agricultural sciences.

PRS: Your Hindi book Madhumakhi Palan-Sidhant Evam Vidhian earned a national award, what motivated you to write it, and how has it influenced beekeeping practices among Hindi-speaking farmers in India?

DPA: No doubt several books on beekeeping both Indian and foreign were available but no book was available in accordance with the local conditions and in their own language. Beekeepers and farmers wanted to learn beekeeping in their own language. This prompted me to make efforts to present beekeeping in simple form in their own language. This book in Hindi has revolutionized beekeeping industry all over the country for the beekeepers to learn and practice beekeeping. This book serves as practical guide for farmers, beekeepers, students, hobbyists and all those interested in bees and beekeeping. The second edition of Madhmakhi Palan ki Nai Dashain published in 2021 has helped beekeepers in rearing and raising the European honeybee colonies to a highly respectable 3.5 million colonies at present producing more than 100 thousand metric tons of honey, 10 thousand metric tons of beeswax, and tons of pollen. Beside this, this venture has helped generating self-employment for more than 100 thousand rural and urban unemployed youths, and providing pollination service to over 2.5 million acres of cross-pollinated plants. Fortunately, this book is available on shelf of each university and in the hands of all those interested in beekeeping. More than trained 5000 farmers, beekeepers, students, unemployed youth, hobbyists and empowered women in beekeeping entrepreneurship through different national Bee Board, university, department of agriculture and non-governmental social organizations. With my

assistance, many beekeepers have established their own entrepreneurship enterprises, some have been appreciated by Hon'ble Prime Minister of India. My text books in beekeeping is being used for teaching purposes not only in India but throughout the world. My research findings have been appreciated all over the world with many awards and appreciation.

PRS: Can you share insights from your collaborative projects with ETH Zurich and Jagiellonian University on honeybees and bumblebees? What key findings emerged, and how are they being applied in Indian apiculture?

DPA: The populations of honeybees and bumblebees have been decreasing around the world in the recent decades. A variety of pathogens and parasites, including bacteria, fungi, protozoa, nematodes, mites and insects play significant role in honeybee and bumblebee colonies loss. Parasites of the genus *Nosema* (Microsporidia: Nosematidae) and the genera *Crithidia* and *Lotmaria* (Kinetoplastida: Trypanosomatidae) have a significant negative impact on honeybee and bumblebee colonies. Recent studies of nuclear DNA markers of these parasites allowed to describe new species and genetic variants. Collaborative project on Assessing large scale environmental risks for biodiversity with tested methods (Contract number: GOCE-CT-2003-506675 ALARM) was conducted with European Union with Prof Michal Woyciechowski of Department of Behavioural Ecology Jagiellonian University, Krakow Poland. The studies revealed the prevalence of parasites in honeybee and bumblebee populations of the two Indian states (Jammu and Kashmir, Karnataka) identified using PCR with primers specific for the ribosomal RNA genes cluster of *Nosema*, *Crithidia* and *Lotmaria* species. Co-

infection by microsporidian and trypanosomatid parasites was detected in several honeybee and bumblebee specimens from Jammu and Kashmir state. Comparative analysis of ribosomal RNA genes sequences showed that honeybee samples from India studied were infected by *N. bombi*, *N. ceranae* and *L. passim*. Bumblebee populations were infected by *Nosema D*, *Crithidia bombi* and *Crithidia expoeki*. No honeybee's specimen with trypanosomatid infection was found in Karnataka state. For the first time *N. bombi* infection was detected in the honeybee population.

Another collaborative project was conducted with ETH Laboratory in Switzerland on parasites of honeybees and bumblebees with Dr Schmid Paul Hempel, ETH Zurich Switzerland. The animal gut is a habitat for diverse communities of microorganisms (microbiota). Honeybees and bumblebees have recently been shown to harbour a distinct and species poor microbiota, which may confer protection against parasites. Here, we investigate diversity, host specificity and transmission mode of two of the most common, yet poorly known, gut bacteria of honeybees and bumblebees: *Snodgrassella alvi* (Betaproteobacteria) and *Gilliamella apicola* (Gammaproteobacteria). We analysed 16S rRNA gene sequences of these bacteria from diverse bee host species across most of the honeybee and bumblebee phylogenetic diversity from North America, Europe and Asia. These focal bacteria were present in 92% of bumblebee species and all honeybee species but were found to be absent in the two related corbiculate bee tribes, the stingless bees (Meliponini) and orchid bees (Euglossini). Both *Snodgrassella alvi* and *Gilliamella apicola* phylogenies show significant topological congruence with the phylogeny of their bee hosts, albeit with a considerable degree of putative host

switches. Furthermore, we found that phylogenetic distances between *Gilliamella apicola* samples correlated with the geographical distance between sampling locations. This tentatively suggests that the environmental transmission rate, as set by geographical distance, affects the distribution of *G. apicola* infections. We show experimentally that both bacterial taxa can be vertically transmitted from the mother colony to daughter queens and social contact with nest mates after emergence from the pupa greatly facilitates this transmission. Therefore, sociality may play an important role in vertical transmission and opens up the potential for co-evolution or at least a close association of gut bacteria with their hosts. These studies helped to understand and diagnose the bacterial, viral and protozoan diseases of honeybees, bumblebees and other pollinators.

PRS: As a visiting professor at institutions in Poland, Switzerland, Malaysia, South Korea, Saudi Arabia, and Thailand, what cross-cultural lessons have you brought back to strengthen pollination research in India?

DPA: Beekeeping practices in India are largely traditional and differ markedly from those followed in many other countries. In India, beekeeping is primarily oriented toward honey production, with limited emphasis on the crucial role of honeybees in pollination within natural ecosystems and agroecosystems for biodiversity conservation and enhanced agricultural productivity. Most beekeepers maintain colonies using only brood chambers, and the use of supers is uncommon. Moreover, greater emphasis is placed on frequent colony division and the extraction of maximum honey from the brood chamber. Such practices weaken colonies, reducing their ability to survive winter conditions or periods of floral scarcity.



Dr. Abrol Chairing a scientific Sessions in 44th Apimondia international conference held at Daejeon South Korea, September, 2015

In contrast, in European and several other Asian countries, honey is not extracted from the brood chamber; instead, extraction is confined to supers, with colonies commonly maintained with two to six supers. Strong colonies not only yield higher honey production but also function as efficient pollinators and exhibit greater resistance to pests, diseases, and natural enemies. Additionally, little attention has been given in India to the diversification of hive products. In some countries, as many as 72 value-added by-products have been developed from hive resources. Furthermore, the practice of hiring honeybee colonies for pollination services has yet to gain popularity in India, whereas in most European countries, renting colonies for pollination—particularly for fruit crops such as almond—is widely practiced.

PRS: Your research spans pollination biology, honeybee management, and IPM.

How has climate change affected honeybee populations in India, and what adaptive strategies do you recommend?

DPA: Among the various drivers, climate change is one of the most serious factors, directly and indirectly influencing the abundance, geographical distribution, vigour, phenology, and behaviour of both plants and their pollinators. Climate change has been shown to severely disrupt plant-pollinator interactions, leading to increased incidence of pests and diseases in honeybee colonies. In addition, populations of natural pollinators such as bumblebees and wild solitary bees have declined markedly in recent years. As climatic conditions shift, habitats suitable for supporting pollinators may be lost in some regions while emerging in others. When suitable habitats disappear or when pollinators are unable to track these changes through dispersal, local extinctions



Dr. Abrol Participating International Conference: Apimondia

may occur. Climate change may also disturb the temporal synchrony between plant flowering periods and the seasonal activity of pollinators. A diverse assemblage of pollinators, with different traits and responses to ambient conditions, is one of the best ways of minimizing risks due to climatic change. The “insurance” provided by a diversity of pollinators ensures that there are effective pollinators not just for current conditions, but for future conditions as well.

PRS: As a member of NITI Aayog’s Sub-Committee for Beekeeping Development and QRT teams for AICRP on Honeybees & Pollinators, what policy recommendations are you advocating to boost India’s honey

production?

DPA: Key Recommendations include

1. Institutionalize the National Bee Board and rename it as the Honey and Pollinators. Board of India under the Ministry of Agriculture and Farmers’ Welfare as it will help in advancing beekeeping through multiple mechanisms such as:
2. Setting up of new integrated bee development centers and strengthening the existing ones.
3. Establishment of a well-equipped, sophisticated National Research Centre on Apiculture (NRCA) with its head quarters in a suitable location

4. This facility will efficiently combine research and teaching space to improve bee health and biodiversity, train new undergraduate and graduate students, mentor new beekeepers and assist commercial and small beekeepers.
5. Creating a honey price stabilization fund. Collection of data on important aspects of apiculture.
6. Simplifying procedures and specify clear standards for ease of exporting honey and other bee products.
7. Beekeeping should not be restricted to honey and wax only instead marketing of bee products such as pollen, propolis, royal jelly, and bee venom can contribute to the income of Indian farmers.
8. Recognize honeybees as inputs to agriculture and consider landless beekeepers as farmers.
9. Training and development of beekeepers should be provided by state governments. National and regional infrastructure should be developed for storage, processing, and marketing of honey and other bee products.
10. Plantation of bee-friendly flora at appropriate places and engaging women self-help groups in managing such plantations.
11. Recognition of apiculture as a subject for advanced research under the aegis.

PRS: What were the major milestones during your tenure as Dean at SKUAST-Jammu, which ones you cherish the most?

DPA: Marked improvement in research and academics. Faculty lectures and seminars helped the student to update their knowledge with the current advances in science.



PRS: Over the years, you have mentored students, researchers, and extension workers. What qualities do you believe are essential for young scientists entering entomology?

DPA: Students need to be independent researchers and motivated to undertake problems confronting farmers. Research problems should be identified based on direct feedback from farmers and should integrate applied research with fundamental studies. Field visits and on-site stay programs in farmers' fields are the most effective ways for researchers and extension workers to gain a deeper understanding of these issues. Additionally, students should develop an interest in insects through entomological clubs and regular interactive activities.

PRS: Looking ahead, what emerging technologies or research areas do you believe will transform apiculture in India over the next decade?

DPA: Despite their pivotal role, honey bees face a myriad of threats including deforestation, habitat loss, climate change, pesticides, and competition from introduced species. These factors have contributed to declines in local populations, necessitating urgent attention and coordinated efforts to safeguard their biodiversity and

ecological contributions. Honey bees not only contribute significantly to agricultural productivity through pollination but also play integral roles in traditional medicine and local economies, reflecting their dual importance in health and cultural practices. There is a need for enhancing employment generation and rural development, through beekeeping. Ensuring nutritional security to resource-crunch Indian public, through hive products. Augmenting agricultural productivity, through planned pollination with honey bees. Augmenting biodiversity and environmental sustainability, through honey bees.

Some of the critical areas needing attention:

1. Hive health & pests (Varroa control, queen management)
2. Forage planning & floral diversity
3. Training & beekeeping organizations
4. Quality standards & certification
5. Marketing, branding & product diversification
6. Infrastructure, finance & policy support
7. Sustainable, pollinator-friendly practices

To achieve these areas there is a need to focus on:

- Impact of climate change on beekeeping and pollination is one of the most issue which needs to be considered seriously.
- Asia is very rich in biodiversity of bees. There is serious decline in honeybee colonies both domesticated as well as wild. There is a need to make an in-depth exploration of biodiversity native honey bee species
- Assess the overall biodiversity of bee pollinators, monitor their decline, its causes and its impact on pollination services
- Undertake taxonomic studies, and evaluate the impact of pollinators on economic yields.
- Promote the conservation and the restoration and sustainable use of pollinator diversity

in agriculture and related ecosystems

- More research is required in crop pollination along with better coordination of the research efforts at the community level in different producing areas to help sustain production of the diverse crops that nourish humanity.
- The improvement in the current policy to provide pollinators with abundant well-connected habitat, plentiful food and freedom from toxic chemicals and disease is the need of the hour.
- Utilizing all the Honey bee colonies for planned Pollination of various crops to boost up crop production and to increase farmers' income without any additional expenditure on this Input. Migration of bee colonies wherever bee flora is available has triple benefits i) Honey production, ii) Colony multiplication and Bee pollination.
- Use of pesticides should be judicious with due advanced intimation to Beekeepers. Linkage between Farmers and Beekeepers should be established.
- Risk assessment of specific pesticide ingredients and regulation based on the identified risks are important responses, and the environmental hazard from pesticides used in agriculture can be decreased at the national level.
- Managing urban and recreational green spaces to increase the local abundance of nectar-providing and pollen-providing flowering plants increases pollinator diversity and abundance.
- Land restoration and reclamation through beekeeping, both in rainforests and arid lands. That many areas in Asia are facing problems due to water shortage and

climatic changes, covering such a topic, taking in consideration, planting nectar and pollen forage shall be most important. Preparing pollen atlas of different plants for Identification of bee flora.

- Multipurpose tree species, with staggered flowering and useful to honey bees during their flowering, to be selected in Social Forestry and Afforestation Programmes.
- All the stakeholder viz. farmers, beekeepers, land managers, urban communities, indigenous people and local communities etc. should be encouraged to adopt pollinator-friendly practices through print and electronic media and social media.
- Cropping pattern and Inter-cropping to be suitably adjusted to provide food to Honey Bees for major part of the year and for additional income to the farmers also (This will support large number of Honey Bee colonies and increase their number)
- The honey bee culture and rural development for enhanced agriculture production and conserving biodiversity
- Making aware the stakeholders of existing global and regional policy initiatives and providing with advice on how national legislation can integrate effectively into existing global and regional policy frameworks for the conservation of pollinators.
- Promoting education and awareness in the public and private sectors of the multiple values of pollinators and their habitats, in improving the tools for decision-making, and in providing practical actions to reduce and prevent pollinator decline in different landscapes. Syllabus of Schools may be

revised to include practical aspects of beekeeping. Syllabus of Colleges, Forest Guards Colleges etc. may be revised to create technicians, research workers and scientists.

- Work out contribution of pollination crop wise in the country
- Linking bee keeping with job opportunities
- Improvement in existing management practices
- Encouraging bee products as food and medicine.
- Diversification and value addition of bee products
- Marketing of bee products
- Assess constraints in beekeeping
- Problem of diseases, pests, predators and natural enemies.
- Exploration, identification and domiciliation of non-Apis bee pollinators for enhanced productivity of crops,
- Urban beekeeping utilizing roof tops, hidden gardens. Parks private or public spaces.
- Census of beekeepers, bee colonies, etc. should be done
- Technical skills of beekeepers should be upgraded
- Bee colonies should be well maintained for higher honey production
- Rapid multiplication of bee colonies should be done
- Productivity of Bee colonies should be increased
- Bee-hives, Comb Foundation Sheets etc. should be readily made available to beekeepers on subsidized rates.
- Diversification of Bee-products should be done to make the beekeeping industry self-reliant.

- Quality control of bee-products to safeguard interests of both, producer & consumer
- If the existing beekeepers are encouraged, motivated and assisted to become semi-commercial beekeepers. The number of bee colonies can be doubled within a short period and with minimum cost.
- To promote agri- entrepreneurs & agri-startup for their involvement in beekeeping/ Honey production
- Empowerment of Women through Beekeeping
- Developing beekeeping infrastructural facilities. Easily available beehives and other beekeeping materials
- Packaging processing and storing
- Technologies need to be developed for effective identification of adulterated honey products

PRS: Finally, if you were to describe your journey in one sentence, what would it be?

DPA: It is essential to recognize that pollination is not a free service, and that investment and stewardship are required to protect and sustain it. Economic assessments of agricultural productivity should account for the “cost” of sustaining wild and managed pollinator populations. There is a need for well-documented cases of specific pollinator declines notwithstanding, rapid extrapolation from our current knowledge to imply worldwide

pollinator and crop production crises regarding pollinator-pollination declines. As Pavan Sukhdev notes in *The Economics of Ecosystems and Biodiversity* UN report, “Not even a single bee has ever sent you an invoice—and that is part of the problem. Because most of what we receive from nature is not priced, traded, or invoiced, it is often overlooked.”

The foregoing interview was conducted by Dr. P.R. Shashank, Managing Editor of Indian Entomologist. He serves as Senior Scientist and Incharge of the National Pusa Collection (NPC) at the Division of Entomology, ICAR–Indian Agricultural Research Institute, New Delhi. His areas of specialization include insect taxonomy, invasive insect pests, molecular diagnostics, and the application of artificial intelligence in pest detection. In his combined roles as a researcher and editor, Dr. Shashank has made substantial contributions to the advancement of taxonomic research and the dissemination of scientific knowledge in Entomology.

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WOMEN IN ENTOMOLOGY

Interview with Dr. M. Shanthi, Director of Centre for Plant Protection Studies, Tamil Nadu Agricultural University, Coimbatore

Dr. M. Shanthi is a distinguished Agricultural Entomologist and academic leader and at present, the Director of the Centre for Plant Protection Studies (CPPS) at Tamil Nadu Agricultural University (TNAU), Coimbatore. With over three decades of experience in teaching, research, extension, and administration, she has made significant contributions to insect ecology, eco-friendly pest management, and plant protection technologies. Trained in TNAU and mentored by some eminent Indian Entomologists, Dr. Shanthi has guided numerous postgraduate and doctoral students and has been instrumental in developing innovative botanical and bio-based pest management formulations targeting major crop pests such as *Spodoptera frugiperda* and *Plutella xylostella*. Her career reflects a strong commitment to integrating scientific research with practical solutions for farmers. As the first woman Director of CPPS from the discipline of Agricultural Entomology, she exemplifies the growing leadership of women scientists in crop protection and continues to inspire the next generation of entomologists through her contributions to research, education, and institutional development.



Dr. M. Shanthi
Director, Centre for Plant Protection
Studies, Tamil Nadu Agricultural
University, Coimbatore

Tamil Nadu Agricultural University (TNAU) is a pioneering institution in agricultural education, research, and extension in India, consistently contributing to the advancement of sustainable agriculture. Unique among state agricultural universities, TNAU has established a Centre for Plant Protection Studies, dedicated to addressing crop protection challenges through research, innovation, and training. The university has also been a centre for nurturing expertise in integrated pest management and has also established a state-of-art museum exclusively for insects in the country for the first time. Dr. M. Shanthi, an

eminent agricultural entomologist from TNAU, has the distinction of being the first Directress from Agricultural Entomology, exemplifying the university's commitment to leadership, scientific excellence and the development of skilled professionals in plant protection.

Dr. Chitra Narayanasamy (CN): When was the Centre for Plant Protection Studies started in TNAU?

Dr. M. Shanthi (MS): The Centre for Plant Protection Studies (CPPS) was established in April, 1984 in TNAU to coordinate and strengthen



CABI PlantwisePlus National Stakeholders Meeting

teaching, research and extension activities in Plant Protection and Sericulture. Agricultural Entomology, Plant Pathology, Plant Nematology and Sericulture are the constituent departments of this Directorate.

CN: What is the advantage of having a Centre for Plant Protection Studies instead of individual directorates of separately for entomology, pathology, nematology and sericulture?

MS: The consolidation of entomology, plant pathology, nematology and sericulture within a unified Directorate of the Centre for Plant Protection Studies (CPPS) at TNAU establishes a comprehensive, multidisciplinary platform for plant health management. This integrated organizational model offers clear advantages in coordination and efficiency and can therefore be recommended as a best-practice framework for other universities.

CN: Since you have indicated that this structure can serve as a model for others, could you please elaborate on how such an integrated system contributes to effective plant protection?

MS: The integrated structure of the Centre for Plant Protection Studies enables close collaboration among allied disciplines and creates a comprehensive framework for addressing complex crop protection challenges more effectively. This multidisciplinary approach strengthens teaching, research, and extension by bringing together expertise across the major components of plant health management.

Scientific and academic integration

- The four disciplines together cover the full spectrum of biotic stresses: insects, pathogens, nematodes and insect-based cropping systems (mulberry–silkworm), enabling truly holistic teaching and research in plant protection.

- This structure facilitates interdisciplinary course design and joint guidance of PG/ PhD students, allowing problems like vector-borne diseases or disease–nematode complexes to be handled in a single academic ecosystem.

Integrated research and IPM development

- Many field problems require combined expertise, for example, insect-vectored plant diseases or soil-borne complexes involving fungi and nematodes; a single directorate makes it easier to design integrated experiments and solutions.
- CPPS already coordinates state-wide pest and disease surveillance and IPM-linked biocontrol development (e.g. *Trichoderma*, *Pseudomonas*, *Beauveria*), demonstrating how co-location of disciplines accelerates

technology development and refinement.

Stronger extension and surveillance impact

- With all plant protection disciplines under one roof, TNAU can offer “one-stop” plant health clinics, unified advisories, and joint farmer trainings, rather than fragmented messages from separate departments.
- The integrated directorate has enabled state-wide pest and disease surveillance programmes and coordinated awareness campaigns (including nematode awareness and IPM trainings), which are harder to manage when units are administratively separate.

Efficient use of infrastructure and human resources

- Shared diagnostic labs, culture collections, insectaries, nematode facilities and



Recent field problem: Coconut Rugose Spiralling Whitefly awareness campaign



Recent field problem: Sugarcane Crown mealybug and Pokkah boeng disease

sericulture units reduce duplication of infrastructure and allow specialized equipment to be optimally used across disciplines.

- Centralized leadership under one Director improves planning, budgeting and prioritization of plant protection research, ensuring resources flow to cross-cutting problems of state and national importance.

Uniqueness of CPPS in TNAU

- CPPS in TNAU is explicitly constituted as a multi-department plant protection directorate (entomology, pathology, nematology, sericulture), which is not commonly seen as a single integrated directorate in other SAUs or general universities, where these subjects are often scattered across separate faculties or

departments.

- Given global calls for multidisciplinary crop protection and integrated pest and disease management, this TNAU model can be logically recommended for other centres/universities, especially where fragmented plant protection units hinder coordinated research, teaching and extension; adopting a similar directorate would strengthen IPM, surveillance, and farmer advisory systems.

CN: What are the recent field based problems that has been the primary focus in the directorate?

MS: The recent field problems addressed include coconut wilt, Rugose whitefly in coconut, sugarcane mealybug, Pokkah boeng disease of sugarcane and tapioca mealy bug. Prime research

is undertaken on the above in addition to the regular mandates of directorates. *Anagyrus lopezi* a parasitoid was released against the invasive mealy bug *Phenacoccus manihoti* in collaboration with National Bureau of Agricultural Insect Resources, Bengaluru.

CN: Could you elaborate the key development initiatives undertaken under your leadership as Director like new collaborative programmes with national and international agencies?

MS: To strengthen research, student training, technology transfer and international linkages, several Memoranda of Understanding (MoUs) were facilitated with global and national agencies. At the international level, collaborative agreements were established with the World Vegetable Centre, Taiwan (for 3 years) to develop innovative IPDM strategies in tomato and lablab bean, Observatoire Regional de Lutte Anti-Termites (ORLAT) – CIRBAT, France (for 3 years) for termite management

strategies, and the Minor Use Foundation, USA (for 3 years) for generating MRL data for insecticides in minor-use export crops.

At the national level, a five-year MoU was signed with the ICAR–National Bureau of Agricultural Insect Resources (NBAIR), Bengaluru to support Ph.D. student research programmes. In addition, collaborations with private and development organizations were established to strengthen interdisciplinary research, student training, AI-based agricultural solutions and farmer empowerment. These include MoUs with NEC Corporation India Pvt. Ltd. for AI research; SMJ Smart Products Pvt. Ltd. and Zensit Smart Products Pvt. Ltd., Madurai for web-based applications; Indian Oil Corporation Ltd., Chennai for CSR-funded research and extension; and farmer-producer organizations such as Siruvani Uzhavar Producer Company Ltd. and Perur Jai Hind Vegetable Farmers Producer Company Ltd. for technology dissemination and farmer empowerment. Industry partnerships were forged



International Conference on One Health Perspectives in Global Plant Protection Research (19th to 21st February 2025)



International Day of Plant Health (12th May 2024)

with Syngenta India Pvt. Ltd. for product testing; Sri Sivasubramaniya Nadar College of Engineering, Chennai and KIT Kalaingarunanidhi Institute of Technology, Coimbatore for AI-based research; Angalamman Hi-Tech Agro Industry, Trichy for M.Sc. student research; and SMBRK Environment Solutions Pvt. Ltd., Dharapuram for converting solid waste into value-added products using black soldier flies. A recent agreement with Indofil Pvt. Ltd., Maharashtra supports fellowship programmes for students. These strategic collaborations collectively promote multidisciplinary research, innovation, student capacity building, technology validation and industry-academia integration in plant protection and allied disciplines.

CN: What are the outreach activities, like trainings and seminars that were conducted under your leadership?

MS: We successfully organized the International Conference on One Health Perspectives in Global Plant Protection Research (OHPGPR 2025), which

brought together more than 500 scientists, researchers and academicians from India and abroad. A total of 466 participants registered under nine scientific themes, featuring six keynote speeches, 30 lead papers, 145 oral presentations and 288 brief oral contributions, covering multidisciplinary areas of global significance in plant health. This international meet facilitated knowledge exchange, strengthened global collaborations, and promoted integrated approaches aligned with sustainable crop protection and food security goals.

To commemorate the International Day of Plant Health on 12 May 2024, an international webinar titled “Promoting Awareness on Plant Health, Safe Trade and Digital Technologies” was organized in hybrid mode. The Vice Chancellor awarded prizes to students who excelled in national-level competitions on themes related to biodiversity protection, healthy plants and environmental sustainability. Approximately 450 postgraduate students, researchers and scientists

from TNAU constituent colleges, affiliated institutions, Krishi Vigyan Kendras, research stations and universities such as SRM, CUT, Karunya and CICR benefited through this programme. The webinar emphasized the importance of phytosanitary measures, digital surveillance tools, regulatory frameworks and safe trade practices.

A comprehensive pesticide orientation programme was organised on 21–22 March 2024 to sensitize final-year B.Sc. (Hons.) Agriculture and Horticulture students before their Rural Agricultural Work Experience (RAWEx) programme. Postgraduate and doctoral scholars specializing in Agricultural Entomology, Plant Pathology and Nematology were also oriented on safe handling of pesticides, label claims, toxicity classifications, residue management and resistance prevention strategies. Executives from major agro-chemical

industries such as Coromandel, Syngenta, Rallis, FMC, Corteva, PCI, Bannariamman Sugars Ltd., Aerotics, and De Pest showcased novel technologies, shared product stewardship information and interacted with students. The programme enhanced practical knowledge, improved awareness on regulatory norms, and highlighted emerging trends in precision pest management.

World Bee Day was celebrated on 20 May 2024 at the Department of Agricultural Entomology, CPPS, TNAU, for widespread awareness on bee conservation, pollination services and youth engagement. Following the global theme “Bees Engaged with Youth”, nearly 100 students participated in competitions on bee crafts, honey collection, pollination games and nest building. Students were exposed to



Visit to ARK Tomato facility cultivation, Changhua, Taiwan

the apiary unit to learn about bee species, colony structure, safe handling, and modern scientific beekeeping practices. In addition, activities under the National Bee Board sponsored Advanced Multi-Centre Programme (AMCP) worth ₹99.10 lakhs were implemented across 4 colleges, 15 KVKs and research stations through seminars, district training programmes and on-site demonstrations. The initiative expanded scientific beekeeping literacy, strengthened extension support for bee-based livelihoods, and promoted pollinator-friendly agricultural practices across Tamil Nadu.

An International Conference on Unleashing the Power of Seed and Crop Health Innovations for a Food-Secure World (ICUCF 2024) was jointly organized by CPPS and the Seed Centre, TNAU, on 21–22 November 2024. The event brought together 415 participants from national and international institutions, representing scientists, policy-makers, entrepreneurs, educators and students. Scientific activities included 16 lead lectures, 218 poster and oral presentations across 10 specialized technical sessions encompassing Plant Pathology, Entomology, Nematology and Sericulture. The conference highlighted advancements in seed technology, diagnostics, bio-intensive pest management, disease resistance breeding, and phytosanitary regulations. By promoting collaboration between research bodies and seed industries, the conference emphasized the linkage between crop health innovations, food security and sustainable agricultural development. It provided a significant platform for integrating seed quality, disease-free planting material, and resilient germplasm strategies into future farming systems.

CN: Could you explain the strategies or guidance you provided to help faculty achieve their objectives in the field?

MS: I have consistently motivated and guided the plant protection scientists to achieve their goals by encouraging them to develop and deliver practical technologies to the farming community. As a result of this continuous support and gentle nudging, several plant protection technologies from entomology (including apiculture), plant pathology and nematology were successfully developed and patented.

For the first time registered CPPS, TNAU in CIB&RC for registration of biopesticides developed at Pathology, Nematology and Entomology. The following formulations are under pipeline for registration in CIB&RC by CPPS.

- *Pochonia chlamidospora*,
- *Trichoderma viride*,
- *Bacillus subtilis*,
- *Metarhizium anisopliae*

To recognise and celebrate these achievements, I initiated the establishment of a “**Wall of Honour**” in the Directorate, where all patents obtained by the scientists are prominently displayed. This not only acknowledges their contributions but also inspires a culture of innovation and excellence within the Directorate.

CN: Could you outline the major hurdles you encountered during your tenure as Director?

MS: I would not describe them as “hurdles.” Instead, I have always viewed such situations as opportunities to strengthen the Directorate and move forward with greater clarity and purpose. Every challenge—whether related to coordination among disciplines, resource limitations, or meeting the expectations of stakeholders—served as a chance to innovate, refine our strategies and enhance our collective performance.

CN: What are the future lines of research that are likely to dominate plant protection?

MS: The future of plant protection research is being shaped by evolving challenges like climate change, pesticide resistance, emerging pests and diseases, and the demand for sustainable agriculture. Based on current trends, the major lines of research likely to dominate plant protection include: Climate – Smart and adaptive plant protection: Studying how climate change affects pest and disease dynamics, developing forecasting models for emerging pests and diseases, digital tools, AI driven pest/disease monitoring and decisions support systems could be crucial in plant protection in the near future, in addition to our other mandatory programmes as host plant resistance, biological control and other methods of pest management.

CN: What motivated you to specialise in Entomology? Could you share your journey to becoming the Director of CPPS in TNAU and your significant achievements?

MS: When I joined the B.Sc. Agriculture program at the Agricultural College and Research Institute (TNAU), Madurai, I observed that entomology-related field problems played a critical role in achieving higher crop yields. I was profoundly inspired by Professor Dr. K. Gunathilagaraj, whose teaching further fuelled my interest in entomology.

I was the recipient of ICAR Post Matric Scholarship for B.Sc. Ag (1985-1989) and ICAR Junior fellowship for M.Sc. Ag). I pursued my post graduate research on management of storage pests in paddy and pulses under the eminent guidance of Dr.G.Logeeswaran, Professor of Entomology (Retd.) in TNAU. Served in TNAU as Senior Research Fellow in January 1992, worked in DBT schemes on Biological control under Dr. S. Jayaraj, Former Vice

Chancellor and Dr. R.J.Rabindra, Former Director, NBAIR, Bengaluru till 1995. Joined as a faculty in 1995 in TNAU and later pursued my Ph.D. research programme “Insect plant interactions study on okra shoot and fruit borer” under the chairmanship of Dr. S. Uthamasamy, Former Director of Extension Education, TNAU, Coimbatore.

I have been an undergraduate teacher for 24 years and for 15 years also taught post graduate students. Have handled 66 courses as course teacher and 48 courses as course associate. I have guided 12 postgraduate students and 11 Ph.D. students. Developed eco-friendly and innovative formulations including Mahogany Methanolic Extract (MME 30 EC), *Sesbania grandiflora* 40 SL, synthesized N-Alkyl Chitosan and Chitosan O-Arginine targeted against the Fall Armyworm *Spodoptera frugiperda* and Diamondback moth *Plutella xylostella* through student thesis research. Further, I initiated research on efficacy of proteinase inhibitor and synthesis of chitosan derivatives and their effect on insect pests, viz., *P. xylostella* and *S. frugiperda*. I worked in AICRP Tropical fruits scheme for 2 years at Periyakulam and AICRP Cotton for 2 years at Srivilliputtur and was in administration for 9 years and have associated extension service for the past 31 years. I have operated 29 externally funded schemes with budget outlay Rs. 11.12 crores from national and international funding agencies. I have also operated 24 bioefficacy schemes, collaborated in the release of six crop varieties and have four patent copyrights related plant protection tools/ technology. I have developed 37 technology transfer modules. I have undergone a training and attended 4 conferences abroad and 48 conferences within the country. I am also serving as the principal member Bureau of Indian Standards - FAD 34: P4 - Plant Health Management Panel, representative in the IBSC of

TNAU –DBT, part of the team of Board of Directors in Centre of Excellence in Biotechnology (CPMB, TNAU), State-level committee member to monitor Pesticide residues under the MPRNL Scheme and the Board of Studies member for Postgraduate Education, Agriculture, Horticulture, Agricultural Engineering and Community Science in the University. I have published around 160 research papers and have authored 18 book chapters. I also was awarded the best teacher award during 2011 in TNAU.

The above conversation was conducted by Dr. Chitra Narayanasamy, Professor of Agricultural Entomology and Curator of the TNAU Insect Museum at the Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore. With over 15 years of experience in teaching and

research, she specializes in insect taxonomy and biodiversity. Dr. Chitra has played a significant role in the establishment and development of the TNAU Insect Museum and has led funded research projects in insect taxonomy supported by the Department of Science and Technology, Government of India. She also serves as a member of the editorial boards of two scientific journals, contributing actively to the advancement and dissemination of entomological research.

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GENERAL ARTICLE

Physiological Adaptation in Digestive Capability of Insects

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Abstract

The evolutionary success of insects is largely attributed to specialized physiological adaptations of their digestive system that correspond closely with dietary diversity. The profile and activity of digestive enzymes vary according to feeding habits and undergo substantial changes during development, particularly between larval and adult stages. In addition to endogenous enzymes, gut-associated microorganisms contribute significantly to digestive processes and nutritional supplementation by facilitating cellulose degradation and synthesizing essential nutrients, thereby enhancing digestive efficiency and supporting the ecological diversification of insects.

Key Words: Physiological adaptation, digestive ability, nature of insect diet, role of micro-organisms

Introduction

Insects are among the most successful and diverse groups of organisms on Earth. One of the key factors contributing to their evolutionary success is their remarkable ability to adapt to a wide range of ecological conditions. Insects have successfully colonized almost all ecosystems, including terrestrial, aquatic, soil, forest, and desert environments (Purdue University website, 2025). Many insect species have evolved parasitic modes of life in animals and humans and act as vectors of several serious diseases. In addition, insects constitute major pests of agricultural crops and ornamental plants. However, despite their pest status, insects have also established highly specialized and beneficial mutualistic relationships with plants, particularly for obtaining food and other resources (Kumar, 2024).

Dietary Specialization

Among the many successful adaptations

exhibited by insects, one of the most significant and unique features is that their digestive capacity is physiologically adapted to, and positively correlated with, the nature of their diet. Consequently, the digestive system of insects has evolved and become modified in parallel with changes in feeding habits. For example, an omnivorous insect such as the cockroach possesses a wide array of digestive enzymes in the midgut, including proteases for protein digestion, amylase for starch, invertase for sugars, lipase for fats, and maltase for maltose, reflecting the diverse constituents of its diet. In contrast, phytophagous insects primarily consume starch-rich plant material and therefore exhibit high amylase activity in the gut. Carnivorous insects, on the other hand, show an abundance of proteolytic and lipolytic enzymes, whereas carbohydrate-digesting enzymes occur only in trace amounts. In predatory beetles of the family Carabidae, protease activity is high, lipase activity is comparatively weak, and amylase activity is minimal. Similarly, in the larvae of *Lucilia*, which feed on blood or

animal tissues, proteases and lipases predominate. However, in the adult blowfly (*Calliphora*), a shift in feeding habit results in increased activity of invertase and maltase, while protease and amylase activities are reduced. Adult blowflies can be successfully reared on sugar solutions and require proteins primarily for egg development.

Enzymatic Adaptations Across Feeding Guilds

Owing to the close relationship between digestive capacity and diet, insects often exhibit marked changes in digestive ability during the course of their development. For instance, caterpillars generally possess a wide spectrum of digestive enzymes in their gut, whereas adult lepidopteran insects, which predominantly feed on nectar, typically exhibit mainly invertase activity in their alimentary canal. In certain moths, such as *Lymantria* and *Dicranura*, where the mouthparts are vestigial and feeding does not occur, even invertase is absent (Chapman, 1969). It is noteworthy that cellulase is generally absent in insects; however, enzymes facilitating partial cellulose digestion have been reported. For example, hemicellulase in earwigs and lichenase in lichen-feeding insects contribute to the partial breakdown of cellulose.

A classical example of physiological digestive adaptation is observed in the omnivorous insect *Apolygus lucorum*, which feeds on both plant and animal matter. Studies have demonstrated that plant-derived food induces amylase activity, whereas animal-derived food stimulates protease activity in this species (Li et al., 2017).

Role of Gut Microorganisms in Insect Digestion and Nutrition

Another highly advanced and sophisticated physiological adaptation in insects is the presence of gut-associated microorganisms that play a crucial role in digestion and nutrition (Chapman, 2008; Douglas, 2015). A diverse assemblage of symbiotic flagellates, bacteria, and fungi inhabits the gut of termites and the wood-feeding cockroach *Cryptocercus*, where they facilitate the digestion of cellulose. In termites, symbiotic flagellates such as trichomonads, hypermastigotes, and oxymonads are commonly present in the hindgut. Additionally, fungi of the genus *Termitomyces*, associated with higher termites of the family Macrotermitinae, contribute significantly to cellulose degradation. Bacteria are also primarily responsible for cellulose digestion in cockroaches, scarab beetles, and crickets that feed on decaying wood. Furthermore,

Table.1. Relationship between digestive ability and nature of insect diet (Source: Chapman, 1969)

Insect	Diet	Protease	Lipase	Amylase	Invertase	Maltase
Cockroach	Omnivorous	+	+	+	+	+
<i>Carausius</i>	Partly omnivorous	+	+	+	+	+
Lepidoptera (larva)	Polyphagous	+	+	+	+	+
Lepidoptera (adult)	Nectar feeding	-	-	-	+	-
Silk moth (adult)	Non-feeding	-	-	-	-	-
<i>Lucilia</i> (larva)	Meat	+	+	-	-	-
<i>Calliphora</i> (adult)	Nectar feeding	-	-	+	+	+
<i>Glossina</i>	Blood	+	-	-	-	-

in insects such as aphids, tsetse flies, cockroaches, and weevils, specialized endosymbiotic microorganisms—often housed in distinct cells or tissues known as mycetocytes—are embedded within the host and play an essential role in meeting nutritional requirements, including the synthesis of essential amino acids and B-complex vitamins.

Conclusion

In conclusion, the digestive physiology of insects is tightly linked to dietary specialization, with enzyme secretion patterns reflecting feeding habits. In addition, symbiotic microorganisms significantly contribute to the nutritional requirements of insects.

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GENERAL ARTICLE***Tropilaelaps mercedesae*: An Emerging Global Threat to Honey Bees****Gaurav Vinod Rao Sadafale¹ and Sujal Suhas Munj²**¹Department of Agricultural Entomology, College of Agriculture, Vishweshwaraiah Canal Farm, Mandya, University of Agricultural Sciences, Bangalore, Karnataka-571 405, India²Department of Agricultural Entomology, College of Agriculture, Dharwad, University of Agricultural Sciences, Dharwad, Karnataka-580 005, India*gauravsadafaleuasb@gmail.com (ORCID - 0009-0006-2648-1158)**Abstract**

The ectoparasitic mite *Tropilaelaps mercedesae* has emerged as a significant global threat to the Western honey bee (*Apis mellifera*), a species critical to global agriculture and food security. First described in association with Asian giant honey bees, this parasite has now adapted successfully to *A. mellifera*, where it feeds on brood, shortens adult bee lifespans, and transmits viral pathogens including Deformed Wing Virus. Unlike *Varroa destructor*, which has dominated global discourse on honey bee health, *T. mercedesae* reproduces faster, remains largely hidden within brood cells, and can disperse via phoresy on adult bees, enhancing its spread potential. New diagnostic tools such as rapid brood decapping have recently been developed to improve detection. The establishment of stable populations in Europe underscores the urgency of coordinated action. This article synthesizes recent advances in knowledge on the biology, spread, impacts, detection, management, and policy implications of *T. mercedesae*, highlighting research gaps and emphasizing the need for global vigilance to prevent a crisis greater than that caused by *V. destructor*.

Keywords: *Tropilaelaps mercedesae*, *Apis mellifera*, honey bee health, brood parasite, emerging pest, diagnostics, biosecurity, pollination services.

Introduction

Honey bees play an essential role in pollinating crops and maintaining biodiversity. As key contributors to global food security, pollinators support agriculture, ecosystem functioning, and sustainable crop production. Among them, the Western honey bee (*Apis mellifera*) is the most economically significant managed pollinator, providing vital pollination services for hundreds of crops worldwide (Klein et al., 2007). However, over recent decades, honey bee populations have experienced substantial declines due to multiple interacting stressors, including habitat fragmentation, pesticide exposure, nutritional

deficiencies, climate change, and numerous pathogens and invertebrate pests (Goulson et al., 2015). Of these threats, parasitic mites remain among the most destructive agents affecting global apiculture.

The mite, *Varroa destructor* is widely regarded as the most devastating ectoparasite of honey bees, having spread from Asia to nearly every beekeeping region worldwide. Its invasion has resulted in severe colony losses, diminished pollination services, and the widespread adoption of expensive and complex management strategies (Rosenkranz et al., 2010). Yet emerging evidence increasingly suggests that *Varroa* may not

remain the most damaging mite threat. Growing scientific concern now centers on *T. mercedesae*, a lesser-known but potentially more aggressive brood parasite capable of surpassing *Varroa* in reproductive capacity and colony-level damage under suitable conditions.

Unlike *Varroa*, which has an extended phoretic period on adult bees, *T. mercedesae* remains almost entirely within brood cells. This brood-focused lifestyle enables exceptionally rapid population growth whenever ample brood is available, making the mite particularly challenging to manage in regions lacking natural brood breaks (Sammataro et al., 2000). Comparative studies have long documented that *Varroa destructor* and *Tropilaelaps* have co-infested *A. mellifera* colonies for about fifty years across Asia (Delfinado, 1963). In regions such as Thailand, Afghanistan, and Vietnam, infestations of *T. clareae* now largely synonymous with *T. mercedesae* were often higher than those of *V. jacobsoni* (now *V. destructor*) (Burgett et al., 1983; Woyke, 1987a, 1989). Seasonal shifts have been observed as well; for example, in the Philippines, colonies with higher *T. clareae* levels in April later showed higher *Varroa* loads by September (Fajardo & Cervancia, 2004). In Northern Thailand, *T. clareae* infestations were similarly dominant in both Thai *A. mellifera* and Russian honey bees (Kavinseksan et al., 2003).

The reproductive dynamics of these mites further shape their competitive interactions. Although both *Tropilaelaps* and *Varroa* produce similar numbers of progeny on average, a significantly higher proportion of *Tropilaelaps* females (=70%) successfully produce at least one progeny compared with *Varroa* females (=50%). Even minimal reproductive success per cycle allows *Tropilaelaps* populations to expand more rapidly, contributing to their dominance in

suitable environments. Host brood preferences also differ markedly. *Varroa* preferentially infests drone brood at rates three to eight times higher than worker brood (Fuchs & Langenbach, 1989), meaning its population growth can be limited when drone brood is scarce. In contrast, *T. clareae* infests worker brood approximately 1.5 times more than drone brood (Woyke, 1987), while *T. mercedesae* shows no significant brood-sex preference when parasitizing its indigenous host *Apis dorsata*, infesting worker and drone brood at similar rates (Buawangpong et al., 2013). Notably, co-infestation of individual brood cells or the same hosts by *Tropilaelaps* and *Varroa* is rare—a pattern also observed by Ritter & Schneider-Ritter (1988) and Burgett et al. (1989) in studies on the *Acarapis* species complex—suggesting potential competitive exclusion or differing host exploitation strategies.

Originally a parasite of Asian giant honey bees such as *Apis dorsata*, *T. mercedesae* has successfully shifted to managed *A. mellifera* colonies, where it inflicts substantial brood damage, accelerates viral transmission, and reproduces more rapidly than *Varroa* (Dong et al., 2017; Ling et al., 2023). While traditional *Varroa* monitoring tools rely on detecting mites on adult bees, the brood-centric nature of *Tropilaelaps* makes field detection more difficult. Recent findings show that *T. mercedesae* can disperse long distances by hitchhiking on adult foragers (Tokach et al., 2025), further increasing its invasive potential.

The first confirmed establishment of *T. mercedesae* outside Asia occurred in western Russia and Georgia, where overwintering colonies were found infested (Brandorf et al., 2024; Uzunov et al., 2025). These incursions highlight the mite's capacity to survive in temperate climates and raise serious concerns for Europe, the Middle East, and other vulnerable regions. Given the global

reliance on pollination for food security, apiculture now faces a critical decision—either implement proactive surveillance and integrated management strategies or risk widespread impact from delayed intervention.

In India, the closely related mite *Tropilaelaps clareae* is primarily associated with the indigenous hive bee *Apis cerana*. First described by Delfinado and Baker (1961), *T. clareae* is a major pest of beekeeping in several Indian states (Abrol & Putatunda, 1995; Koeniger et al., 1983). Its impact is particularly severe in Haryana and Punjab (Putatunda, 1996), and it has also been reported from Jammu & Kashmir (Abrol & Putatunda, 1995). Only isolated exceptions exist; Anderson and Morgan (2007) reported a single *T. mercedesae* female parasitizing *A. cerana* brood in Thailand, concluding that this was likely an anomalous event because *T. mercedesae* rarely infests or reproduces within *A. cerana* colonies.

Apis mellifera, though not native to India, is globally valued for its role in crop pollination, biodiversity maintenance, and the production of economically important hive products such as honey, beeswax, propolis, pollen, and royal jelly. It has been widely introduced due to its economic importance and is one of the most extensively studied bee species (Free, 1993; Seeley, 2011). Honey bees are threatened by a broad array of pathogens and parasites, including bacteria, viruses, fungi, microsporidia, and acarine mites (Genersch et al., 2010). Mites (Acari) inhabit diverse ecological niches; parasitic species feed on host haemolymph or fat body tissue, causing direct damage while also acting as vectors of pathogens (Walter & Proctor, 2013).

The developmental cycle of *Tropilaelaps* is broadly similar to that of *Varroa*, with one crucial

difference: *Tropilaelaps* mites infest both worker and drone brood simultaneously, enabling rapid and sustained population expansion (Kapil & Aggarwal, 1987, 1989). Gravid females enter brood cells shortly before capping, feed on larval haemolymph for up to two days, and lay three to four eggs in a typical cycle. Offspring develop rapidly, with adults emerging in 6–7 days. Female mites exit the cell with the newly emerged bee and quickly reinfest new brood cells. During broodless periods, adult mites survive in a phoretic stage on adult bee sclerites until brood becomes available (Koeniger & Muzaffar, 1988; Rinderer et al., 1994; Wilde, 2000).

Identification of *Tropilaelaps* mites relies on both morphological and molecular diagnostic tools. Visual inspection of hive debris or brood combs can reveal characteristic signs, including irregular brood patterns, dead or deformed pupae, crawling bees with deformed wings, and the presence of fast-moving, reddish-brown, elongated mites on the comb surface (Anderson & Morgan, 2007).

Biology and Life Cycle of *T. mercedesae*

T. mercedesae was first described by Delfinado and Baker (1961) from the Philippines. Belonging to the Laelapidae family, it is morphologically distinct from *Varroa*: elongated, smaller, and highly mobile. These mites are adapted for parasitism, with piercing mouthparts optimized for feeding on developing brood. Genomic sequencing reveals streamlined sensory genes but expanded detoxification repertoires, reflecting its specialized parasitic life history and potential resilience to chemical controls (Dong et al., 2017).

The mite's reproductive cycle is rapid. Females invade brood cells shortly before capping, laying eggs that hatch within hours. Development

from egg to adult takes less than a week, enabling explosive population growth under favorable conditions (De Guzman et al., 2017). Unlike *Varroa*, which can spend extended periods on adults, *T. mercedesae* depends heavily on brood availability, starving quickly when brood is absent (Anderson & Roberts, 2013). However, evidence now shows the mite can survive on adult bees for short periods, facilitating dispersal (Rinderer et al., 1994).

Recent breakthroughs confirm that *T. mercedesae* engages in phoresy on *A. mellifera* foragers exiting colonies, demonstrating a capacity for spread greater than previously assumed (Tokach et al., 2025). Feeding on larvae and pupae causes mortality, reduced weight of surviving bees, shorter adult lifespans, and impaired cognitive function (Gao et al., 2021). Infested bees also show disrupted gut microbiota. Combined with virus transmission, these effects severely compromise colony viability.

Geographic Spread and Pathways of Transmission

For decades, *T. mercedesae* remained largely restricted to Asia, reported in Thailand, China, and Papua New Guinea (Burgett et al., 1990; De Guzman et al., 2017). Its spread has accelerated due to globalization of apiculture and trade in hive products. Khongphinitbunjong et al. (2019) demonstrated that mites can survive in wax and pollen shipments for days, posing biosecurity risks. Migratory beekeeping further amplifies dispersal potential (Edwards & Smith, 2021).

The paradigm shifted in 2024 with the detection of established populations in Krasnodar, Russia (Brandorf et al., 2024). Shortly thereafter, infestations were confirmed in Georgia, including overwintering populations (Janashia et al., 2024; Uzunov et al., 2025). These findings demonstrate the mite's capacity to adapt to temperate climates,

Table 1. Schematic Comparison of *Varroa* vs. *Tropilaelaps* Life Cycles

Feature	<i>Varroa destructor</i>	<i>Tropilaelaps</i> spp.
Primary Host Stage	Brood (larvae and pupae)	Brood (larvae and pupae)
Reproductive Phase	Performed inside a capped brood cell	Performed inside a capped brood cell
Phoretic Phase	Extended; can survive on adult bees for months by feeding on fat bodies	Abbreviated; can only survive on adult bees for 1-3 days
Adult Feeding	Capable of feeding on adult bee fat bodies during the phoretic phase	Mouthparts not suitable for feeding on adult bees
Cell Invasion	Enters brood cell shortly before capping (approx. 60 hours prior)	Enters brood cell just before capping (approx. 10 hours prior)
Egg Laying Rate	Slower; approx. every 30 hours	Faster; approx. every 24 hours
Reproductive Rate	Lower than <i>Tropilaelaps</i>	Higher than <i>Varroa</i>
Feeding Site	Establishes one feeding site shared by offspring	Uses multiple feeding sites on one host
Brood Preference	Prefers drone brood over worker brood	Does not show a preference for drone or worker brood

contradicting earlier assumptions that cold winters would prevent establishment. Climate modeling further suggests that large portions of Europe, North America, and Africa could support the mite's survival (Tsvetkov et al., 2022; Liao & Chen, 2023). With phoretic dispersal on foragers now established (Tokach et al., 2025), the potential for global expansion mirrors and may exceed that of *Varroa*.

Impacts on Honey Bee Health and Colony Survival

The consequences of *T. mercedesae* infestations are multifaceted. At the brood level, feeding results in direct mortality, developmental deformities, and reduced weight of emerging adults (Ling et al., 2023). Survivors often exhibit reduced longevity, impaired navigation, and weakened foraging performance (Gao et al., 2021). At the colony level, infestations destabilize brood patterns, weaken adult populations, and accelerate collapse. A particularly alarming feature is the mite's role as a viral vector. *T. mercedesae* transmits Deformed Wing Virus (DWV) and other pathogens, amplifying their prevalence and pathogenicity (Dainat et al., 2009). The synergy between mite parasitism and viral spread mirrors the *Varroa*–DWV complex but may progress more rapidly given *T. mercedesae*'s shorter reproductive cycle. Colony losses in Papua New Guinea, Thailand, and now Russia and Georgia have been directly attributed to this parasite (Roberts et al., 2020; Brandorf et al., 2024). Beyond apiculture, risks to wild bee populations remain poorly studied but are cause for concern (Jaffe & Pires, 2020).

Detection and Diagnostics

Detecting *T. mercedesae* is challenging due to its cryptic behavior. Methods used for *Varroa*, such as sugar shakes, underestimate infestation levels

because they target mites on adult bees. Direct brood inspection is essential but labor-intensive.

Recent innovations have improved detection. Rapid brood decapping, validated in European field trials, provides a sensitive, practical method for assessing brood infestations (Uzunov et al., 2025). Molecular tools such as qPCR and DNA barcoding also allow for precise identification (Luo et al., 2011; Nielsen & Williams, 2021). Gill et al. (2024) compared field and laboratory diagnostic methods, highlighting the value of integrated approaches. Early detection is critical, as eradication is only feasible in the initial stages of incursion (Ciobanu et al., 2023). International initiatives such as COLOSS are working to harmonize surveillance protocols across regions (Neumann & Yañez, 2022).

Control and Management Strategies

Controlling *T. mercedesae* is particularly challenging due to its rapid reproductive cycle, short phoretic phase, and strict dependence on brood for survival, which limits the effectiveness of adult-bee-based interventions. Chemical control options remain limited; commonly used acaricides such as amitraz have shown poor efficacy against *Tropilaelaps* because the mites spend minimal time on adult bees, reducing exposure (Roberts et al., 2020). In contrast, formic acid—capable of penetrating capped brood cells has demonstrated greater promise as a practical treatment, although its effectiveness varies with temperature and colony strength (Pettis et al., 2017). Reliance on chemical interventions also raises concerns about resistance development, residue accumulation, and impacts on colony health (Simões & Oliveira, 2021).

Given these constraints, alternative strategies are drawing increasing attention. Biotechnological approaches such as RNA interference (RNAi) targeting essential mite genes,

Table 2. Comparison of Diagnostic Methods for *T. mercedesae* Detection

Diagnostic Method	Target Stage	Sensitivity	Advantages	Limitations	Key References
Sugar Shake / Powdered Sugar Roll	Adult bees (phoretic mites)	Low for <i>T. mercedesae</i>	Non-destructive, easy to perform, widely used for <i>Varroa</i> monitoring	Ineffective because <i>Tropilaelaps</i> spend very little time on adult bees; severe underestimation	Uzunov et al. (2025); Gill et al. (2024)
Alcohol Wash	Adult bees	Low-Moderate (higher than sugar shake but still underestimates)	Good for <i>Varroa</i> ; kills mites and bees, improving dislodgement	Still misses most <i>T. mercedesae</i> due to minimal phoretic phase	Neumann & Yañez, 2022
Direct Brood Inspection (uncapping & examining brood cells)	Brood (larvae/pupae)	High	Gold standard for detecting brood-cell parasites; identifies presence, reproductive status	Labor-intensive, time-consuming; requires significant brood sampling	Anderson & Morgan (2007); Kapil & Aggarwal (1987)
Rapid Brood Decapping Method	Brood	Very High	Fast, scalable, validated in field trials; more sensitive than standard uncapping	Requires trained personnel and consistent sampling	Neumann & Yañez, 2022
Sticky Boards / Hive Debris Analysis	Fallen mites / debris	Moderate	Non-intrusive, easy to deploy, captures natural mite drop	Drop rates vary widely; early infestations often missed	Sammataro et al. (2000)
Molecular Diagnostics (qPCR, DNA barcoding)	All life stages; Environmental DNA	Very High	Highly sensitive and specific; detects low-level or early-stage infestations; differentiates species	Requires lab facilities, costlier, slower turnaround in field settings	Luo et al. (2011); Nielsen & Williams (2021)
Integrated Diagnostic Panels (Field + Molecular)	Combined	Very High	Best accuracy; compensates weaknesses of single methods	Requires coordination of sampling and lab analysis	Neumann & Yañez, 2022

fungal biocontrol agents, and pheromone-based disruption of host-parasite interactions represent promising future tools. However, these methods remain largely experimental and require rigorous field validation, optimization of delivery systems,

and cost-effective formulations before they can be integrated into beekeeping practice. An integrated pest management framework that combines chemical, biotechnological, and cultural strategies such as brood interruption, selective breeding for

hygienic behavior, and improved colony monitoring will be essential for sustainable long-term control of *T. mercedesae* (Roberts et al., 2020; Ling et al., 2023).

Policy, Trade, and Biosecurity Challenges

The global spread of *T. mercedesae* underscores significant weaknesses in international and national biosecurity frameworks. Although the World Organisation for Animal Health (WOAH) lists *Tropilaelaps* as a notifiable pest, enforcement of these regulations is often inconsistent, particularly in regions with limited monitoring infrastructure. International trade in hive products- including honey, wax, pollen, and bee packages as well as migratory beekeeping practices, represent key pathways for unintentional dispersal of the mite (Khongphinitbunjong et al., 2019; Edwards & Smith, 2021). Recent incursions into Europe demonstrate that even countries with strong veterinary and apicultural systems are not immune to establishment, highlighting the need for proactive rather than reactive strategies.

Preventing further spread requires a multi-layered approach. Strict import controls on live bees and hive products, coupled with targeted surveillance at ports of entry, are essential first lines of defense. Rapid response contingency plans, including quarantine, colony destruction if necessary, and localized chemical or biological interventions, can significantly reduce the risk of establishment (Maiolo et al., 2022). Economic analyses suggest that early detection and intervention are far more cost-effective than prolonged management or mitigation of established infestations (Reed & Baxter, 2021).

International collaboration is critical to strengthen biosecurity and prevent global escalation. Networks such as COLOSS (Prevention of

Honey Bee Colony Losses) provide frameworks for sharing surveillance data, coordinating diagnostic efforts, and harmonizing response protocols across borders (Neumann & Yañez, 2022). In addition, regional cooperation among neighboring countries can limit cross-border spread, particularly in areas with intensive migratory beekeeping or high-volume trade in hive products. Without coordinated, proactive action, *T. mercedesae* has the potential to replicate and possibly exceed the catastrophic impacts of *Varroa destructor*, threatening global apiculture, pollination-dependent agriculture, and food security.

Research Gaps and Future Directions

Despite substantial progress in understanding *T. mercedesae*, significant knowledge gaps remain, hindering the development of effective management strategies. Comprehensive epidemiological modeling is urgently needed to predict the mite's potential global spread under varying climate, land-use, and trade scenarios (Liao & Chen, 2023). Such models should integrate factors such as brood availability, colony density, seasonal patterns, and international hive product movements to improve risk assessment and inform targeted interventions. The role of *T. mercedesae* in virus transmission and pathogen amplification remains poorly understood. While *Varroa* is a well-known vector for several honey bee viruses, limited research exists on virus-*Tropilaelaps* interactions. Understanding the dynamics of viral transmission, including co-infection scenarios with *Varroa* and other pathogens, is critical to assess the broader impacts on colony health, pollination efficiency, and agricultural productivity.

Early detection is a cornerstone of effective management, yet current diagnostic tools are often insufficient, particularly in resource-limited

settings. Improved, cost-effective molecular, immunological, and rapid field-based diagnostic methods are needed to detect low-level infestations before widespread establishment (Gill et al., 2024). Additionally, monitoring programs should incorporate standardized protocols for both managed and wild bee populations to provide early warnings and track infestation trends over time.

Control strategies require rigorous validation across diverse climates, beekeeping systems, and apicultural contexts. Chemical, mechanical, and biological interventions need to be assessed not only for efficacy but also for their sustainability, cost, and environmental impacts. Parallel efforts in selective breeding programs should focus on identifying and propagating honey bee strains with natural resistance or tolerance to *Tropilaelaps* infestation, including behavioral, physiological, or immunological traits that limit mite reproduction.

Socioeconomic research is equally critical. The direct and indirect costs of *T. mercedesae* spread including colony losses, reduced pollination services, and increased management expenditures are likely substantial but remain poorly quantified. Detailed cost-benefit analyses can guide policymakers and stakeholders in allocating resources effectively and prioritizing preventative measures (Finlayson & Zayed, 2020).

The potential impact of *T. mercedesae* on wild pollinator species is an urgent and largely unexplored area. Spillover effects from managed honey bees to wild pollinators could exacerbate declines in native bee populations, disrupt ecosystem services, and reduce agricultural yields. Long-term ecological studies are needed to assess these risks and develop mitigation strategies. Addressing these research gaps

requires strong global collaboration, sustained and well-coordinated funding, and the integration of molecular, ecological, behavioral, and policy-oriented research. Collaborative networks and data-sharing platforms can facilitate cross-border monitoring, accelerate discovery, and inform harmonized biosecurity measures. Only through a multidisciplinary and proactive approach can the apicultural sector prepare for, and ideally prevent, the potentially devastating consequences of *T. mercedesae* expansion.

Conclusion

T. mercedesae is no longer a regional anomaly but an accelerating global threat to apiculture. Its rapid reproductive cycle, short phoretic phase, and severe disruption of brood development position it as a potentially more destructive parasite than *Varroa destructor*. The recent establishment of stable populations in parts of Europe highlights its expanding geographic reach, driven by global trade, colony movement, and gaps in early-warning systems. Advances in diagnostic tools—such as refined brood decapping methods, improved phoresy detection, and molecular confirmation have expanded scientific understanding of this mite's biology, revealing that current risk assessments may significantly underestimate its invasion potential. Yet, effective management options remain limited, fragmented, and insufficiently validated. To prevent repeating the costly lessons of *Varroa*'s global spread, urgent and coordinated action is essential. At the policy level, harmonized international surveillance protocols, strengthened biosecurity standards, and clear regional contingency plans must be prioritized. Governments should invest in developing novel miticides, RNAi-based tools, brood-targeted technologies, and mite-resistant bee lineages. Equally important is supporting beekeepers through incentives and extension

programs that promote adoption of integrated pest management practices. Cooperative international networks and open data-sharing platforms must be expanded to ensure timely information flow and synchronized responses across borders.

Future research should deepen understanding of reproductive biology, host-parasite interactions, climate-driven spread potential, and diagnostic innovations, alongside long-term studies quantifying ecological and economic impacts. Protecting global apiculture now depends on immediate, unified, and science-driven policies that address *T. mercedesae* before its spread becomes irreversible.

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GENERAL ARTICLE**Seasonal Migration Patterns and Practices of Litchi Beekeepers in Bihar**

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Abstract

Bihar's litchi belt around Muzaffarpur, Samastipur, Sitamarhi, Vaishali, and Darbhanga supports one of eastern India's most organised migratory beekeeping systems. This article summarises migration routes, forage calendars, and practices used by commercial beekeepers who follow sequential blooms to sustain colonies and income reliably year-round. The cycle starts mid-March to early April in litchi (*Litchi chinensis* Sonn.) orchards for pollination and monofloral honey. Apiaries then shift among short in-state floral flows within Bihar after litchi to maintain brood and nutrition. During the monsoon dearth (June–October), colonies move to Uttar Pradesh and Rajasthan, sometimes northwestern Madhya Pradesh, to use sesame, millet, pigeon pea, ber, and ajwain. Rabi (November–February) provides the main secondary bee flora from mustard/rapeseed, with onion, coriander, and grass pea as support. Phenology-aligned logistics, pre-bloom equalisation, timely supering, judicious pesticide application, microclimate management, and pest management in bee hives underpin performance. Migration boosts honey yield, pollination returns, and colony demographics, while adaptive scheduling and integrated management address climate, invasive pest, and transport challenges.

Key words: Migratory beekeeping, bee flora, commercial beekeepers, honey yields and pollination

Introduction

Bihar's litchi belt (Muzaffarpur, Samastipur, Sitamarhi, Vaishali, and Darbhanga districts) attracts hundreds of migratory beekeepers each spring. Bee colonies arrive before the litchi bloom, build up on early nectar and pollen, and provide the cross-pollination that sets the crop (Samal et al., 2025). Once litchi flowering finishes by early April, beekeepers shift their hives through a predictable sequence of floral resources within Bihar and into neighboring states. The goal is simple: keep colonies on forage nearly year-round so they stay strong, productive, and ready to return to litchi the

next season. Here we outline this seasonal pattern – including the timing, routes, and management practices – based on regional crop calendars and beekeeping guidelines.

Spring Anchor: Litchi Bloom in Bihar (Mid-March to Early April)

Bee hives are placed within and along the edge of an orchard to pollinate the crop (Bihar, India). Litchi flowers are available roughly from mid-March to early April in Bihar's prime litchi belt (Cronje et al., 2023). This is the first major nectar flow of the year and a critical pollination period for the region's famous litchi belt (Ghosh et al., 2024).

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receive enough bee visits; studies report that honey bee pollination can raise fruit yield by about 25–30%. Therefore, orchard owners and beekeepers coordinate hive placement (typically around 3–5 colonies per hectare) and agree to avoid pesticide sprays during the bloom period (Kumar, 2012; Hossen et al., 2024). For example, it is standard practice to avoid spraying any insecticides while trees are in bloom. These measures protect the bees and maximize pollination.

Why it matters?

The litchi flow is the first big nectar source of the year and the economic anchor that often funds subsequent migratory moves. Colonies typically leave litchi bloom with abundant honey stores and expanded brood nests. This strong buildup helps them endure any forage gaps in late April. Beekeepers also harvest a premium monofloral litchi honey crop at this time, usually extracting the honey right after the bloom ends, before moving the colonies. It is important to extract litchi supers immediately and separately, to preserve the distinctive light, floral litchi honey character for the market. Once litchi flowering finishes (usually by the first week of April), the migratory journey continues.

Immediate Options of Post-Litchi Forage in Bihar (April–June)

After litchi, beekeepers disperse their colonies to a series of shorter, staggered bloom periods within Bihar. These minor flows from April through July keep the bees busy and fed, though each may last only a few weeks (Table 1). Post-litchi forage within Bihar is supported by a sequence of short, overlapping blooms that maintain colony nutrition and brood rearing. Jamun flowers mainly in May–June around Darbhanga and Muzaffarpur and provides a moderate nectar flow, yielding about

Table 1. Annual Migratory Calendar at a Glance (Information collected from local beekeepers of Bihar).

Month	Primary sources	Backup/Bridge
January	Mustard (<i>Brassica juncea</i> (L.) Czern.), Coriander (<i>Coriandrum sativum</i> L.), Grass pea (<i>Lathyrus sativus</i> L.), Berseem (<i>Trifolium alexandrinum</i> L.), Pigeon pea (<i>Cajanus cajan</i> (L.) Millsp.), Black nightshade (<i>Solanum nigrum</i> L.)	Citrus spp., Wild basil (<i>Ocimum gratissimum</i> L.)
February	Mustard, Coriander, Tisi/Flax (<i>Linum usitatissimum</i> L.), Semal (<i>Bombax ceiba</i> L.), Kusum (<i>Schleichera oleosa</i> (Lour.) Oken), Kerwa/Kewda (<i>Pandanus odorifer</i> (Forssk.) Kuntze), Broad bean (<i>Vicia faba</i> L.), Black nightshade, Rosewood/Shisham (<i>Dalbergia sissoo</i> Roxb.)	Fennel (<i>Foeniculum vulgare</i> Mill.), Jira/Cumin (<i>Cuminum cyminum</i> L.), Snake gourd (<i>Trichosanthes cucumerina</i> L.), Bottle gourd (<i>Lagenaria siceraria</i> (Molina) Standl.), Early berseem, Chilli (<i>Capsicum annum</i> L.), Karonda (<i>Carissa carandas</i> L.)
March	Watermelon (<i>Citrullus lanatus</i> (Thunb.) Matsum. & Nakai), Litchi (<i>Litchi chinensis</i> Sonn.), Citrus sp., Maize (<i>Zea mays</i> L.), Late semal, Fennel, Drumstick (<i>Moringa oleifera</i> Lam.), Ajwain (<i>Trachyspermum ammi</i> (L.) Sprague), Khira/Cucumber (<i>Cucumis sativus</i> L.), Karela/Bitter gourd (<i>Momordica charantia</i> L.), Nenua/Sponge gourd (<i>Luffa cylindrica</i> (L.) M.Roem.), Pointed gourd	Banana (<i>Musa spp.</i>), Onion (<i>Allium cepa</i> L.), Rosewood/Shisham, Citrus sp.
April	Jamun (<i>Syzygium cumini</i> (L.) Skeels), Sunflower (<i>Helianthus annuus</i> L.), Laal ghass (<i>Euphorbia macrophylla</i> Hook. & Arn.), Mung (<i>Vigna radiata</i> (L.) R.Wilczek), Till/Sesame (<i>Sesamum indicum</i> L.), Chilli (<i>C. annum</i> L.), Muskmelon (<i>Cucumis melo</i> L.), Snake melon (<i>C. melo</i> var. <i>flexuosus</i> (L.) Naudin), Khira/Cucumber, Karanj (<i>Pongamia pinnata</i>)	Mahua (<i>Madhuca longifolia</i> (J.Koenig ex L.) J.F.Macbr.), Teak (<i>Tectona grandis</i> L.f.), Neem (<i>Azadirachta indica</i> A.Juss.), Banana (<i>Musa spp.</i>), Palmyra palm (<i>Borassus flabellifer</i> L.)
May	Jamun, Sunflower, Laal ghass, Mung, Till/, Banana, Chilli, Muskmelon, Snake melon	Teak, Pointed gourd, Banana
June	Sunflower, Chilli, Cucumber, Bitter gourd, Early urad/Black gram (<i>Vigna mungo</i> (L.) Hepper), Maize	Banana
July	Chilli, Khira/Cucumber, Bitter gourd, Maize, Brinjal, Pearl millet (<i>Pennisetum glaucum</i> (L.) R.Br.), Okra (<i>Abelmoschus esculentus</i> (L.) Moench), Sponge gourd, Pointed gourd	Banana, Motha (<i>Cyperus rotundus</i> L.)
August	Maize, Chilli, Sponge gourd, Bitter gourd, Buckwheat (<i>Fagopyrum esculentum</i> Moench)	Banana, Gumma (<i>Leucas cephalotes</i> (Roth) Spreng.)
September	Jamun, Dhaicha (<i>Sesbania bispinosa</i> (Jacq.) W.F.Wight), Cucumber, Chilli, Sponge gourd, Pearl millet/Bajra, Brinjal/Eggplant, Bitter gourd	Bhringraj (<i>Eclipta prostrata</i> (L.) L.)
October	Pigeon pea, Chilli, Brinjal/Eggplant, Karela/Bitter gourd, Gumma	Banana
November	Mustard, Karela/Bitter gourd, Chilli, Brinjal/Eggplant	Banana, Tomato, Laheri grass/Khesari
December	Mustard, <i>Eucalyptus</i> spp.	—

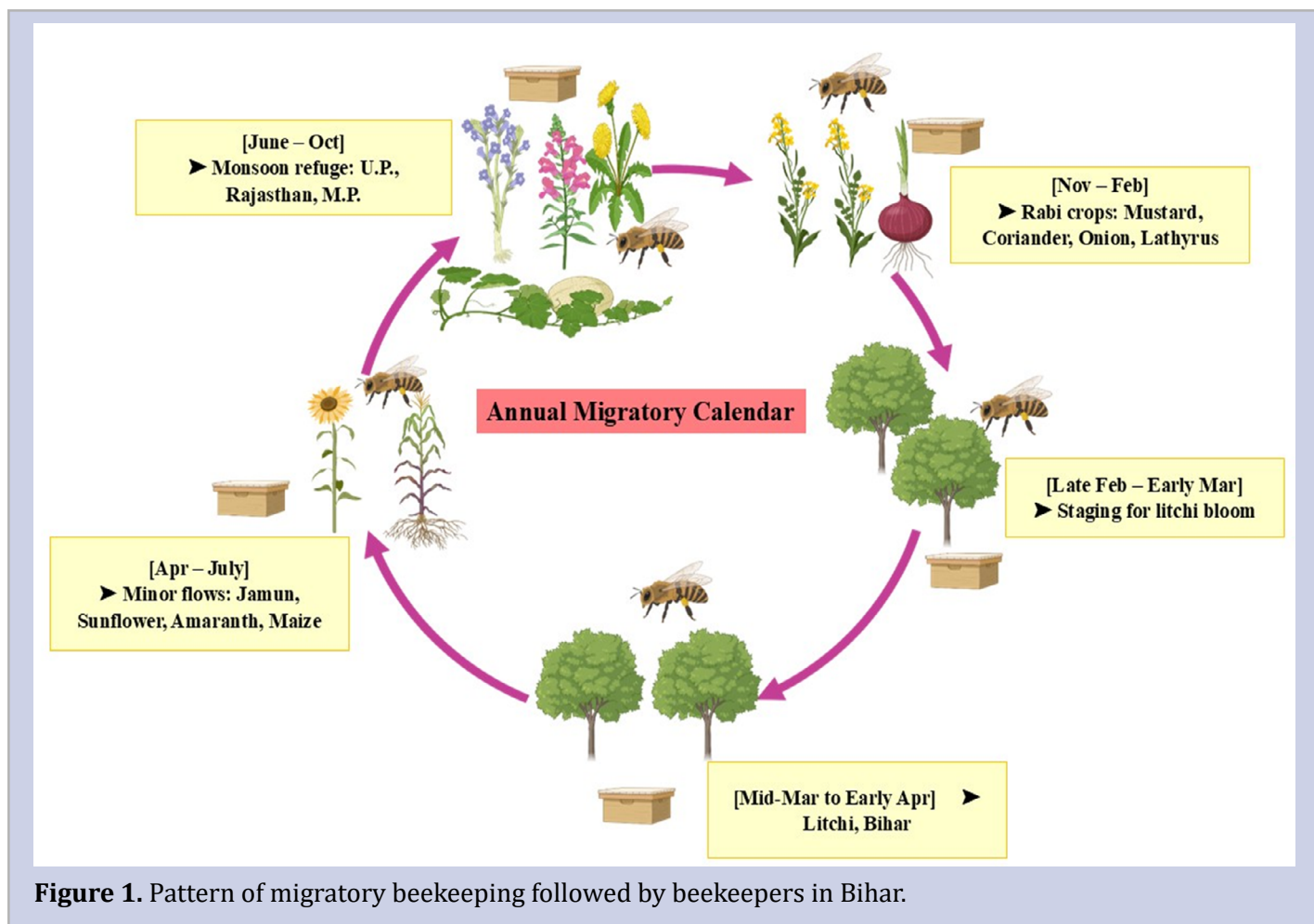


Figure 1. Pattern of migratory beekeeping followed by beekeepers in Bihar.

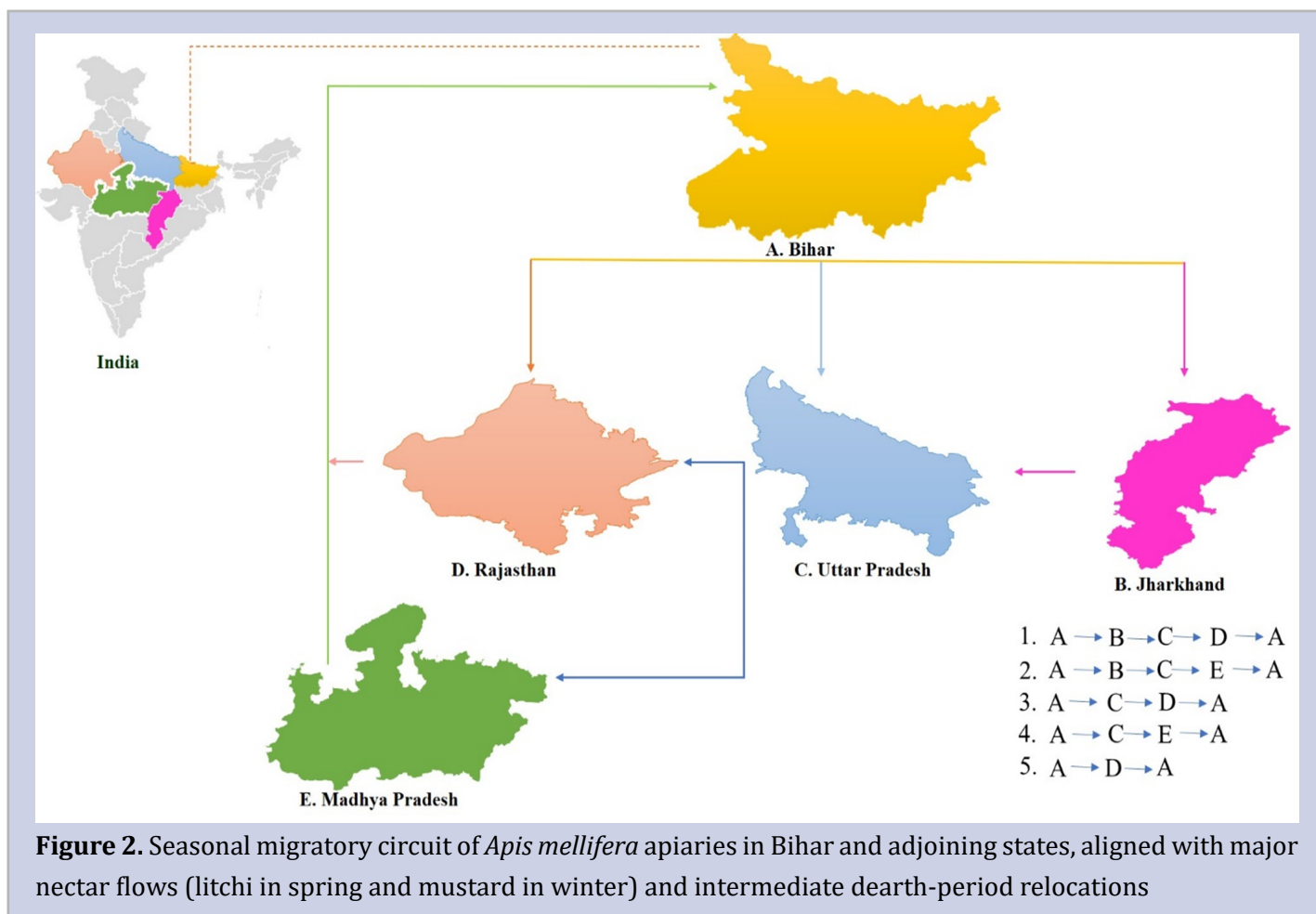
10–15 kg honey per colony in favourable years, so a portion of apiaries is commonly staged near jamun groves. Lal ghash (*Euphorbia macrophylla*) flowers during May–June and serves primarily as a pollen (and minor nectar) source under summer scarcity, aiding colony maintenance (Figure 1 and Figure 2). Sunflower is a stronger summer nectar and pollen resource, blooming from mid-May to early July in northeastern districts such as Purnea, and can produce a distinct honey crop, though heat-management (shade, water provisioning) is required during hot spells. With monsoon onset, maize tassels from early July to late August across central Bihar; it contributes protein-rich pollen but negligible nectar, supporting brood buildup rather than surplus honey, with foraging often constrained by heavy rains. To maintain uninterrupted forage, beekeepers often divide their colonies into two or

more mobile groups and move them in a staggered manner between these short flows, ensuring that some hives are always positioned where nectar or pollen is available.

Jharkhand (Mid-April – late May): After the litchi season, many beekeepers migrate from Bihar to Gumla, Garhwa districts of western Jharkhand during April to May, when Karanj flowers blossom, attracting a larger number of honey bees. During the early-summer flows, many beekeepers migrate to Uttar Pradesh.

Monsoon and Early Kharif: Out-of-State Circuits (June–October)

By June, as the monsoon rains arrive in Bihar, many commercial beekeepers start migrating westward out of the state. This is done to avoid the prolonged heavy rains and dearth of blooms



in Bihar’s mid-monsoon period (late June through August). Neighbouring states often have more varied or earlier flowering during this season. Two common circuits are:

Uttar Pradesh (June–October): After litchi and early-summer flows, many Bihar beekeepers migrate to western/central Uttar Pradesh (e.g., Kasganj, Etawah, Badaun, Kanpur, Aligarh–Hathras–Firozabad belt). Monsoon crops such as pearl millet/bajra, pigeon pea, sesame, maize, and riverbed cucurbits provide staggered flowering from late July through September (Srivastava and Gautam, 1999; Dash et al., 2024; Tanwar et al., 2025). Individually, these are minor flows, but together they supply steady nectar and pollen, allowing colonies to maintain brood and survive the rainy-season dearth; honey harvest here is usually negligible, and colony maintenance is the

priority (Figure 2).

Rajasthan (July–November): Some operators move further west into relatively drier eastern/northern Rajasthan (Bharatpur, Alwar, Hindaun, Gangapur and adjoining arid zones). Early kharif blooms of sesame and bajra can support colonies in July–August, followed by high-value autumn flows, notably ber in September–October and ajwain around October, with additional contribution from wild *Ocimum* sp. (Singh and Vats, 2006; Bal, 2014). Routes are chosen based on transport logistics and honey-market goals; some beekeepers target single monofloral crops, while others shift more frequently to ensure continuous forage (Figure 2).

Madhya Pradesh (October–early November): Before returning to Bihar for rabi blooms, some beekeepers make a short stop in

northwestern Madhya Pradesh (e.g., Shivpuri–Gwalior), where late ajwain and wild basil overlap in October and can yield small ajwain/tulsi honey while rebuilding brood. This final monsoon-circuit stop helps restore colony strength ahead of winter mustard flows, so colonies return by mid-October to early November in good condition for the main rabi honey season (Meena et al., 2017; Rawat and Kumar, 2024).

Rabi Season: Mustard and Companion Crops (November to February)

Winter rabi crops (sown October–November and flowering in winter) provide the most dependable honey flows after litchi and deliver the year’s largest harvest for many migratory beekeepers. Mustard/rapeseed forms the backbone of this season, blooming for about 6–8 weeks from mid-November in Rajasthan and parts of Madhya Pradesh and later from late December to February in Bihar. Bihar-based operators often exploit early western mustard belts first, then return to Bihar districts with extensive mustard acreage for the peak flow. Under good conditions, rapeseed can yield roughly 25–40 kg of honey per colony, so colonies are strengthened in advance through requeening or combining weak units, timely supering to prevent swarming, and basic cold-season hive management during foggy weather; Brassica remains highly attractive even in winter. Smaller rabi blooms extend forage and diversify products, including onion seed crops in Rajasthan/M.P. during December, and Bihar’s late-winter coriander and grass pea during January–February, which provide a short nectar/pollen bridge as mustard tapers. Colonies typically peak in population during mustard, enabling sequential harvests (mustard in January followed by a brief coriander crop in February) before the spring cycle restarts.

Pre-Season Staging and Return to Litchi (Late February to Early March)

By late February, the migratory loop is coming full circle. Beekeepers begin consolidating their apiaries back toward the litchi-growing belt of Bihar to get ready for the new cycle. This pre-spring staging period (last week of February into the first week of March) is used for equipment maintenance and colony health checks after the long travels. Common activities include: cleaning or replacing old dark brood combs with fresh foundation, repairing hive boxes and stands, and treating colonies for any pests or diseases (Jones et al., 2024) (e.g. a prophylactic treatment for *Varroa mites* or *Nosema*, if needed) now, so that no chemical treatments will be necessary during the upcoming litchi bloom. By early March, the goal is to have every colony with a large amount of sealed and emerging brood and a young, vigorous queen, so that when litchi flowers (around March 10th onward), the hives explode with foragers. Many beekeepers try to time their brood cycles such that the peak of new forager emergence coincides with the litchi flowering peak – this way, the maximum number of worker bees is available to collect litchi nectar and pollen (Kumari et al., 2024). Achieving this timing can be tricky, but it’s a hallmark of the most experienced migratory operations. Just 7–10 days before the first litchi blossoms open, truckloads of bee boxes once again pull into the orchards of Muzaffarpur and beyond. The annual journey comes full circle, and the cycle repeats with the spring honey flow that started it all.

Migratory Beekeeping in Bihar: An Academic Recasting

In Bihar, the litchi bloom constitutes the principal early-season resource that sets the performance trajectory for migratory beekeeping

enterprises. Colonies that attain high strength during the March litchi flow typically generate substantial honey yields, thereby enhancing subsequent productivity. Average honey yield during this flow was estimated at 15–20 kg per colony, contributing roughly 30–40% of annual production. Building on this foundation, leading operators organise a year-round migratory circuit aligned with regional bee flora phenology: they capitalise on minor summer nectar flows within Bihar, relocate westward through the monsoon to sustain foraging activity and brood turnover, and exploit the major winter mustard (*Brassica* sp.) bloom before returning to home bases. Across migratory systems in India, total annual yields are often around 50–60 kg per colony obtained through 4–5 harvests, and operators typically move about a minimum of 300 colonies per seasonal shift, completing 3–5 migratory stops per year. Each relocation is synchronised with flowering calendars, while inter-flow intervals are used for timely supering, brood and queen management, and proactive control of *Aethina tumida* and other colony pests. Beehive operators reported honey sales of approximately Rs 100–130 per kg during the litchi season, implying a seasonal gross income of about Rs 13,000 per operator for an operation of 100 colonies. Net returns from migratory beekeeping in our sample were approximately Rs 5,200–6,500 per colony per year. Further, migratory operations can generate net profits of about Rs 2,900 per colony annually, several-fold higher than those typically achieved under stationary beekeeping systems.

The practice of “following the blooms” is associated with substantial gains in honey yield and pollination-related income, aligning with broader agricultural monitoring trends. Bihar, which typically provides three to four distinct honey flows

annually, functions both as a key source region for major blooms (notably litchi and mustard) and as a recipient of migratory pollination services that enhance crop set and yields. However, increasing interannual climatic variability and invasive or resurgent pests are driving adaptive management, including temporal shifts in migration schedules in response to rainfall anomalies and the adoption of pest-control measures compatible with mobile operations. Overall, migratory beekeeping in Bihar sustains colony health and productivity through improved colony–crop synchrony at spring onset, thereby supporting regional agroecosystem resilience. Beyond its livelihood role, the practice contributes to India’s evolving pollination-service framework by stabilizing orchard and vegetable production, while also serving as an adaptation pathway to market pressures and changing flowering calendars.

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GENERAL ARTICLE

The Fascinating Mating Swarms of Dance Flies (Diptera: Empididae: Empidinae)

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Abstract

Dance flies (Diptera: Empididae: Empidinae: *Hilara*, *Empis* and *Rhamphomyia*) exhibit some of the most striking reversals of conventional sex roles among insects. Their mating systems are characterized by swarm-based courtship, obligatory nuptial gifts and frequent female ornamentation. Empirical, ecological and phylogenetic studies demonstrate that female-specific ornaments function as sexual signals in male mate choice and have evolved repeatedly under conditions of female-biased operational sex ratios. While ornamentation enhances mating success, it incurs survival costs, highlighting trade-offs between sexual and natural selection. Male counter-strategies, including deceptive nuptial gifts, further reveal intense sexual conflict. Together, these dynamics make Empidinae an exceptional model for studying sexual selection and mating system evolution.

Keywords: Dance flies, Empidinae, female ornamentation, nuptial gifts, sexual selection

Introduction

The dance flies (sometimes called balloon flies or dagger flies) from the subfamily Empidinae (Diptera: Empididae) is divided into three genera, *Hilara*, *Empis* and *Rhamphomyia* consisting of approximately 1,450 described species worldwide. Empidinae are known for their unusual mating behaviour where individuals aggregate in mating swarms with the exception of a few species and where the males approach the females from below. The male presents the female with a nuptial gift, often in the form of prey, sometimes wrapped in silk. In many Empidinae species, adult females rely almost entirely on nuptial gifts as their primary source of protein. Males actively hunt

prey items to present during courtship and this foraging behavior is thought to expose them to greater mortality risk compared with the relatively sedentary females. Approximately, 28 per cent of species within the genera *Rhamphomyia* and *Empis*, females display conspicuous secondary sexual traits. These female-specific ornaments include inflatable abdomens, pinnate (feather-like) scales on the legs and enlarged or darkened wings. Such traits believed to be a signalling mechanism to attract mates, either for their gametes or to obtain more prey from males to provide for ovarian maturation since mating behaviour is repeated by both sexes (Myllyaho, 2022).



Figure 1. (Left) Balloon fly (*Hilara* sp.) showing typical slender body and elongated legs (Source: <https://savemountdiablo.org/blog/7-new-species-of-dance-flies-discovered-in-the-diablo-range/>) and (Right) Dagger fly (*Empis* sp.), a predatory empidid with elongated proboscis and agile flight typical of dance flies (Source: [https://commons.wikimedia.org/w/index\).arch=dagger+flies&title=Special%3AMediaSearch&type=image](https://commons.wikimedia.org/w/index).arch=dagger+flies&title=Special%3AMediaSearch&type=image)).

Female ornaments as signals in male mate choice

Empirical research has provided strong support for the role of these ornaments as signals used by males during mate choice. Funk and Tallamy (2000) confirmed the male preference for enlarged abdomen females by using plastic models of varying sizes (Figure 2 & 3). Given choice for four sizes, male approached the largest of the model more significantly. Also, a simple regression of female's abdominal area against egg length in lekking sites of *Rhamphomyia sociabilis* (Williston) revealed a highly significant relationship. They also studied the exaggerated sexual traits of *R. longicauda* Loew, which provided misleading sexual signals to males. Females had bizarre abdominal extensions that might deceive males indicating the incorrect size and particularly, the maturity status of their eggs.

While elaborate ornaments can improve mating success, they also impose fitness costs. Gwynne and Bussière (2002) demonstrated that ornamented females of *R. longicauda* experienced

higher rates of predation, particularly from web-building spiders. The increased body size, altered flight dynamics and conspicuous appearance of ornamented females likely make them more vulnerable to capture by the predators and make females less capable of escaping from webs. These findings illustrate the classic evolutionary trade-off between sexual and natural selection, sexual selection favours exaggerated traits, while natural selection - penalises traits that reduce survival.

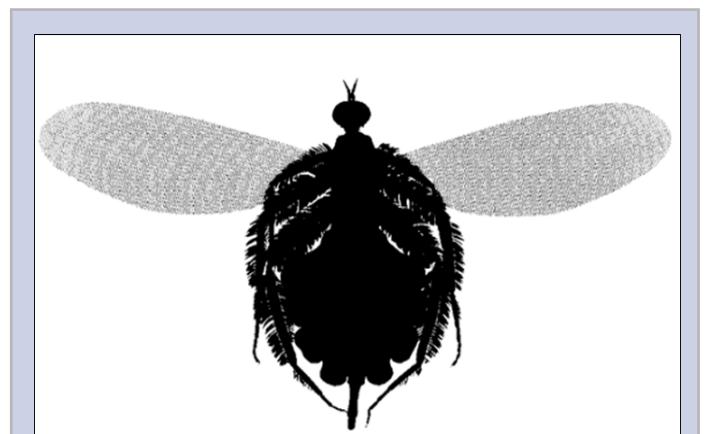


Figure 2. Black and white composite print used as an artificial model of an inflated *R. longicauda* female for quantifying the effect of female size on male preference (Source: Funk and Tallamy, 2000).

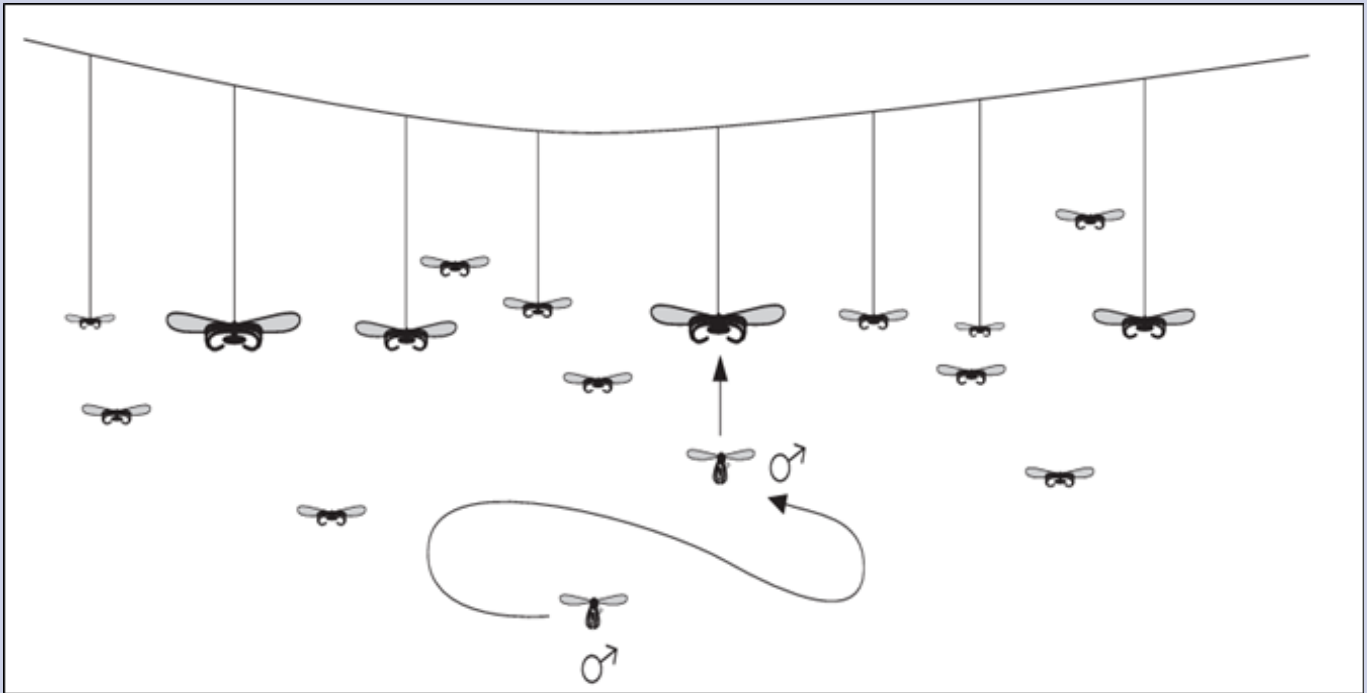


Figure 3. The pattern in which various-sized models of inflated *R. longicauda* females were suspended from monofilament line among actual lekking females to quantify the effect of female size on male preference (Source: Funk and Tallamy, 2000).

Phylogenetic origins of female ornamentation

The evolutionary origins of female ornamentation in dance flies have been explored using molecular phylogenetic approaches. Murray *et al.* (2020) analysed *cad* gene sequences across 22 Empidinae species and demonstrated that female-specific ornaments evolved multiple times independently from unornamented ancestors. Their results revealed a strong association between mating system structure and ornament evolution; species with strongly female-biased operational sex ratios in mating swarms exhibited more pronounced female ornamentation. This pattern supports the idea that intense competition among females for access to males drives the evolution of exaggerated female traits.

Reproductive Dependence on Nuptial Gifts

The degree to which females depend on nuptial gifts varies considerably among dance fly species. Hunter and Bussière (2019) showed that in

ornamented species, egg development was strictly dependent on successful mating and the receipt of nuptial gifts. Unmated females in these species failed to develop mature eggs, underscoring the central role of male-provided resources

in female reproduction. In contrast, unornamented species exhibited weaker (facultative) dependence on mating for egg development, suggesting that reliance on nuptial gifts has evolved in tandem with female ornamentation and sex role reversal.

Male Strategies and Sexual Conflict

Males are active participants in the sexual selection process, as selection acts on their ability to obtain, produce and present nuptial gifts, thereby influencing both male behaviour and morphological traits associated with prey capture and mating success (Murray *et al.*, 2022). LeBas *et al.* (2004) showed that in *R. sulcata*, smaller males carrying smaller gifts achieved higher mating success than larger males with more substantial

offerings. This counterintuitive result suggests that constraints related to flight performance and manoeuvrability can outweigh the benefits of large gifts, favouring efficiency over extravagance.

In addition, males in some Empidinae species have evolved deceptive strategies of their own. Rather than providing nutritious prey, some males present inanimate or low-quality items such as empty prey husks, plant seeds or silk-wrapped debris. Others exaggerate the apparent size of gifts using silk balloons or enlarged tarsal segments that mimic prey items. These forms of male deception, documented by Daugeron *et al.* (2011), further illustrate the ongoing sexual conflict over reproductive investment, with each sex evolving strategies to maximise its own fitness.

Conclusion

Taken together, these studies reveal a highly dynamic mating system in which males and females are locked in a continual evolutionary arms race. Nuptial gifts, female ornamentation, male choice and deceptive signalling all interact to shape reproductive outcomes. Rather than following a fixed pattern, the direction and intensity of sexual selection in dance flies can shift depending on ecological conditions, population structure and the relative costs and benefits of reproduction for each sex.

Because of their remarkable diversity of mating strategies and their frequent departures from conventional sex roles, Empidinae dance flies have emerged as valuable model organisms for studying the evolution of mating systems, sexual selection and sexual conflict. However, progress in this field has been constrained by practical challenges. Dance flies often fail to exhibit natural behaviours under laboratory conditions

and their mating swarms are fast-moving, short-lived and difficult to observe in the field. Despite these obstacles, continued research on dance flies promises to yield important insights into how complex reproductive behaviours evolve and persist. Ultimately, the courtship behaviour of dance flies serves as a powerful reminder that the rules of reproduction are far from universal. By reversing traditional sex roles and embracing both honesty and deception in sexual signalling, these small insects challenge long-held assumptions about mating systems and underscore the creative force of evolution in shaping life's diversity.

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GENERAL ARTICLE

Seasonal Dormancy and Developmental Plasticity in Parasitoid Wasps: Ecological Drivers and Molecular Mechanisms

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Abstract

Parasitoid wasps are keystone regulators of insect populations and cornerstone agents of sustainable biological control. Beyond the classical concept of diapause, parasitoids display a continuum of seasonal dormancy and developmental plasticity strategies that enable precise synchronization with host phenology and fluctuating environmental conditions. Recent research has revealed that dormancy in parasitoids is shaped by interacting ecological, evolutionary, physiological, and molecular processes, involving metabolic reprogramming, endocrine signaling, circadian regulation, and epigenetic modulation. These processes govern the induction, maintenance, and termination of dormant states, with important consequences for survival, reproduction, and post-dormancy performance. Dormancy also plays a critical role in determining parasitoid resilience to climate variability, influencing host-parasitoid synchrony, population stability, and the reliability of biological control services. Advances in genomics, transcriptomics, metabolomics, and functional genetics are providing new insights into the regulatory architecture of dormancy and revealing practical opportunities for improving mass rearing, shelf life, and field efficacy of parasitoid. Together, these developments underscore the central importance of developmental plasticity in parasitoid ecology and highlight its growing relevance for sustainable pest management under global environmental change.

Keywords: Biological control, Climate adaptation, Developmental plasticity, Diapause, Parasitoid wasps, Seasonal dormancy

Introduction

Parasitoid Hymenoptera constitute one of the most diverse and ecologically influential guilds of insects, with more than 600,000 estimated species worldwide (Quicke, 2015). By regulating herbivore populations and mediating trophic cascades, parasitoids contribute substantially to ecosystem stability and agricultural productivity

(Doutt, 1959; Desneux et al., 2010). A defining life-history feature underpinning their ecological success is seasonal dormancy, classically termed diapause, which allows individuals to survive periods of adverse environmental conditions and host scarcity (Košťál, 2006; Denlinger, 2002).

Historically, diapause has been viewed as a discrete developmental arrest induced by photoperiod and temperature cues (Saunders, 2013; Denlinger, 2023). However, accumulating evidence suggests that parasitoids display a continuum of dormancy phenotypes encompassing quiescence, oligopause, reproductive arrest, and facultative diapause, each regulated by overlapping but distinct ecological and molecular mechanisms (Hahn and Denlinger, 2011; Tougéron et al., 2020). This plasticity enables fine-tuned synchronization with host phenology and fluctuating climates, particularly in temperate and subtropical agroecosystems (Ragland et al., 2019).

Despite extensive literature on insect diapause, parasitoids remain underrepresented in mechanistic syntheses, largely due to their small body size, trophic complexity, and strong host dependence (Brodeur and McNeil, 1989; Evans, 2021). Moreover, applied entomology increasingly demands dormancy-based solutions for extending shelf life, synchronizing field releases, and enhancing the resilience of mass-reared biocontrol agents (Zang et al., 2021; Wang et al., 2024).

This article departs from traditional diapause-centric perspectives by emphasizing developmental plasticity, systems-level regulation, and translational relevance. We integrate ecological drivers, physiological remodeling, molecular control networks, and emerging technologies to propose a unified framework for understanding and harnessing parasitoid dormancy in a rapidly changing world.

Diversity of Dormancy Phenotypes in Parasitoids

Facultative versus Obligatory Dormancy

Parasitoid species exhibit both obligate dormancy, which occurs regardless

of environmental conditions, and facultative dormancy, which is induced by external cues such as photoperiod, temperature, and host availability (Košťál, 2006; Christiansen-Weniger and Hardie, 1999). Obligatory dormancy is typical of univoltine species inhabiting highly seasonal environments, whereas facultative dormancy predominates in multivoltine taxa such as *Trichogramma*, *Aphidius*, and *Cotesia* (Hance et al., 2007).

Geographic variation in dormancy strategies reflects local climatic adaptation. For example, northern populations of *Cotesia glomerata* exhibit longer critical photoperiods and higher diapause incidence than southern conspecifics (Silveira et al., 2019). Similar latitudinal clines have been documented in *Trichogramma dendrolimi* and *Aphidius ervi*, underscoring the evolutionary plasticity of dormancy thresholds (Zhang et al., 2017; Christiansen-Weniger and Hardie, 1999).

In tropical agroecosystems, dormancy in parasitoids helps maintain effective biological control. For example, *Trichogramma chilonis*, widely used in India against pests such as *Helicoverpa armigera*, shows temperature- and photoperiod-mediated diapause that aids survival and synchronization with host populations. Similarly, *Campoletis chloridae*, a larval parasitoid of *Helicoverpa armigera*, exhibits seasonal developmental variation influenced by temperature and host availability, supporting its persistence in Indian cropping systems (Bandara et al., 2021).

Life-Stage Specificity

Dormancy may occur at embryonic, larval, pupal, or adult stages, with marked taxonomic patterns. Egg and larval diapause are common in braconids and ichneumonids, whereas pupal diapause predominates in Trichogrammatidae and Encyrtidae (Denlinger, 2002; Zang et al., 2021). Adult reproductive diapause, characterized by

Table 1. Types of dormancies in parasitoid wasps and their practical importance

Type of Dormancy	Definition	Environmental Triggers	Occurrence in Life Stage	Practical Importance in Biological Control
Diapause	A hormonally regulated, genetically programmed developmental arrest that occurs at a specific life stage.	Photoperiod, temperature, host availability, seasonal changes	Egg, larva, pupa, or adult	Helps parasitoids survive unfavorable seasons; useful for mass rearing, long-term storage, and synchronization with host pests.
Quiescence	Immediate and reversible developmental arrest caused directly by unfavorable environmental conditions.	Sudden temperature drops, drought, lack of food	Any developmental stage	Allows short-term survival during temporary stress; important for field persistence.
Aestivation	Summer dormancy that occurs during hot and dry conditions.	High temperature, drought	Usually larval or pupal stage	Enables parasitoids to survive extreme summer conditions in tropical and subtropical regions.
Hibernation	Winter dormancy characterized by reduced metabolic activity.	Low temperature, short photoperiod	Often pupal or adult stage	Ensures overwintering survival and early-season pest suppression when favorable conditions return.
Facultative Diapause	Dormancy expressed only when specific environmental cues are present.	Photoperiod, host quality, temperature	Usually larval or pupal stage	Provides developmental flexibility allowing parasitoids to adapt to variable environments.
Obligate Diapause	Dormancy that occurs in every generation regardless of environmental conditions.	Genetically programmed	Usually, a fixed life stage	Ensures survival in highly seasonal environments but may limit flexibility in biological control programs.

ovarian arrest and suppressed vitellogenesis, is widespread among aphid parasitoids such as *Aphidius gifuensis* and *Praon volucre* (Table.1) (Polgár et al., 1991; Colinet and Hance, 2010).

Stage-specific dormancy reflects adaptive trade-offs between survival, development time, and post-dormancy performance. For instance, pupal diapause in *Trichogramma* extends shelf life for mass-rearing but may reduce fecundity if excessively prolonged (Pizzol and Pintureau, 2008;

Wang et al., 2011).

Continuum of Metabolic Suppression

Rather than a binary on-off state, dormancy involves graded metabolic depression (Hahn and Denlinger, 2011). Respirometric and calorimetric studies reveal progressive reductions in oxygen consumption and ATP turnover, with interspecific variation reflecting ecological niche and overwintering strategy (Košťál et al., 2017). This metabolic continuum underpins the concept

of developmental plasticity, whereby parasitoids dynamically adjust energy budgets in response to environmental and trophic constraints (Hance et al., 2007).

Ecological and Evolutionary Drivers

Host Phenology and Trophic Synchrony

Parasitoid dormancy is intricately coupled to host availability and developmental rhythms, reflecting coevolutionary fine-tuning (Brodeur and McNeil, 1989; Van Nouhuys and Punju, 2010). Host decline or absence triggers dormancy entry, as observed in *Tetrastichus julis* parasitizing *Oulema melanopus* (Evans, 2021). Conversely, diapause termination is often synchronized with host emergence to maximize reproductive success (Carton and Claret, 1982).

Host species identity, morph, and developmental stage significantly influence dormancy induction. In *Pauesia unilachni*, diapause propensity depends on aphid host morph and endocrine state (Polgár and Hardie, 2000). Such host-mediated effects highlight the trophic complexity of dormancy regulation in parasitoids (Hance et al., 2007).

Climatic Cues and Geographic Variation

Photoperiod and temperature are primary environmental cues regulating dormancy induction, maintenance, and termination (Saunders, 2013; Hance et al., 2007). The concept of a critical photoperiod, defined as the day length inducing dormancy in 50 % of individuals, varies widely among species and populations. In parasitoid, *Nasonia vitripennis* shows diapause induction under short-day conditions, with a critical photoperiod of about 14–15 hours of light at moderate temperatures. Similarly, populations of the egg parasitoid *Trichogramma brassicae* exhibit

geographic variation in critical photoperiod, where northern populations require longer day lengths to prevent diapause compared to populations from lower latitudes. These variations reflect local adaptation to seasonal environmental conditions and host availability. (Jackson, 1963).

Temperature modifies photoperiodic responses and independently influences diapause. Low temperatures induce diapause in *Cotesia glomerata* and maintain dormancy in *Trichogramma cacoeciae* (Ishii et al., 2000; Pizzol and Pintureau, 2008). Geographic variation in these thresholds reflects local adaptation to climatic regimes (Ragland et al., 2019).

Maternal and Transgenerational Effects

Parental environments shape offspring dormancy propensity via cytoplasmic provisioning, hormonal signaling, and epigenetic inheritance (Mousseau and Fox, 1998; Bell and Hellmann, 2019). In *Aphidius nigripes*, mothers exposed to short photoperiods produce a higher proportion of diapausing offspring (Polgár et al., 1991). Similar maternal effects occur in *Trichogramma* spp. and *Oobius agrili* (Pizzol and Pintureau, 2008; Petrice et al., 2019). These transgenerational cues enhance population-level synchronization and may buffer parasitoids against stochastic climatic fluctuations.

Physiological Remodeling during Dormancy

Energy Metabolism and Reserve Allocation

Dormant parasitoids undergo profound metabolic reprogramming that prioritizes survival over growth and reproduction. During dormancy, resources are reallocated toward glycogen, trehalose, and lipid reserves, ensuring energetic stability during prolonged periods of host absence and environmental adversity (Hahn and Denlinger,

2011). Glycogen functions as the primary short- to medium-term energy source, supporting basal metabolism during metabolic depression, whereas trehalose plays a dual role as both an energy substrate and a stabilizing agent that protects cellular membranes and proteins against dehydration and temperature stress (Ren et al., 2016).

In *Aphidius gifuensis*, trehalose concentrations increase markedly during diapause and decline rapidly upon diapause termination, reflecting its central role in both stress tolerance and post-dormancy recovery (Li, 2011). This dynamic regulation highlights the reversible nature of carbohydrate metabolism during dormancy. Lipids, particularly triglycerides and fatty acids, serve as long-term energy stores and are mobilized during extended dormancy when carbohydrate reserves become limiting. In *Microplitis mediator*, triglyceride levels are significantly higher in diapausing individuals than in non-diapausing counterparts and decrease progressively following diapause termination, underscoring their importance in sustaining prolonged metabolic arrest (Li et al., 2010).

Together, these shifts in energy allocation reflect a strategic balance between immediate survival and future reproductive potential, with the depth and duration of dormancy shaping post-dormancy performance traits such as longevity and fecundity.

Cryoprotectants and Stress Tolerance

Dormancy in parasitoid wasps is also associated with enhanced tolerance to abiotic stresses such as low temperatures and oxidative stress. The accumulation of polyols, particularly glycerol and sorbitol, lowers the supercooling point of body fluids, reduces ice nucleation,

and stabilizes cellular membranes, thereby protecting tissues from freezing injury (Košťál et al., 2017). Similar physiological responses have been reported in parasitoids. For instance, overwintering pupae of *Nasonia vitripennis* accumulate cryoprotective compounds such as glycerol and trehalose during diapause, which improve cold tolerance and enhance survival under low-temperature conditions. Likewise, diapause-destined individuals of the parasitoid, *Trichogramma brassicae* exhibit increased levels of polyols and sugars that function as cryoprotectants during cold storage and overwintering (Košťál et al., 2017; Denlinger, 2002).

In parallel, antioxidant defense systems are also strengthened during dormancy. Increased activities of enzymes such as catalase and superoxide dismutase help mitigate oxidative damage caused by prolonged metabolic suppression and reoxygenation during diapause termination (Sun, 2018). For example, studies on *Nasonia vitripennis* have shown elevated antioxidant enzyme activity during diapause, which limits the accumulation of reactive oxygen species and protects cellular membranes during long-term developmental arrest. Together, the accumulation of cryoprotectants and the upregulation of antioxidant defenses illustrate the complex physiological remodeling that enables parasitoid wasps to survive extended periods of environmental stress and resource limitation (Denlinger, 2002).

Trade-offs with Post-Dormancy Performance

Dormancy duration influences adult longevity, fecundity, and host-search efficiency, revealing fitness trade-offs critical for biocontrol efficacy (Ellers and Van Alphen, 2002; Colinet and Hance, 2010). Prolonged diapause reduces egg load in *Asobara tabida* and shortens lifespan in

Praon volucre (Ellers and Van Alphen, 2002; Colinet et al., 2010). Conversely, moderate diapause can enhance locomotory activity and parasitism rates in *Trichogramma dendrolimi* (Zhang et al., 2018).

Molecular and Endocrine Control Networks

Circadian and Photoperiodic Clocks

Clock genes such as period (*per*), timeless (*tim*), and cryptochrome (*cry*) play an important role in translating photoperiodic signals into endocrine responses that regulate diapause (Saunders, 2014; Doležel, 2015). Evidence for this mechanism has also been reported in parasitoid wasps. For example, studies on *Nasonia vitripennis* have shown that circadian clock genes, particularly period and timeless, exhibit differential expression under short-day conditions that induce larval diapause. These genes interact with photoreceptors and neuroendocrine signaling pathways to modulate juvenile hormone activity and trigger diapause development.

Similarly, research on the parasitoid *Trichogramma brassicae* indicates that photoperiod-dependent diapause is associated with changes in circadian clock gene expression, linking environmental light cues with hormonal regulation of development. These findings suggest that circadian clock systems function as a molecular bridge between environmental photoperiod and endocrine pathways controlling diapause in parasitoid wasps (Zhang et al., 2018).

Juvenile Hormone and Ecdysteroid Signaling

Juvenile hormone (JH) plays an important regulatory role in diapause of parasitoid wasps by suppressing metamorphic progression and maintaining developmental arrest, while reduced ecdysteroid titers prevent further development (Denlinger et al., 2012). Evidence for this hormonal

control has been reported in several parasitoid species. For example, in *Nasonia vitripennis*, maternal photoperiodic cues influence endocrine signaling in the offspring, where increased JH activity during early larval stages contributes to the induction and maintenance of diapause. Experimental manipulation of JH levels has been shown to affect diapause incidence and developmental timing in this species.

Similarly, in the parasitoid, *Aphidius ervi*, diapause in the prepupal stage is associated with reduced ecdysteroid activity and hormonal regulation linked to juvenile hormone signaling. These hormonal adjustments prevent metamorphic progression until environmental conditions become favorable. Such endocrine mechanisms demonstrate how interactions between JH and ecdysteroids regulate diapause induction and maintenance in parasitoid wasps (Yin and Chippendale, 1976).

Insulin-FOXO and Metabolic Signaling

The insulin signaling pathway integrates nutritional status with dormancy regulation, modulating fat body metabolism and reproductive arrest (Sim and Denlinger, 2008; Hahn and Denlinger, 2011). In *Lysiphlebus testaceipes*, genes associated with carbohydrate metabolism are differentially expressed during diapause (Liu et al., 2020).

Epigenetic and Transcriptomic Regulation

Epigenetic mechanisms, including DNA methylation, histone modifications, and non-coding RNAs, are emerging as regulators of dormancy-associated gene networks (Ragland et al., 2019; Tougéron et al., 2020). Transcriptomic studies in *Aphidius gifuensis* reveal differential expression of insulin and FOXO pathway genes during diapause

(Zhang et al., 2018).

Dormancy under Climate Change

Phenological Mismatches

Rising temperatures, altered precipitation regimes, and increasing climatic variability are disrupting the seasonal cues that regulate dormancy in parasitoids, leading to mismatches between parasitoid life cycles and host availability (Hance et al., 2007; Bandara et al., 2021). Because dormancy induction and termination are closely synchronized with photoperiod and temperature, even modest seasonal shifts can strongly affect host–parasitoid interactions. For example, studies on *Aphidius ervi*, an aphid parasitoid widely used in biological control, show that warmer spring temperatures can accelerate the development of aphid hosts while parasitoids remain in diapause, reducing parasitism efficiency. Similarly, research on *Nasonia vitripennis* demonstrates that temperature-driven changes in diapause timing can alter the synchronization between parasitoid emergence and host availability.

In addition, prolonged warm autumns may delay dormancy induction in parasitoids such as *Trichogramma brassicae*, increasing the risk of mortality due to incomplete diapause preparation. Extreme climatic events, including heatwaves and unseasonal frosts, can further disrupt dormancy regulation and survival during transition phases between active and dormant states. Together, these climate-driven disruptions may reduce parasitism rates and compromise the stability of parasitoid-mediated pest suppression in agricultural ecosystems (Liu et al., 2020).

Plasticity versus Evolutionary Adaptation

Resilience to climate perturbations in parasitoids is shaped by the interaction

between short-term phenotypic plasticity and long-term genetic adaptation (Ragland et al., 2019). Developmental plasticity allows rapid adjustments in dormancy expression in response to environmental cues. For example, populations of *Nasonia vitripennis* show strong plasticity in diapause induction, where maternal photoperiod and temperature influence whether offspring enter larval diapause. Similarly, studies on the aphid parasitoid, *Aphidius ervi* have demonstrated plastic variation in diapause incidence depending on host morph, photoperiod, and temperature, enabling populations to adjust dormancy expression under changing seasonal conditions.

Over longer timescales, evolutionary adaptation can modify dormancy traits. Comparative studies on *Aphidius ervi* populations from different climatic regions in Europe show geographic variation in diapause frequency and critical photoperiod, suggesting local adaptation to regional winter conditions. Likewise, research on egg parasitoids such as *Trichogramma brassicae* has revealed population-level differences in diapause induction thresholds associated with latitude and climate (Liu et al., 2020).

Together, these examples indicate that both phenotypic plasticity and evolutionary change influence dormancy strategies in parasitoids, determining their ability to maintain synchrony with hosts and sustain biological control under changing climatic conditions (Liu et al., 2020).

Translational Applications in Biological Control

Precision Induction and Termination Protocols

Standardized photothermal regimes and nutritional manipulations enable reliable dormancy control in mass-reared parasitoids (Ma and Chen, 2006; Zang et al., 2021). For example,

diapause induction in *Trichogramma dendrolimi* at 10 °C extends shelf life for industrial production (Wang et al., 2011).

Extended Shelf-Life and Storage Technologies

Cold storage, hypoxic atmospheres, and cryopreservation are widely used to extend the viability of parasitoids and improve the logistical flexibility of biological control programs (Pintureau and Daumal, 1995; Zhang et al., 2022). For example, egg parasitoids such as *Trichogramma* spp. are commonly maintained under low-temperature cold storage ($\approx 4\text{--}10$ °C) to delay emergence and synchronize mass releases against lepidopteran pests in crops such as maize and rice (Zang et al., 2021). Similarly, the aphid parasitoid *Aphidius gifuensis* has been successfully preserved using cold storage and controlled-temperature regimes, allowing temporary storage of mummies without significantly reducing parasitism efficiency (Wei et al., 2003; Song et al., 2021). In greenhouse biological control programs, the parasitoid, *Encarsia formosa* is frequently stored under short-term refrigerated conditions to maintain pupal viability and ensure timely release for the management of whiteflies (van Lenteren, 2012). These storage approaches reduce production costs and enable better synchronization between parasitoid release and pest outbreaks.

Emerging Frontiers

Omics-Guided Dormancy Engineering

The advent of high-throughput omics technologies has transformed the study of dormancy from a descriptive to a mechanistic discipline. Genomic resources for parasitoids, including *Trichogramma pretiosum*, *Aphidius ervi*, and *Nasonia vitripennis*, now provide foundational platforms for identifying candidate genes involved in

diapause induction, maintenance, and termination (Werren et al., 2010; Burke et al., 2014; Ragland et al., 2019). Comparative genomics has revealed conservation of core diapause-related pathways, including insulin–FOXO signaling, circadian clock components, and juvenile hormone biosynthesis genes, across distantly related insect taxa (Sim and Denlinger, 2008; Ragland et al., 2019).

Transcriptomic profiling has further illuminated stage-specific and tissue-specific expression dynamics during dormancy. In *Aphidius gifuensis* and *Trichogramma dendrolimi*, RNA-seq analyses revealed upregulation of genes associated with carbohydrate metabolism, stress tolerance, and antioxidant defense during diapause, alongside downregulation of genes involved in cell cycle progression and protein synthesis (Zhang et al., 2018; Liu et al., 2020). These transcriptional shifts underscore a coordinated metabolic reprogramming that prioritizes maintenance and survival over growth and reproduction.

Metabolomics complements transcriptomics by capturing the biochemical phenotype of dormancy. Elevated trehalose, glycerol, and polyol levels, coupled with altered lipid profiles, have been documented in diapausing parasitoids and provide candidate biomarkers for dormancy status and depth (Košťál et al., 2017; Ren et al., 2016). Integration of multi-omics datasets enables the construction of regulatory networks linking environmental cues to endocrine outputs and metabolic remodeling (Ragland et al., 2019).

From an applied perspective, omics-guided dormancy engineering offers opportunities to optimize mass-rearing protocols and shelf-life management. Molecular markers for diapause propensity and termination readiness could enable real-time quality control in commercial production facilities. Moreover, identification of regulatory

bottlenecks—such as rate-limiting enzymes in juvenile hormone biosynthesis or key transcription factors in the insulin pathway—opens avenues for targeted manipulation using hormonal analogs, RNA interference, or nutritional interventions (Li et al., 2022).

Gene Editing and Synthetic Ecology

Recent advances in CRISPR/Cas9 genome editing have enabled functional genomic studies in non-model insects, including parasitoid wasps (Duan et al., 2023; Li et al., 2022). Editing key endocrine regulators such as juvenile hormone acid methyltransferase (JHAMT), insulin receptor (InR), and FOXO transcription factors could allow the development of parasitoid strains with controlled dormancy traits and predictable diapause induction or termination (Fernandes et al., 2026).

Studies in other insects show that manipulation of insulin signaling and circadian clock genes can significantly influence diapause expression and metabolic regulation (Sim and Denlinger, 2008; Doležal, 2015). Applying similar approaches to parasitoids may facilitate the development of strains suitable for long-term storage, rapid field activation, or improved stress tolerance.

The concept of synthetic ecology further proposes engineering life-history traits to enhance ecological compatibility and biological control efficiency (Duan et al., 2023). For instance, strains with delayed diapause termination may target late-season pests, whereas reduced diapause propensity could benefit tropical or greenhouse systems. However, the use of gene editing in biocontrol agents requires careful ethical, ecological, and regulatory evaluation to avoid unintended impacts such as altered host specificity or gene flow into wild populations (Shen et al., 2025).

Integrative Modeling and Decision Support

Mechanistic and statistical models provide powerful tools for linking dormancy dynamics with pest population forecasts and release strategies (Corley et al., 2004; Hance et al., 2007). Degree-day models, photoperiodic response curves, and phenological simulations can predict diapause induction and termination under variable climatic conditions, enabling more precise timing of parasitoid releases.

Host–parasitoid interaction models incorporating dormancy parameters have been used to explore the consequences of phenological mismatches, storage-induced fitness costs, and climate-driven shifts in synchrony (Corley et al., 2004; Bandara et al., 2021). Such models reveal nonlinear dynamics and tipping points beyond which biocontrol efficacy may decline abruptly.

The integration of dormancy models with decision support systems and real-time environmental monitoring offers a pathway toward precision biological control. Remote sensing data, automated weather stations, and pest surveillance networks can feed into predictive algorithms that recommend optimal release windows and storage durations. Coupling these tools with omics-derived biomarkers of dormancy status could enable adaptive, feedback-driven management strategies (Li et al., 2022).

Looking forward, digital twin frameworks—virtual replicas of parasitoid populations and agroecosystems—could be developed to simulate alternative management scenarios and climate futures. These platforms would facilitate scenario testing, risk assessment, and stakeholder decision-making, ultimately enhancing the robustness and sustainability of parasitoid-based pest management.

Conclusions

Seasonal dormancy and developmental plasticity play a crucial role in the ecology, evolution, and practical utility of parasitoid wasps. Dormancy is not merely a developmental pause but a complex adaptive strategy integrating ecological signals, endocrine regulation, metabolic adjustments, and epigenetic mechanisms. These processes enable parasitoids to synchronize with host phenology, withstand environmental variability, and persist across diverse habitats. Recent advances in omics technologies, gene editing, and integrative modeling are expanding our understanding of dormancy regulation and offering new opportunities to optimize mass rearing, extend storage life, and improve the field performance of biological control agents. In the face of climate change, such knowledge is increasingly important as shifting seasonality, phenological mismatches, and extreme climatic events threaten the reliability of parasitoid-based pest management. Integrating ecological knowledge with molecular and technological innovations will be essential for developing resilient and effective next-generation biological control strategies, ultimately supporting sustainable agriculture and global food security.

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FIELD NOTE

A Note on Pyrrolizidine Alkaloid Sequestration by Milkweed Butterflies (Danainae) from Indian Heliotrope

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Abstract

Butterflies of the subfamily Danainae were observed communally sequestering pyrrolizidine alkaloids (PA) from *Heliotropium indicum* in Mysore, India. Multiple species tolerated close foraging, highlighting PA-driven defence, mating, and ecological interactions that support predator avoidance and butterfly community resilience.

Keywords: Pyrrolizidine alkaloids, Danainae, *Heliotropium indicum*, Sequestration behavior

Butterflies are phytophagous insects that have evolved to interact closely with the diverse array of secondary metabolites produced by plants as chemical defences against herbivores (Dennis et al. 2004). These insects are highly adapted to plant compounds, sequestering unpalatable or toxic substances from their host plants rather than synthesizing their own defensive chemicals, using them not only as cues to locate suitable host plants but also as defensive substances, often displayed through warning coloration (aposematism) and also serve as components of their sex pheromones (Nishida, 2002 & 2014).

During a nature walk on 23rd August 2025 at around 0830 hrs, the authors observed and recorded an ecological phenomenon of alkaloid sequestration of butterflies from the subfamily Danainae (milkweed butterflies) on *Heliotropium indicum* (Indian Heliotrope) at Marasettihalli Lake (12°24'09"N, 76°69'61"E), Mysore, Karnataka, India. The lake appeared to be shallow and seasonally flooded, with patches of emergent

aquatic plants scattered across the water surface, including grasses and sedges, creating a mosaic of open water and plant patches ideal for wading birds. The surrounding landscape includes dense green vegetation and coconut groves, indicating a semi-rural setting with mixed wetland agricultural influence. A flutter of approximately 14 butterflies sequestering on the *H. indicum* was documented using a Nikon D3200 camera. The gathering included *Danaus chrysippus* (Plain Tiger or African Monarch), *Danaus genutia* (Common Tiger), *Tirumala septentrionis* (Dark Blue Tiger) and *Euploea core* (Common Crow) belonging to the sub family Danainae occupied the same feeding substrate simultaneously, engaging in mineral-uptake behaviour. Interactions were mostly neutral; individuals fed in close proximity with minimal displacement. Occasional gentle jostling occurred as butterflies repositioned themselves, and no aggressive encounters or territorial displays were noted. The observation suggests tolerant inter-specific coexistence at a shared, resource-rich

microhabitat, typical of communal sequestering events (Fig. 1).

The *Heliotropium indicum* (Indian Heliotrope) belongs to the family Boraginaceae, is an aromatic, erect herb found in pantropical moist habitats (Flowers of India, 2025), with rich source of Pyrrolizidine Alkaloids (PA) and other phytochemical compounds (Sarkar et al. 2021). PAs are a group of naturally occurring toxic compounds (secondary metabolites) found in many angiosperms, especially in families like, Boraginaceae (e.g., *Heliotropium*), Asteraceae (e.g., *Senecio*, *Eupatorium*, *Ageratum*), and Fabaceae (e.g., *Crotalaria*) (Koleva et al. 2012).

The four species of butterflies were seen (Fig.1) feeding on white flowers of Indian

Heliotrope. The PAs are subsequently transferred from males to females, and further to the eggs, thereby providing protection to the offspring (Dussourd et al. 1989; Honda et al., 2018; Smith et al., 2019). Many butterfly species that sequester these alkaloids exhibit bright warning colouration (aposematism) (Dell'Aglio et al. 2016), signalling their toxicity to potential predators and offering protection that extends from the larval stage through to adulthood. By selectively foraging on PA-rich plants such as *Heliotropium indicum*, Danainae contribute to pollination networks, particularly in semi-arid, agricultural, and disturbed landscapes where such plants are abundant (Solomon Raju & Suvarna Raju, 2020). Thus, PA sequestration strengthens predator avoidance, enhances mating systems, promotes mimicry complexes, and

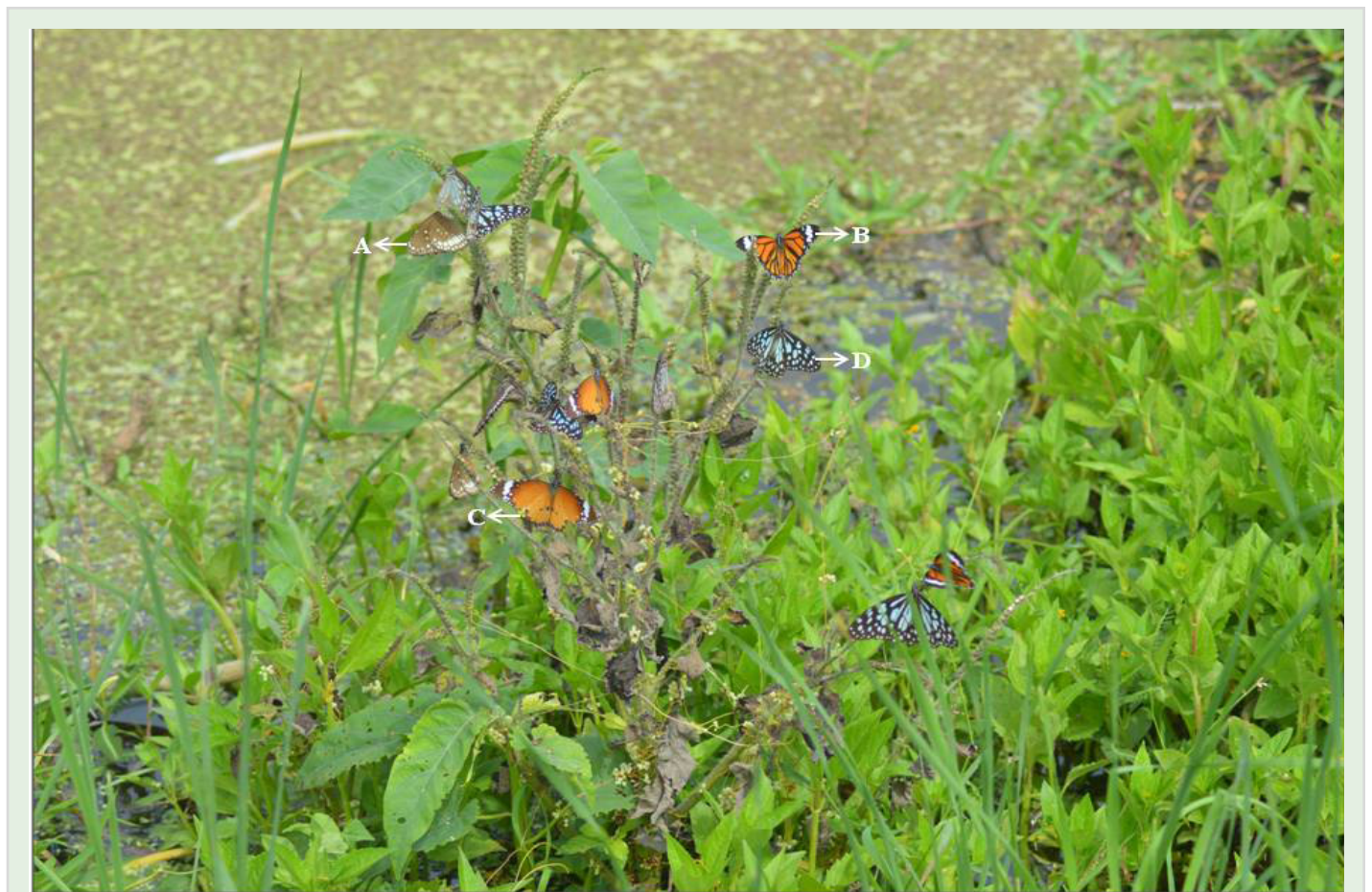


Figure 1. A. *Euploea core* (Common Crow); B. *Danaus genutia* (Common Tiger); C. *Danaus chrysippus* (Plain Tiger or African Monarch); D. *Tirumala septentrionis* (Dark Blue Tiger) sequestering on flowers of *Heliotropium indicum* (Indian Heliotrope)

maintains ecological interactions that support the resilience of butterfly communities.

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OBITUARY

Prof. M. Raghuraman, Professor and Head, Department of Entomology and Agricultural Zoology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, left for his heavenly abode on 18 November 2025 at the untimely age of 52 years. His sudden demise is an irreparable loss to the academic fraternity, the scientific community, and all those whose lives he touched with his knowledge, humility, and warmth. He is survived by his beloved wife, mother, elder brother and two children, to whom he was a devoted and caring family man. Prof. Raghuraman shared a strong and supportive family life. His wife, K. Subathra, was a constant source of encouragement and strength. He was a loving father to his daughter, Vaishnavi Raghuraman, and his son, Anirudh Raghuraman, both of whom were a source of pride and joy to him.



Prof. Mahadevan Raghuraman
June 30, 1973 – November 18, 2025

Early Life and Education

He was born on 30 June 1973 in Tiruvannamalai, Tamil Nadu. Prof. Raghuraman hailed from a disciplined and value-oriented Brahmin family. He was deeply influenced by his father, late A. Mahadevan, who instilled in him strong moral values, and his mother, Smt. M. Bhanumathi, a dedicated Headmistress whose commitment to education left a profound and lasting impact on his academic pursuits. His elder brother, Shri M. Bala Subramanian, was a constant source of affection, guidance, and moral strength in his life. The bond they shared went far beyond that of siblings; it was one of mentorship, care, and unwavering support. The influence of his elder brother played a significant role in shaping Dr. Raghuraman sir into the compassionate human being and dedicated academician he became. He completed his schooling up to the 12th standard at Danish Mission Higher Secondary School, Tiruvannamalai, and went on to earn his B.Sc. (Agriculture) and M.Sc. (Agricultural Entomology) degrees from Annamalai University. Driven by an unwavering passion for research, he completed his Ph.D. in Entomology from the Indian Agricultural Research Institute (IARI), New Delhi, in 2003.

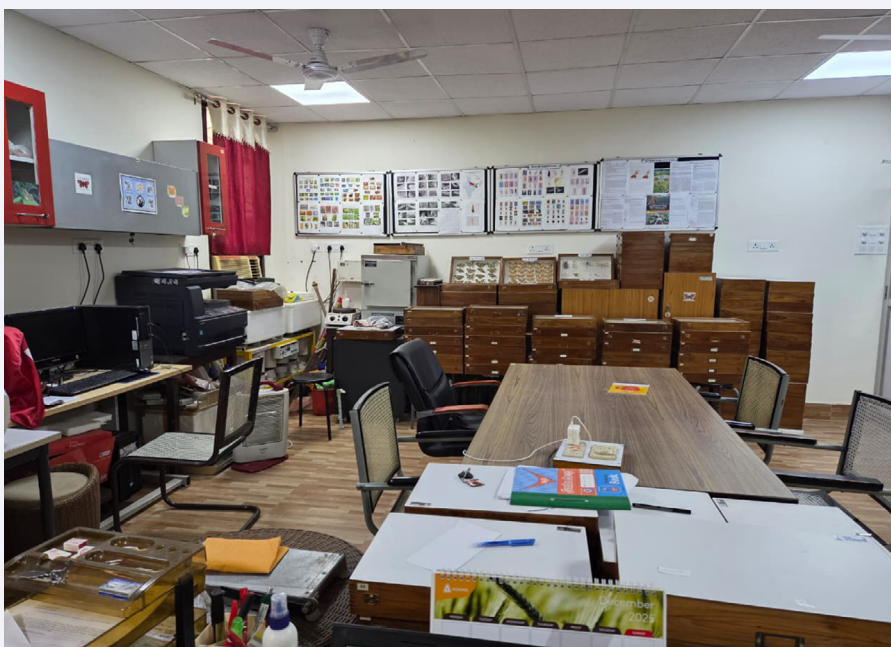
Professional Career

He commenced his academic career as an Assistant Professor of Entomology at the Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu (SKUAST-J, Jammu & Kashmir) on 16 July 2004, where he served with sincerity and dedication until 16 March 2007. Thereafter, on 17 March 2007, he joined Banaras Hindu University (BHU), Varanasi, as an Assistant Professor of Entomology, and remained devoted to the institution throughout his academic life. In recognition of his steadfast commitment to teaching, research, and service, he was promoted to the position of Associate Professor on 17 July 2016, and subsequently elevated to Professor on 16 July 2019. He was later entrusted with the responsibility of Head of the Department of Entomology and Agricultural Zoology, Institute of Agricultural Sciences, Banaras Hindu University, on 24 January 2025, a role he was fulfilling with humility, wisdom, and a deep sense of responsibility till last minutes.

Professional Achievements

During his distinguished academic career, he guided nine Ph.D. scholars and more than a dozen M.Sc. students with great dedication and care. At the time of his untimely demise, six Ph.D. scholars and eight M.Sc. students were continuing their research under his supervision. His mentorship left a lasting impact on his students, many of whom continue to uphold his values in teaching and research.

He successfully executed nine externally funded research projects supported by prestigious agencies such as the Indian Council of Agricultural Research (ICAR), the Department of Science and Technology (DST), and corporate partners, with a cumulative outlay of approximately ₹3.8 crore. His commitment to research excellence was reflected in his substantial scholarly output, comprising 168 publications



Insect Biosystematics Laboratory of Prof. M. Raghuraman

in reputed national and international journals and academic platforms. These include 126 research papers, six books, twenty-four book chapters, six conference and symposium papers, and five popular articles, which continue to serve as valuable resources for students and researchers alike.

He was a Fellow of several esteemed professional societies, including the Entomological Society of India and the Applied Zoological Research Association of India. He also served with distinction as an Editor for several reputed scientific journals and contributed as a Member of the Board of Studies in universities such as Nagaland University. His expertise was widely recognized, and

he was frequently called upon to serve as an Expert for the Union Public Service Commission (UPSC) examinations and as a Member of the Research Advisory Committee of the Central Silk Board.

In recognition of his scholarly contributions and service to the scientific community, he was honoured with several professional fellowships and awards, including the ICAR Junior and Senior Research Fellowships, the ESI Best Presentation Award, the AZRA Young Scientist Award, the Prof. Kameshwar Rao Award, among many others. Despite these achievements, he remained a person of humility, integrity, and quiet dedication to his profession.

Research Contributions

He was keenly interested in research from his B.Sc. (Agriculture) onwards and remained deeply committed to advancing agricultural entomology and insect biosystematics throughout his career. He developed and commercialized cost-effective botanical formulations based on *Callistemon* and *Eucalyptus* for the management of cotton and chickpea pests, and evaluated several botanical molecules for pest management in rice and vegetables under DST-funded projects. His research also included the development of an artificial diet for laboratory rearing of *Helicoverpa armigera* and *Spodoptera litura*, successfully sustaining fourteen generations. He standardized bio-intensive IPM technologies for olive orchards in Jammu & Kashmir using



Some Specimen Display Boxes from his Insect Museum

Trichogramma and NPV for effective management of olive insect pests. As Principal Investigator of the ICAR Network Project on Insect Biosystematics from 2011, he conducted extensive field surveys across several states, including the North-Eastern region, leading to the collection of over 10,000

insect and plant mite specimens and documentation of springtail species from the Leh-Ladakh region. He completed, for the first time, a comprehensive checklist of Indian Apterygotes covering 352 species of Collembola under 103 genera and 18 families, and 20 species of Protura under 10 genera and 3 families, and reported the occurrence of dipluran species for the first time from northern India. His pioneering taxonomic research on soil arthropods, particularly Collembola, greatly enhanced understanding of their ecosystem services, with detailed morphological and SEM-based diagnostic studies; more than 60 species were identified up to genus and species level, including over 10 species reported for the first time. Several springtail species, including *Lepidocyrtus fimetarius*, *L. violaceus*, *Sinella curviseta*, *Ceratophysella granulata*, and *Salina* sp. nov., were studied in detail and pictorial diagnostic keys were developed. In addition, *Rhochmopterum malaviyai* Nikhil, David & Hancock was published as a new species of fruit fly.

He established and maintained a well-recognized Insect Biosystematics Laboratory and museum, identified as a nodal centre for Apterygote insects under the ICAR Network Project, housing 7,094 insect and mite specimens of different orders and providing free identification services to numerous central and state universities across India.

A Loving and Caring Supervisor

With profound grief and deep respect, we mourn the untimely passing of Prof. M. Raghuraman sir, our beloved supervisor, mentor, and guide, whose sudden demise has left an irreplaceable void in our lives. For his students, this loss goes far beyond academia; it is deeply personal and heartfelt. He was not only an outstanding scientist but also a compassionate and humble human being who guided us with patience, kindness, and quiet strength. Always approachable and gentle in his demeanor, he created an atmosphere of trust and



His Interaction with Loving Students and Staff



Department Group Photo on the occasion of Teachers' Day-2025

encouragement, allowing his students to learn, grow, and gain confidence without fear. He stood by us in moments of uncertainty, celebrated our achievements, and offered unwavering support during challenges. His humility, empathy, and respect for students will remain forever etched in our hearts. The untimely departure has left us shocked and heartbroken. It is difficult to accept that we will no longer hear his gentle guidance, see his reassuring smile, or seek his advice. The void he leaves behind in our lives and in our hearts is immeasurable. Though his physical presence is no longer with us, his values, teachings, and love for science will continue to live on through his students. Prof. Raghuraman sir will always remain our mentor and guiding light. May his noble soul rest in eternal peace.

I, Dr. Srinivasa N., first met Prof. M. Raghuraman sir on 6 November 2019, and it was he who shared with me the joyful news of my selection as Assistant Professor at Banaras Hindu University-an act that truly reflected his generous and thoughtful nature. During my initial days at

BHU, he cared for me like an elder brother, offering constant guidance, encouragement, and support. We often shared meaningful discussions about the Division of Entomology, ICAR-IARI, its academic atmosphere, eminent teachers, and rich research culture. He fondly recalled his own Ph.D. days there, cherishing those memories with great pride and warmth. Prof. Raghuraman was widely admired for his vast academic wisdom and his exceptional understanding of university ordinances related to admissions, administration, and student conduct. He served as the Examination In-charge of the Institute of Agricultural Sciences from 2011 until his demise, a responsibility regarded as one of the most respectful and critical positions in the Institute. He was also the longest-serving Secretary of the Departmental Research Committee, a role in which he earned the complete trust and confidence of all Heads of the Department. Even after his passing, his absence is deeply felt-as a caring senior colleague, a wise counsellor, and a guiding presence in administrative decision-making-leaving a void that is difficult to fill.

Despite his seniority, he was always approachable, humble, and compassionate. A loving colleague to the faculty and a respected, affectionate teacher to students, he taught a wide spectrum of courses at undergraduate, postgraduate, and doctoral levels, including Fundamentals of Entomology, Pearl Farming, Fundamentals of Nematology, Beneficial Insects, Insect Anatomy and Physiology, Toxicology of Insecticides, Concepts of IPM, Insect Toxicology and Residues, and Insect Phylogeny and Systematics. Apart from teaching, his keen interest in insect biodiversity led him to establish and maintain a well-managed Insect Biosystematics Laboratory and Insect Museum. The laboratory has been a regular point of visit for scholars, scientists, and other visitors to the Institute seeking scientific knowledge. The museum houses many valuable and rare insect specimens of immense academic and research

importance. His unwavering commitment to academia, his kindness, and his quiet dignity will remain forever etched in our hearts. May his noble soul rest in eternal peace.

Memories Shared by the Non-Teaching Staff of the Department

All the non-teaching staff have had a long experience with Professor M. Raghuraman, both within and outside the department. Our experience with Raghuraman Sir was unparalleled and unique in the field of work he performed. His soft-spoken demeanor was captivating. His teaching, administrative skills, research, and the warmth and cooperation he displayed towards his staff and colleagues were unparalleled/unique. All the employees will always be grateful for his amazing support and contribution. His sudden demise is an irreparable loss to us, department, the field of research & education.



Prof. M. Raghuraman Assuming the Charge of Head of the Department from Prof. U.P. Singh on 24/12/2025

His National and International Reputation was affirmed by numerous Honors, including:

Fellows of the society

- Fellow of Applied Zoological Research Association
- Fellow of Society of Plant Protection Sciences
- Fellow of Entomological Society of India since 2008

Role in Journals

- Editor, Indian Journal of Agriculture and Allied Sciences, ISSN: 2395-1109.
- Subject editor, Indian Journal of Entomology, ISSN: 0367-8288
- Member, Editorial Board, Journal of Plant Prot. & Environment ISSN: 0973-1717
- Member, Editorial Board, Biological forum, ISSN: 2249-3239.
- Counsellor, Journal of Plant Protection and Environment: ISSN: 0973-1717

Honorary roles

- Expert, UPSC, New Delhi
- Member, Research Advisory Committee, Central Silk Board
- Member, Board of studies – Nagaland Central University
- Member Board of studies – Dharendra Mahila Post Graduate College, Varanasi

Awards / Honours / Distinctions / Recognitions:

- “ICAR - Best Teacher Award” for Excellence in Teaching in Agriculture by BHU, funded by ICAR
- Prof. Harihar Nath Tripathi Memorial Award for excellence in teaching.
- Biodiversity Conservation Award-2023 by BV David foundation, Layola College, Chennai
- Best Scientist Award - 2023 by BV David foundation, Layola College, Chennai
- ‘SPSS Outstanding Scientist Award’ 2018 by Society of Plant Protection Sciences, IARI, New Delhi.
- “Best Oral Presentation” award by Entomological Society of India in 2014.
- “Best Oral Presentation” award by ICAR-Society for Natural Resins and Gums, 2015 in the National Entomologists Meet, 2015.
- “Dr. Kameswara Rao Best Oral Presentation Award” by Applied Zoological Research Association, Bhubaneswar, Odisha.
- “Distinguished Scientist Award” – 2017 by Mahima Research Foundation in collaboration with BHU, Varanasi

- “Meritorius Scientist Award” - 2017 by Society of Plant Protection Sciences, IARI, New Delhi
- ‘Outstanding Scientist Award’ – 2016 by Centre for Advanced Research, Venus International Foundation.
- ‘Excellence in Teaching Award’ - 2016 by Vignan Bharti U.P. Chapter III.
- “Young Scientist Award” - 2015 by Applied Zoological Research Association, Bhubaneshwar, Odisha.
- “Best Paper Presentation Award” In the International Conference on Frontiers of Plant Sciences and Developing Technologies, at Institute of Agric. Science, BHU, Varanasi.
- “Best Paper Presentation Award” – 2014 by Entomological Research Association, MPUAT, Udaipur
- “Mahima Agricultural Excellence Award” by Institute of Agricultural Sciences, BHU in collaboration with Mahima Research Foundation.
- Principal Investigator of All India Network Project on Insect Biosystematics (NPIB) from January 2011 to March 2019.
- Academic and Professional Excellence in Plant Protection” Award 2024 by MR Foundation in collaboration with Department of Entomology, Institute of Agricultural sciences, BHU, Varanasi.

Prof. M. Raghuraman sir will always be remembered as an outstanding teacher, an accomplished researcher, a dedicated administrator, and above all, a gentle and compassionate human being. His life was marked by sincerity, intellectual integrity, and selfless service to science and society. Though he is no longer with us, his contributions, values, and inspiring legacy will continue to guide students, colleagues, and researchers for generations to come. May his noble soul rest in eternal peace.

**Srinivasa N., Sonam Tiwari, Nikhil K. Hatwar,
Subrata Goswami, Arindam Pal**

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BUG STUDIO

13TH INDIAN ENTOMOLOGIST PHOTO CONTEST

The Indian Entomologist Photo Contest aims to promote insect photography among photographers, professionals, amateur entomologists, and laymen. The theme for the 12th edition of the photo contest was “Insects and aspects related to insect life.” The contest was open from the 1st of May until June 15th, 2025. Each participant was asked to submit one good photograph that meet a few specified formats, as well as a filled-in application form in which he or she must include his or her details, caption, description, photograph specifications and a declaration of the ingenuity of the photograph. We received an overwhelming response from 134 participants, who submitted a total of 134 images. The photos were initially screened by Bug Studio associate editors for the prescribed standards and overall image quality and further sent to three independent and anonymous external reviewers to judge the best three photos. Based on the reviewer results, the final evaluation was done by a committee of independent members under the oversight of the three editorial board members. During the complete review process, the entries were assessed based on the following criteria: quality (clarity, lighting, depth of field, composition), relevance of the subject matter (theme, rareness of subjects), creativity and originality. To ensure a blind review, the details of the photographer were hidden, and the evaluators were only presented with the photograph, caption, description and technical specifications.

The following are the winner for 13th Indian Entomologist photo contest:

- The first place was won by Arvind Prajapat from Kerala, who captured incredible photo of Tiger moth caterpillar (Lepidoptera: Geometroidea: Geometridae).
- The second place was won by Dr. Devanand Rajaram Bankar (c/o Department of Entomology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra), for his incredible close up photo of Stable fly, *Stomoxys* sp. resting on a leaf.
- The third place was won by Payal Yadav (Fatehpur, Shekhawat Sikar, Rajasthan) for capturing a proximate photo of Robber fly capturing and feeding a Prey.

Congratulations to the winners, and we acknowledge all the participants who took an interest in 13th Indian Entomologist photo contest and sent their entries!!

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First place: Tiger moth caterpillar (Lepidoptera: Geometroidea: Geometridae)
submitted by Arvind Prajapat from Kerala, India.



Second place: A close up shot of Stable fly, *Stomoxys* sp. resting on a leaf by Dr. Devanand Rajaram Bankar, Department of Entomology, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra.



Third place: Proximate photo of Robber fly capturing and feeding on a fly prey by Payal Yadav, Fatehpur, Shekhawat Sikar, Rajasthan.

STUDENT CORNER

Rutik Ghanshyambhai Pansuriya

Mr. Rutik Ghanshyambhai Pansuriya is currently pursuing his M.Sc. in Entomology at the Department of Entomology, B. A. College of Agriculture, Anand Agricultural University, Anand. He is conducting his postgraduate research under the guidance of Dr. C. B. Varma, Associate Professor. His research focuses on the biology, seasonal occurrence, and management of the sapota midrib folder, *Banisia myrsusalis elearalis* Walker, an emerging pest of sapota. The study includes detailed laboratory investigations on the biology of the pest reared on sapota leaves. Observations are being recorded on the duration of different developmental stages—egg, larva, pupa, and adult—as well as the total life cycle, with the aim of understanding its life history, behavior, and identifying the most vulnerable stage for effective management.



In addition, the research examines the seasonal incidence of the midrib folder in sapota orchards and its relationship with various weather parameters to understand population dynamics under field conditions. The study also evaluates the efficacy of selected natural inputs against the pest under both laboratory and field conditions, using standard experimental methodologies. Through this work, he aims to generate insights that will contribute to the development of eco-friendly management strategies for sapota midrib folder.

Amogha

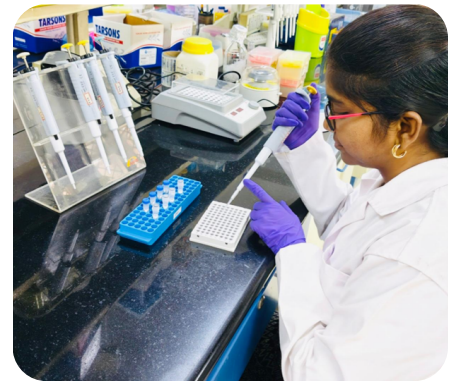
Ms. Amogha is currently pursuing her Ph.D. in Entomology at the Department of Agricultural Entomology, College of Agriculture, GKVK, University of Agricultural Sciences, Bangalore. She completed her undergraduate degree in Agriculture from the College of Agriculture, Hassan, UAS Bengaluru. Her interest in entomology developed from a deep fascination with insects and their remarkable versatility in nature—from ecosystem engineers and decomposers to important agricultural pests—highlighting their critical roles in maintaining ecological balance. She obtained her Master's degree from Rani Lakshmi Bai Central Agricultural University (RLBCAU), Jhansi, under the guidance of Dr. Usha Maurya. Her M.Sc. research focused on "Screening of chickpea genotypes for resistance against the pod borer, *Helicoverpa armigera*, and its management." During this work, she screened 100 chickpea genotypes and identified 11 lines exhibiting significant resistance to the pest. She also developed an integrated management module combining Spinosad 45% SC with Datura leaf extract, which proved highly effective in suppressing pod borer populations.



Currently, her doctoral research is titled “Deciphering the role of insecticide-degrading gut bacteria of *Spodoptera frugiperda* and its susceptibility responses to insecticides.” She is working under the guidance of Dr. Shivanna B., Professor, Department of Agricultural Entomology, UAS Bengaluru. Her research aims to identify and characterize specific gut bacteria involved in the metabolic degradation of insecticides in *S. frugiperda*. Understanding these microbial pathways may provide valuable insights for developing more effective Insecticide Resistance Management (IRM) strategies. Ms. Amogha is an ICAR Senior Research Fellowship (SRF) awardee and has also qualified the ICAR-NET examination in 2023, reflecting her academic excellence and commitment to advancing research in agricultural entomology.

Sabitha Chellem

Ms. Sabitha Chellem is currently pursuing her Ph.D. in Entomology at Acharya N. G. Ranga Agricultural University (ANGRAU), Andhra Pradesh. Her interest in entomology developed during her postgraduate studies, where hands-on exposure to insect physiology and pest management research sparked a deep fascination with insect science and its relevance to sustainable agriculture. She completed her Master’s degree from Acharya N. G. Ranga Agricultural University, where her thesis, titled “Study on Compatibility and Bioefficacy of Insecticides and Fungicides Against Insect Pests and Diseases of Rice,” was carried out under the guidance of Sanyasi Dhurua. Her doctoral research focuses on “Identification and Validation of miRNA in *Spodoptera frugiperda*,” and is being conducted as a collaborative effort between Acharya N. G. Ranga Agricultural University and ICAR–National Bureau of Agricultural Insect Resources (ICAR-NBAIR). She is working under the guidance of D. V. Sai Ram Kumar, Professor of Entomology at ANGRAU, and R. Gandhi Gracy, Principal Scientist at ICAR-NBAIR.



Her research aims to identify and validate microRNAs involved in the biology of the fall armyworm, with a focus on developing RNA interference (RNAi)-based strategies for pest management. One of the most rewarding moments in her research journey was successfully observing consistent gene silencing and associated phenotypic effects following dsRNA treatment. The study is expected to establish effective dsRNA- and miRNA-mediated silencing of key reproductive genes in adult fall armyworm, potentially leading to reproductive suppression and providing a basis for species-specific, environmentally safe pest management strategies. Ms. Sabitha has qualified the ASRB–NET (2021) and received the Best Master’s Thesis Award (2024) for academic excellence in entomology. She also won the Best Rapid Oral Presentation Award (2025) at the International Conference on Biological Control for her review work on miRNA. In addition, she has actively participated in several national-level scientific conferences. Following the completion of her doctoral studies, she aspires to pursue a career in academic research and teaching, focusing on sustainable insect pest management and molecular entomology.

SEMIOCHEMICALS: THE HIDDEN LANGUAGE OF INSECTS

A poetic glimpse into the chemical communication

Priyanka Kaundal

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No words to express their views
Insects speak by chemical cues
Derived from the Greek word Semeon
These chemicals are not well known

Leading to their distinct zones
Classified as allelochemicals and pheromones
To signal, coordinate and bond them tight
Within the same species, pheromones unite

Trail pheromones keep the colony align
By guiding ants along a straight line
Alarm pheromones spread panic and fear
Warning the colony when threats are near
With sex pheromone, attraction is clear
Mates find each other, whether far or near
Aggregation pheromones lead to the crowd
For feeding or mating, making the colonies proud

Released by one species, received by the other
Allelochemicals aid communication with one another

Signals that make the others prone
Allomone benefits the emitter alone
Kairomone guides the predator to prey
Only beneficial to the receiver coming its way
Signals aid both receiver and emitter
Synomone serves as a mutualistic transmitter
No benefit no gain to either
Antimones favour neither emitter nor receiver

Not just an interacting chemical molecule
Semiochemicals can also serve as a pest management tool
For monitoring and mass trapping orders like Lepidoptera and Diptera
Invisible whispers shape the era

Indian Entomologist is a biannual on-line magazine and blog site that publishes articles and information of general, scientific and popular interest. The magazine publishes letters to the editor, columns, feature articles, research, reviews, student opinions and obituaries. The magazine accepts articles on all aspects of insects and terrestrial arthropods from India and worldwide. Short field notes and observations are also welcome. This magazine is intended to provide a broad view of topics that appeal to entomologists, other researchers interested in insect science, and insect enthusiasts of all stripes.

Note for Contributors:

Articles submitted should not have been published elsewhere and should not be currently under consideration by another journal/ magazine. Interested authors are advised to follow the author guidelines of Indian Journal of Entomology for reference citations and to follow as closely as possible the layout and style, capitalization and labelling of figures. All papers are subject to peer review and may be returned to the author for modification as a result of reviewers reports. Manuscripts are acknowledged on receipt and if acceptable proofs are sent without further communication. Minor editorial alterations may be made without consulting the author. Make sure to submit the photographs of high quality in .jpg format. For those who want to contribute commentary and feature articles please contact editors before submission.

About articles:

IE is intended to publish following categories of Articles.

Commentary – We encourage opinions or critical analysis of current entomological happenings. Submissions should be no more than 5,000 words in length.

Reviews – two types of reviews will be published a. invited review (editorial team will contact eminent entomologists to contribute) and b. peer reviewed

review (any author/s can submit a comprehensive reviews on modern entomological developments).

Feature articles – these must be of broad interest to biologists, amateur and professional entomologists. These articles should be no longer than approximately 5,000 words. Articles should contain high quality photographs.

Natural histories & short research articles with focus on insect life cycle, occurrence etc. and have the same requirements as feature articles. Submissions should be up to 5,000 words in length.

Field notes – on unusual observations entomologists encounter during fieldwork (Invasive insects, outbreaks, behaviour etc.). Submissions should be no more than 2,000 words in length.

Bug studio – “Indian Entomologist Photo Contest” will be conducted for every volume of the magazine and best three winners will be announced in the magazine. Images should be submitted as high quality (300 dpi TIFF, jpeg files) files with a detailed photo caption. The announcement for photo contest will be made on our website www.indiantentomologist.org

Student corner – students working on interesting topics of entomology to share their views and opinions about their research work. Can submit with personal photograph; it should not be more than 1,000 words in length.

We encourage entomologists to contact us if you have any interesting story to share about insects. Contributions to be sent to the Managing Editor, in digital format (MS Word) as an e-mail attachment to indiantentomologist@gmail.com

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