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FEATURING:

- **Revolutionizing Honey Production on the International Borders**
- **Inspiring women entomologist: Dr. K. Vijayalakshmi**
- **TÊTE-À-TÊTE with Dr. N.K. Krishna Kumar**
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Cover page image: Parasitic wasp ovipositing into the freshly laid eggs of the Banana Skipper (*Erionota thrax*) by Raghuram Annadana from Bengaluru, Karnataka.

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EDITORIAL

Insects as Catalysts of Innovation: A Call to Rethink Entomological Frontiers

Insects have long served as elegant models for fundamental research, offering insights that transcend disciplinary boundaries. Their biological simplicity, genetic richness, and adaptability make them ideal subjects for experiments that require minimal infrastructure—an advantage especially vital in resource-constrained settings. The knowledge derived from insect-based studies often finds surprising applications in fields as diverse as robotics, medicine, and space science. Consider the evolution of drone technology, inspired in part by the flight mechanics and sensory systems of insects. Such biomimetic breakthroughs underscore the transformative potential of entomological research. I've previously highlighted this in an editorial referencing Raghavendra Gadagkar's work, which showcases how simple experiments with insects have led to profound discoveries in basic science—discoveries that ripple outward into real-world innovations. A recent and striking example is the Axiom-4 mission to the International Space Station (ISS), where Indian astronaut Shubhanshu Shukla participated in a groundbreaking experiment involving Drosophila melanogaster, the common fruit fly. The mission aimed to study how space radiation affects DNA, using fruit flies as proxies due to their genetic similarity to humans (they share approximately 77% of human genes). While Shukla contributed to the mission, fellow astronaut Tibor Kapu oversaw the experiment, observing how fruit fly DNA responds to the harsh conditions of space. The goal: to develop strategies for protecting human DNA during long-duration space travel to the Moon, Mars, and beyond. This experiment exemplifies the profound utility of insects in addressing challenges that extend far beyond Earth. The implications are staggering—not only for space biology but also for genetics, radiation medicine, and planetary health. And all this, achieved through a humble insect model. So, are these findings not invaluable? Do they not demonstrate that insects can serve humanity in ways that are cost-effective, scalable, and visionary? As entomologists, we must be cognizant of these possibilities. We must provoke ourselves—and the next generation—to think beyond the conventional boundaries of our discipline. Let us embrace out-of-the-box thinking. Let us deploy insect science in bold, unexpected directions. In doing so, we reaffirm that entomology is not just a study of insects—it is a gateway to understanding life, solving global challenges, and even exploring the cosmos.

Dr. V. V. Ramamurthy
Editor in Chief

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FEATURED ARTICLE

Revolutionizing Honey Production on the International Borders to Increase Farmers Income for Sustainable Livelihoods

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Introduction

Honey bees are the most important pollinators of Angiosperms, contributing in world's one third food production. Thousands of landless farmers and entrepreneurs are engaged in beekeeping, providing them a means of profitable livelihood. Way back in 1840s, when the British attacked the eastern coast of Odisha, the Kondha tribe fought them with tamed honey bees. While fighting trans-border migration and crime control, honey bees are being used as a saviour by the 32 Battalion of Border Security Force (BSF), led by Commandant Sujeet Kumar, who is trying to control trans-border migration and curb the crimes at the India-Bangladesh border in Nadia district, West Bengal, with a unique way of using beekeeping to ensure livelihood to the local farmers and protecting the international border. This unique initiative, not only deserves special appreciation, but has a great potential to employ this technology along the international borders of India.

The Border Issues and the Villagers

Increasing incidents of fence breach for trans-Border migration and criminal activities are a serious concern for the BSF, across the 4,500 km long India-Bangladesh border. The poor farmers with limited means of livelihood and a sense of deprivation often get allured towards trans-border Crimes. However, considering the inherent threat of being caught and subsequent prosecution, they do not benefit much in return. Taking such huge risk is neither worthy economically nor suitable for a dignified living for the local residents.

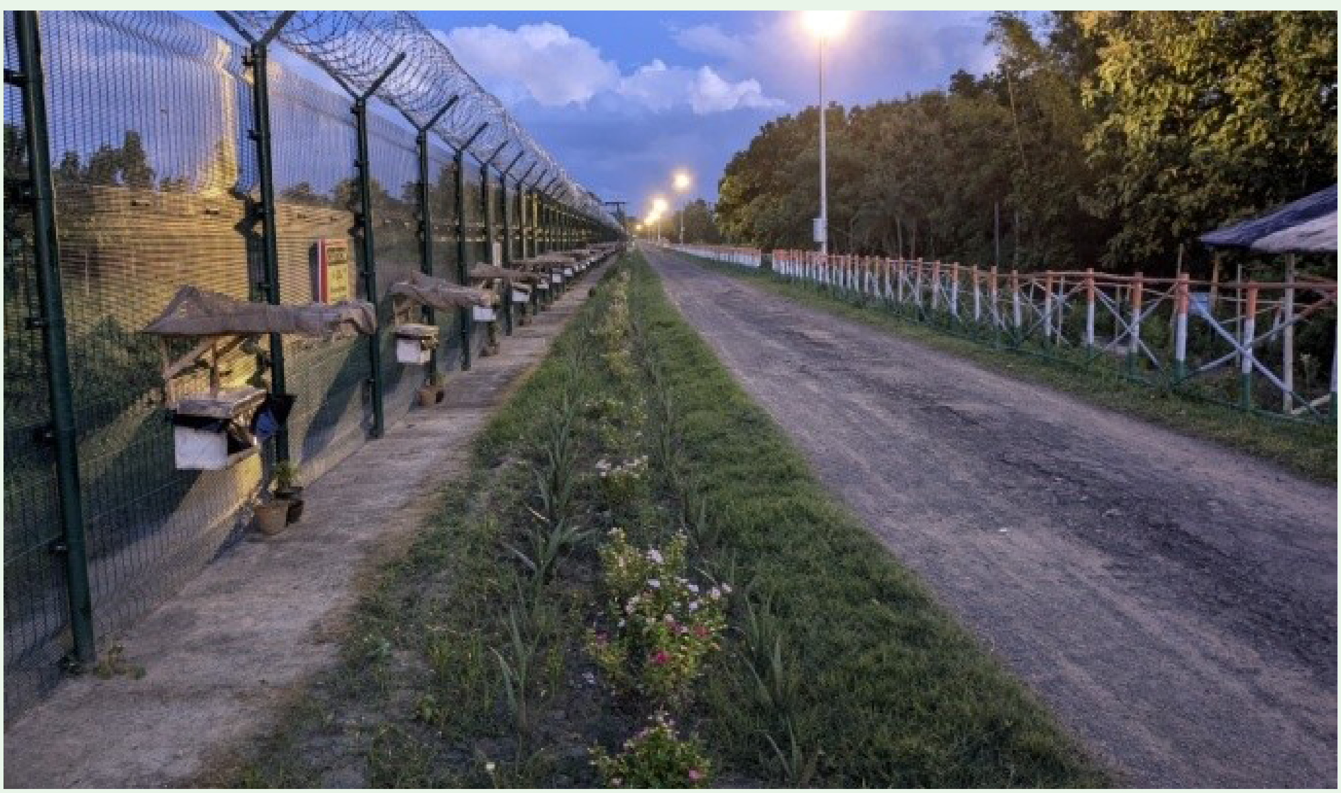
Due to the lack of any social bonding, the villagers also consider the BSF as outsiders to their society. This makes a difficult situation for the BSF to win the common men's confidence and to create a friendly atmosphere. Hence, there is always a lack of heartfelt cooperation from the villagers to share any information with the intelligence agencies for curbing the crimes. Moreover, people on both the sides of International Border have cultural, ethnic and linguistic bonding and thus, refrain from divulging information to the security forces.

Beekeeping – A Great Promise to Address the Border Issues and Provide Economic Security to the Farmers

With this background, Commandant Sujeet Kumar, 32 Battalion of BSF, conceptualized the idea of using beekeeping to strengthen the security of border fencing, augmenting the livelihood of the villagers and to motivate them to guard the border in cooperation with the BSF. The beehives kept along the border fence not only will provide a livelihood option to the villagers, but also act as a deterrent to the smugglers trying to breach the fence, as any such attempt will disturb the bees, which will then form a swarm and attack the smugglers. In addition to beekeeping, the BSF is also promoting cultivation of medicinal plants and flowers, fishery, mushroom cultivation and preparation of bakery products. These programmes aim to generate employment opportunities for people vulnerable to allurements of miscreants, gain confidence of the local residents, create a people friendly image of the BSF and eventually integrate the people living in the border areas with the border security apparatus to make them feel that they are an important role in protecting India's borders. This programme will also instil a sense of pride of working shoulder to shoulder with the BSF for the Mother Nation's cause. This noble initiative adds a new dimension of public participation in the border security framework through providing livelihood opportunities to the people residing in the border areas and by using honey bees as "Bee Warriors" for border security.

The Honey Bee Fence

The responsibility of the 32 Battalion BSF spans over 46 km stretch of the Indo-Bangladesh Border from the Kadipur Border Outpost (BOP) to the Tungi BOP. In this area, the BSF has placed Apis mellifera beehives, strategically hung from the border fence. There are 174 beehives placed at a height of one meter along the 2.6 km fence adjacent to the Kadipur village. The beehives have been provided with appropriate shade and the colonies are connected to the fence in such a way that any tampering or breaching of the fence will



The Honey Bee Fence at the India-Bangladesh International border at Kadipur BPO, Nadia dislodge the beehives and thus, initiating a swarm formation by the bees and attack the intruders. These hives are managed by a group of young girls and boys from the surrounding villages, who have been trained by the AICRP (HB&P) centre of KVK, Nimpith, WB.

The BSF has also undertaken the planting of medicinal, aromatic and flowering plants in

An *Apis mellifera* beehive, fixed on the fence at the India-Bangladesh International border, Kadipur, Nadia

two parallel stretches on either side of the road along the border fence to create a natural habitat for the honeybees (4 km). The villagers are also encouraged to cultivate seasonal bee flora such as mustard, coriander, sesame and orchards of ber and drumstick. The dense vegetation along the border and intensive farming system on both the sides of International Border provide adequate pollen and nectar to the bees throughout the year. A trench is dug along the inner side of the road to culture fishes like Rohu, Catla and Singhi. The trench also acts as a barrier to smuggling from the region.

The Collaborators

The ICAR-All India Coordinated Research Project on Honey Bees and Pollinators (AICRP-HB&P), ICAR-IARI, New Delhi, extended its technical support to the BSF through its regional centre, Ramkrishna Ashram Krishi Vigyan Kendra (KVK), Nimpith. The beekeeping scientist of the KVK-Nimpith, Dr. Prabir Kumar Garain, Principal

Training & technical support on beekeeping extended by PI, ICAR-AICRP on Honey Bees & Pollinators, KVK Nimpith

Investigator, AICRP (HB & P), visited the border post areas and supported the initiative of BSF by imparting training on scientific beekeeping to the BSF Jawans and the village youth. Later on, the Project Coordinator, AICRP (HB&P), ICAR-IARI, New Delhi, Dr. Sachin S. Suroshe organized a field visit with honey bee experts from different parts of India, who were part of the Quinquennial Review Team (QRT), lead by Dr. H.C. Sharma, former Vice Chancellor of Dr. Y.S. Parmar University of Horticulture & Forestry, Solan. Among the other distinguished scientists of the team were Dr. R.K. Thakur, Ex-Project Coordinator, ICAR-AICRP (HB & P), Dr. D.P. Abrol, Ex-Dean, Faculty of Agriculture, SKUAST, Jammu, Dr. M.R. Srinivasan, Ex-Principal Investigator, ICAR-AICRP (HB&P), TNAU, Dr. Chandan Kumar Mondal, Senior Scientist & Head, Ramkrishna Ashram KVK, Nimpith and Dr.

Distribution of *Apis mellifera* beehives to the villagers at the India-Bangladesh International border, Kadipur, Nadia, by ICAR-AICRP on Honey Bees & Pollinators, KVK Nimpith

Distinguished ICAR-QRT members and Honey Bee Scientists interacting with the BSF jawans and young beekeepers at Kadipur BPO, Nadia

Kumarnag K.M., Scientist, ICAR-AICRP (HB&P), New Delhi. The QRT interacted with Commandant, Sujeet Kumar, BSF Jawans, the villagers and made several suggestions to improve the effectiveness of this innovative initiative. They expressed the need for Government support through the National Beekeeping and Honey Mission to exploit the potential of this strategy for providing livelihood to the local residents in the border areas and for effective protection of our international borders. While, this is a highly laudable initiative by the BSF in this area, such an approach needs to be followed all across the international borders on an urgent basis.

The KVK-Nimpith, in collaboration with the ICAR-Indian Institute of Agricultural Biotechnology, Ranchi, also supported the village youth with 50 beehives to improve their livelihood and planning to continue their support in a phased manner. The Ministry of Ayush, GoI, has sponsored the plantation of medicinal and aromatic plants. A local farmer's producer organization, named NEPO-FPO, has also come forward to support with the beehives.

The Immediate Impact and Future Scopes

Social bonding between BSF and villagers

Today, the attitude of the villagers towards the BSF has completely changed due to the participatory developmental activities taken up by the 32 Battalion of BSF. The villagers now interact with the Jawans very freely and have assured their whole hearted support to stop the trans-border smuggling. As a result of the activities of the BSF, the crime rate has nearly zeroed down in this area.

Strengthening of the border fence

The pilot project has covered a 2.5 km stretch of the border fence installed with beehives. If, similar activity is replicated in the entire 4,500 km border fence under the responsibility of the BSF, it will require 4.5 lakh colonies to cover the Indo-Bangladesh border. The bee fencing will deter the smugglers from breaching the fence, and improve the security system effectively with additional revenue generation source to the villagers.

Uplifting the village economy to counter Trans-Border Crimes

There is huge scope for promoting beekeeping in the adjacent villages. The area is suitable for implementing "Honey Cluster or Honey Village" concept with an integrated approach of producing honey, beehive products and industry for beekeeping equipment. There are around 2,000 villages adjacent to the 4500 km border fence. If all villages adopt beekeeping, there will be a huge uplift in their livelihood. The villagers will be restrained from smuggling activities as well as stop supporting the illegal activities. A honey FPO may be formed with 5,000 beehives.

Approximately, 5q honey was harvested from the 50 beehives within a period of three months. The production is expected to increase up to 25q by the next year. This will help the group to earn more than Rs. 3 lakhs from the raw honey. If the honey is processed, the same will fetch them Rs. 12 lakh per annum.

Inter-Institutional Collaboration

A Memorandum of Understanding (MoU) needs to be formalized between the AICRP (HB & P), the BSF and the Krishi Vigyan Kendras in the respective zones for further collaboration and sustainability of this initiative. The KVKs near the project area may be incorporated in the project to support the villages for the horticultural, fishery and animal husbandry related activities, apart from beekeeping.

This strategy will be a great initiative to realize the sweet revolution in the country and use honeybees as warriors to protect the international borders.

Distinguished ICAR-QRT members and Honey Bee Scientists visiting the 32 Battalion BSF at Kadipur Border Post

FEATURED ARTICLE

Contribution of Augustus Daniel Imms to Indian Forest Entomology

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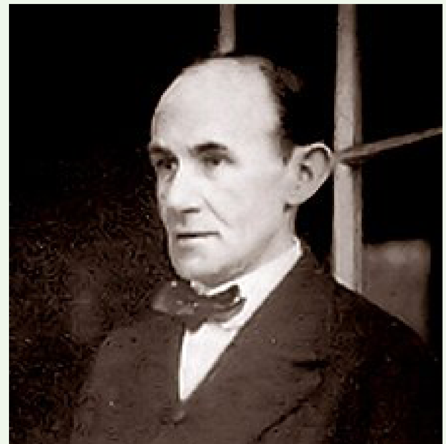
AD Imms (1880 -1949)

Introduction

Augustus Daniel Imms was a British entomologist who served in British India from 1907 to 1913. His pivotal role in the foundation in forest entomology in India remains to be known. With a brief detail of his biography, his contribution to Indian entomology is outlined in this paper.

A.D.Imms the eldest of the two children of Walter Imms, a banker and Mary Jane from Moseley, Worcestershire was born on 24 August 1884. He spent his schooling years in Birmingham (often was privately tutored owing to asthma in early years of schooling) and graduated in Zoology during 1903 from Mason University in Birmingham. He joined Christ's College, Cambridge in 1905. Though his father Walter Imms wanted him to become an industrial chemist, Imms was inspired to specialize in entomology for his master's programme at Cambridge University by Sir Arthur Shipley and Dr. David Sharp. After the completion of his M.Sc. in 1907, he worked as student and assistant demonstrator till June 1907 in Cambridge (Wigglesworth, 1949).

By the end of June 1907, Imms sailed by P&O Steamer *Oriental* to Bombay on his appointment as Professor in Biology at Muir Central College, Allahabad of the then United Provinces of British India and joined in July, 1907 (National Archives of India (NIA), 1907a). He was selected on the recommendation of Sir Arthur Shipley and Dr. David Sharp (NIA, 1907 b). In the communication on his appointment it has been mentioned "A very competent man has been found" (NIA c, 1907). Biology was in its infancy stage in Muir Central College. Without a well-equipped laboratory and inadequate research facilities Imms taught biology for four years there (Wigglesworth, 1949). He found it hard to communicate with his pupils in English, who were limited in their English-language skills and were new to studying entomology. However then, he trained a lecturer and two demonstrators. One of his illustrious students in Muir Central College was Nibaran Chandra Chatterjee, who later became an eminent forest entomologist and the founding member of the Entomological Society of India. While at Muir Central College, Imms documented on the occurrence of *Scutigera* sp. (Myriapoda: Scutigeromorpha: Scutigeridae) collected from different locations of varying elevation from different locations between 1737 and 5578 (msl) in the Himalaya. Earlier known *Scutigera* sp. worldwide were reported to be mostly diurnal and the species studies by Imms was found to be nocturnal in habit (Imms, 1910).

Insects from India described by Imms:

Sl. No	Order / Scientific Name
	Collembola
1	**Entomobryidae**
2	*Coecobrya montana*
3	*Dicranocentrus cercifer*
4	*Drepanosira frigida*
5	*Homidia kali*
6	*Idiomerus pallidus*
7	*Lepidocyrtus (L.) robustus*
	Hypogastruridae
8	*Xenylla obscura*
	Isotomidae
9	*Seira indra*
10	*Sinella siva*
	Neanuridae
11	*Gnatholonche intermedia*
12	*Inameria corallina*
13	*Pseudachorutes anomalus*
	Paronellidae
14	*Dicranocentroides fasciculatus*
15	*Pseudocyphoderus annandalei*
16	*Salina indica*
17	*S.montana*
	Sminthurididae
18	*Sminthurides appendiculatus*
	Embioptera
	Embiidae
19	*Embia major*

In October 1910, Imms resigned from Muir Central College. He reasoned that he was constitutionally unfit to live in India's rainy seasons. Soon after he arrived in India he contracted malaria and jaundice. He took six months sick leave but after resuming work he was again affected with malaria.

In 1911 Imms joined as forest entomologist in Forest Research Institute (FRI), Dehradun after Edward Percy Stebbing. He was also the member of zoological section for the Board of Scientific Advice for India during 1911-12. He established a good library, a well-furnished entomology laboratory, and a museum for insects for the first time at FRI. He laid the foundation for the reference collection of nearly 21,000 authentically identified insects with 1200 type specimens at FRI (Wigglesworth, 1949; Roonwal, 1957). The insects were identified by sending insect specimens in 40 parcels to specialists abroad and in India *viz*., Sir George Hampson, Edward Meyrick (butterflies and moths), Gilbert John Arrow, Charles Joseph Gahan, Max Bernhauer, William Weekes Fowler, Charles Kerremans (beetles) Guy Marshall (weevils), Malcolm Burr (earwigs), Peter Cameron, Claude Morley (wasps), Filipo Silvestri (termites), William Lucas Distant (bugs), Frank Fortescue Laidlaw (dragonflies and damselflies), Edward Ernest Green (mealybugs and scale insects) and John Douglas Tothill (flies). Around 1600 research files were opened with details on each insect. A card catalogue of insects injurious to forests were periodically updated by him. He regularly sent insect specimens to NHM, London, Pusa insect collection at Imperial Agricultural Research Institute, Bihar and the Indian Museum, Calcutta (Imms, 1911).

Imms undertook tours to study the insects injurious to *Shorea robusta* (Dipterocarpaceae) in the Siwalik and Kheri forest divisions and observed that *Aeolesthes holosericea* (*Trirachys holosericeus* presently) and *Hoplocerambyx spinicornis* (Coleoptera: Cerambycidae) were predominantly found damaging *S. robusta* and studied the biology of these insects from the damaged wood. He reported two new species, *Iphiaulax sal* and *I.*

immsii (Hymenoptera:Braconidae) parasitic on *Aeolesthes holosericea* (*Trirachys holosericeus*). He along with Chatterjee thoroughly studied the structure, biology of *Kerria lacca* and its natural enemies with the first ever colour illustration of lac insects. The findings were published in 1915 (Imms and Chaterjee, 1915) and this is still a standard reference on *K.lacca*. Imms reported new host plants records for *Trilocha varia* (Lepidoptera: Bombycidae) on *Ficus elastica* (Urticaceae) and *Epepeotus unicatus* and *Haplohammus punctifrons* (Coleoptera: Cerambycidae) on *Hevea brasiliensis* (Euphorbiaceae) (Imms, 1910).

Imms published the first complete account of the biology and metamorphosis of *Croce filipennis* (Neuroptera: Nemopteridae) (Imms, 1911). He undertook extensive tours in the sub-alpine forests of the Himalaya. Although insect taxonomy never his was never his forte Imms described four new genera and 18 new species of Collembola (Imms,1912) and a new species of Embioptera (Imms, 1913) (Table 1). Imms was the first to describe Collembola from India. In his publication, Imms had referred to his type collection of Collembola as 'Bengal specimens' that were deposited in the Indian Museum, Calcutta. However, the type specimens are not available at present and some of them were lost during floods. The syntypes at British Museum (present Natural History Museum (NHM)), London are referred as "Allahabad specimens" (Mitra, 1973, 1976). He also described a new species *Embia major* (Embioptera) with details on their social life and immature for the first time from India. Until the description of *E. major* by Imms only three species of Embiidae were described from India previously (Imms, 1913). Some Indian insect species named after Imms include: *Khimbya immsi* (Hemiptera:Cicadidae) by Distant in 1912, *Parisolabis immsi* (Dermaptera: Anisolabididae) by Burr in 1913, *Ennalagma immsi* (Odonata: Coenoagrionidae) by Laidlaw in 1913, *Orsunius immsi* (Coleoptera:Staphylinidae) by Bernhauer in 1914 and *Gymnachaeta immsi* (Diptera:Tachinidae) by Tothill in 1918. At this juncture, it is inevitable to recollect Dr.David Sharp's (his mentor at Cambridge) advice to Imms "If you want your name to endure you must do taxonomic work and not morphology" (Wigglesworth, 1949).

In 1913, Imms left India for health reasons. After his return to Britain, his scientific ties with India remained unsevered. For instance, in his appraisal (Imms 1921) of Lindsay and Harlow's *Report on Lac and Shellac* of 1921(which recommended the establishment of separate research institute for lac), he determined the problems to be tackled and measures to be taken to improve the lac production in India. He stressed the need for an exclusive research institute for lac and *Kerria lacca* in a potential area where lac production occurred maximally. Earlier, scientific research on lac and *K. lacca* was undertaken in FRI, Dehra Dun and Agricultural Department, Pusa. The present Indian Institute of Natural Resins (previously Indian Lac Research Institute) was opened in Ranchi in 1924 (Wigglesworth, 1949).

Applied entomology gained momentum with a shift in research from general zoology in England from 1909. Imms joined the Entomology Research Centre (ERC) at the University of Manchester in the newly created post of Reader in Agricultural Entomology in September 1913. Imms was instrumental in the creation of facility for research in agricultural entomology in ERC. While he was attached to ERC, University of Manchester, he and his deputy John Thomas Wadsworth published 21 journal papers on the biology of crop-damaging insects (Kraft, 2004). Imms was not satiated with his work at Manchester. He served as additional crop inspector and reporter for board of agriculture during I World War (1914 -1918). Based on the representation of Imms to Sir Daniel Hall (then Director of Rothamsted Experimental Stattion), an entomological department was established at Rothamsted Experimental Station in 1918. He joined as the chief entomologist and remained there till 1931. Imms occupied the newly created Rockefeller chair at Cambridge till his retirement in 1945.

He was elected a Fellow of the Royal Society of London and was later made a corresponding member of the French Academy of Agriculture and a foreign member of the American Academy of Arts and Sciences. He was President of the Royal Entomological Society of London during 1936-37. He authored three books in entomology *viz*., ***A General Textbook of Entomology, Recent Advances in Entomology and Insect Natural History.*** *A General Textbook of Entomology* was considered as a groundbreaking treatise and a notable event in the history of entomology and is still a standard textbook in entomology worldwide with 10 editions of which the IX in 1958 and X in 1977 were revised by Richard and Davies after Imms passed away in 1949.

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TÊTE-À-TÊTE

A Life in Service of Entomology and Horticulture – Dr. N.K. Krishna Kumar

Dr. N.K. Krishna Kumar (NKK), fondly known by his initials among peers and students, was born on 5 September 1955 in Mysuru, Karnataka, to Mr. N. Kothanda Raman. Over the course of nearly five decades in entomology, he has earned respect as both a pioneering researcher and a capable administrator, as well as an inspiring orator. His firm grounding in biochemistry and statistics enriched his scientific approach, allowing him to design impactful projects and mentor a generation of Ph.D. scholars.

Dr. Kumar completed his B.Sc. (Agriculture) in 1975 and M.Sc. (Agriculture – Entomology) in 1978 at the University of Agricultural Sciences (UAS), Bengaluru. He later pursued a Ph.D. at the University of Hawaii, USA (1989–1993) under the guidance of Dr. Diane Ullman, a global authority on thrips–tospovirus interactions. His academic journey continued with a post-doctoral fellowship at the University of California, Davis (2003–2004), even as he served as Principal Scientist at ICAR-IIHR, Bengaluru.

Dr NKK in front of Mahatma Gandhi statue at Coffee Board, Balehonnur

Dr. N.K. Krishna Kumar is a distinguished entomologist, visionary administrator, and mentor whose pioneering contributions to horticultural pest management, vector–virus interactions, and biological control have shaped the course of Indian agriculture. From his formative years in rural Karnataka to his leadership of national and international research institutions, his career reflects a rare blend of scientific excellence, resilience, and a deep commitment to farmers' welfare. His journey is not only a chronicle of personal achievement but also a narrative of how Indian entomology and horticulture evolved over the last five decades.

Dr NKK with Dr Diane E Ullman, his mentor at University of Hawaii during his PhD during 1991

Dr NKK with his family during late 1990s

As a student, Dr. Kumar's scientific promise was recognized through several awards:

- **University of Hawaii Travel Grant (1991)** to present research at the International Congress of Entomology, Beijing.
- **First Prize (1992)** from the Entomological Society of America (Pacific Branch) for his pioneering paper on thrips–spotted wilt virus interactions.
- **Award of Merit (1993)** from the Honor Society of Agriculture, Gamma Sigma Delta (Pacific Branch), along with a cash prize, for excellence in Ph.D. research.

At ICAR-IIHR, Bengaluru, Dr. Krishna Kumar specialized in insect–virus interactions, biological control, and host plant resistance. He led the Division of Entomology and Nematology for eight years before assuming directorship of the Project Directorate of Biological Control, which was later upgraded to the National Bureau of Agriculturally Important Insects (NBAIR). His research legacy covers vegetable entomology, integrated pest management (IPM) of sucking pests, and the study of insect vectors of plant pathogens. Initiatives like the Operational Research Project on Sucking Pests not only advanced knowledge but also trained young scientists from UAS Bengaluru and Kuvempu University, Shivamogga. Many of these researchers have gone on to make notable contributions in molecular vector entomology, insect systematics, and pesticide resistance.

After serving as **Deputy Director General (Horticulture) at ICAR**, Dr. N. K. Krishna Kumar joined **Bioversity International (2016–2020)**, a CGIAR institute. There, he spearheaded projects across South and Central Asia on managing Tropical Race 4 in banana, developing the Agrobiodiversity Index, and ecosystem service valuation. Dr. Kumar's prolific output includes over 110 research publications, as well as editing influential volumes such as *Advances in IPM for Horticultural Crops* and

Dr NKK with Dr CMKS during 2018 when NKK was in Bioversity International at New Delhi

The Onion (ICAR publication). His contributions have been recognized with prestigious honors including the Nammalvar Award for Biodiversity Conservation, the Dr. Vasanthraj David Award for Entomology, and Fellowship of the Society for Promotion of Horticulture. He continues to contribute actively as a member of several **Research Advisory Committees** and **Quinquennial Review Teams**, including those of the **Central Silk Board** and the **Indian Institute of Spices Research**, ensuring his expertise continues to guide Indian agriculture and entomology.

The following excerpts are from a conversation between **Dr. N.K. Krishna Kumar (NKK)**, an eminent entomologist and former DDG (Horticultural Science), ICAR, New Delhi and his former student **Dr. C.M. Kalleshwaraswamy (CMKS)**, Professor of Entomology at UAHS, Shivamogga. In this dialogue, Dr. Krishna Kumar reflects on his early influences, pioneering research, leadership roles, and his continuing commitment to Indian agriculture.

CMKS: Sir, how did your journey from a UAS Dharwad undergraduate lead you to choose entomology as your career?

NKK: I chose agriculture because of my cousin, my aunt's son, who was a major influence in my life. He taught me English, guided my conduct, and inspired me to aim high. He worked in the Fertilizer Corporation of India, and on his advice, I joined B.Sc. Agriculture. I was awarded the ICAR Junior Fellowship for all four years. Initially, I wanted admission in Bengaluru as it was closer to Mysuru, but I got a seat at Dharwad – which turned out to be a blessing. The rural atmosphere, strict discipline under leaders like Dr. S.W. Mensinkai and Dr. S.V. Patel, and classmates from across Karnataka created a vibrant learning environment. Even after 50 years, my Dharwad batchmates remain a close-knit family. For my Master's, I moved to UAS Bengaluru, which had a strong presence of stalwarts in the Department of Entomology. Teachers like Dr. C.A. Viraktamath, Dr. Jayaramaiah, Dr. G.K. Veeresh, and Dr. Lingappa shaped my passion. Entomology appealed to me because it felt practical, visual, and directly useful to farmers. Yes, it was challenging, but I loved it.

> *"Entomology appealed to me because it was practical, visual, and directly useful to farmers."*

CMKS: Tell us a bit about your childhood.

NKK: I was born in Mysuru in a family of nine children – six sisters and three brothers. My father worked in a coffee curing company, and my mother was a devoted homemaker. We were not wealthy, but our home was full of music, especially Carnatic music, and intellectual discussions. I studied in Kannada medium until Class 7 and switched to

English medium in Class 8 – a tough transition. Our family valued education above all. While most of my siblings leaned toward physics and mathematics, I was drawn to biology. Although I could have pursued medicine, I chose agriculture, thanks to my cousin's influence.

CMKS: You completed your Ph.D. and a post-doc in the USA. What was your experience there, and how did it differ from India?

NKK: In the U.S., they mean business when it comes to science. There is no caste, no community bias, no gender discrimination – only merit. Once you enter a university, your subject becomes your life, 24/7. Teaching methods are independent yet supportive, guiding you step by step so that even challenging topics like statistics and biochemistry become engaging. I was awarded the East-West Center Pre-Doctoral Fellowship to pursue my Ph.D. at the University of Hawaii, Mānoa (1989–1993). Initially, I planned to work with Dr. Bruce Tabashnik, but I ended up under the mentorship of Dr. Diane Ullman – a teacher I regard as nothing short of a goddess. She molded me as a scientist and as a person, instilling honesty, compassion, and scientific rigor. My Ph.D. research focused on tomato spotted wilt virus (TSWV) and its transmission by thrips, as well as identifying resistant sources. I published in reputed journals such as *Plant Disease, Environmental Entomology, Journal of Economic Entomology,* and *Euphytica.* I also gained proficiency in advanced techniques like electron microscopy and microtomy. After my Ph.D., I was invited for a post-doctoral fellowship at the University of California, Davis, once again working with Dr. Ullman. There, I studied the role of viral glycoproteins in thrips acquisition of TSWV, virus replication, and transmission efficiency. The work was deeply satisfying, leading to several quality publications. Though they wanted me to continue, family responsibilities drew me back to India after a year.

CMKS: How about your work experience in a private company before joining ICAR?

NKK: In those days, postgraduate students were recruited as Research Assistants in universities, but such positions were scarce. My family needed financial support, so I had to postpone my Ph.D. plans. Even before completing my degree, I got a job at Ciba-Geigy India Ltd. (later Novartis) as a Research Assistant. Initially, I was posted in Mumbai. The salary was good, but I was not happy with the work culture. The focus was heavily on marketing, and many in leadership positions were not agricultural graduates – they didn't always appreciate the value of scientific methodology or statistical analysis. During my time there, I witnessed large-scale aerial spraying of endosulfan in Kasargod and Goa in 1977–78. I had no idea then that endosulfan would later become a major environmental controversy. After a year, I resigned and began preparing for the Agricultural Research Service (ARS) examination, determined to join ICAR.

CMKS: Sir, how about your career research experience as a young ICAR scientist? What were your Master's days and your early years like at IIHR?

NKK: My M.Sc. research under Dr. Devaraj Urs was on chemosterilants. The learning environment — seminars, peer competition, and excellent faculty — shaped me immensely. I cleared the ARS exam in 1978 and was selected by Dr. T.N. Ananthakrishnan, joining ICAR-IIHR, Bengaluru. Initially, I worked on okra ecology and later led the vegetable entomology section. In 1985, I was transferred to Godhra,

> *"Operational Research Projects not only solved farmer problems but also created a generation of trained scientists."*

Gujarat, which at first felt unjust. Thankfully, the then Director, Dr. T.R. Subramanyam, recognized this and brought me back to IIHR. That brief stint in Godhra, however, gave me valuable field exposure to ber pests. At that time, IIHR had a policy that discouraged study leave, which I found puzzling. After more than a decade, I finally got my application forwarded for the East-West Center Fellowship, and among thousands of applicants, I was selected to pursue my Ph.D. in Hawaii.

CMKS: Your contributions to horticultural entomology are widely known. Could you highlight some milestones?

NKK: At ICAR-IIHR, I worked extensively on insect–virus interactions, biological control, and host plant resistance. I headed the Division of Entomology and Nematology for eight years, before moving to the Project Directorate of Biological Control (later NBAIR). A landmark initiative was the Operational Research Project on Sucking Pests, which trained young scientists at UAS Bengaluru and Kuvempu University, Shivamogga. This fostered work on molecular virus transmission, insect systematics, and pesticide resistance, resulting in quality publications.

CMKS: How was your transition from scientist to administrator?

NKK: Serving as Director of the Project Directorate of Biological Control (later NBAIR) allowed me to expand biological control programs nationally. Later, as Deputy Director General (Horticulture) at ICAR, I could shape policies and research direction for horticultural crops across the country. Following ICAR, I joined Bioversity International (2016–2020), a CGIAR institute. There, I led research in South and Central Asia on banana Tropical Race 4 management, development of the Agrobiodiversity Index, and valuation of ecosystem services.

CMKS: You also headed the National Bureau of Agriculturally Important Insect Resources (NBAIR), which was earlier focused on biological control. What transformations did the institute see under your leadership?

NKK: Before becoming Director of NBAIR (then PDBC), I was Head of the Division of Entomology and Nematology at IIHR. There, I played a role in the commercialization of horticultural technologies – raising the institute's annual revenue from just ₹2 lakh to over ₹1.5 crore. I took charge of NBAIR in June 2011, succeeding Dr. R.J. Rabindra. With the strong support of my scientific team, we made major infrastructure upgrades: establishing new laboratories, enhancing field facilities at the Yelahanka farm, renovating the guesthouse, and relocating the library into a dedicated building. We also hosted what I believe was the largest entomology gathering in India since Independence, with over 300 entomologists participating. On the research side, our biological control programs against papaya mealybug, eucalyptus gall wasp, and erythrina gall wasp delivered measurable impacts. These efforts continued the legacy of my predecessor, while also bringing several projects to full scientific and field-level fruition.

CMKS: You were a proven administrator as well, heading ICAR as Deputy Director General (Horticultural Sciences). What was that experience like, especially working with Dr. Ayyappan?

NKK: Honestly, I sometimes feel I could have stayed longer at NBAIR. But when the post of DDG (Horticulture) was advertised, I decided to apply. Initially, I didn't even get the interview call. Then, just 48 hours before the date, the call arrived – perhaps divine timing! The selection committee included stalwarts like Dr. K.L. Chadha, who was known for preferring horticulturists for this role. Yet, despite tough questioning, they unanimously selected me – breaking the long-standing tradition of appointing only horticulturists. In Delhi, my fluency in Hindi helped me connect well with colleagues such as Dr. G. Kalloo, Dr. H.P. Singh, Dr. Ghosh, and Dr. Chadha. Together, we achieved several milestones: establishing the Floriculture Institute at Pune, launching a phytoplasma research network, and introducing targeted funding for crucial horticultural projects. My tenure coincided with the leadership of Dr. S. Ayyappan, a simple, honest, Gandhian-minded Director General. Together, we witnessed a proud national milestone: India's horticulture production surpassing foodgrain production.

CMKS: After retiring from ICAR, you joined Bioversity International. How have you been engaged since then?

NKK: I joined Bioversity International in 2016, just before completing my tenure as DDG. It's a CGIAR institute, and I coordinated research across South and Central Asia – focusing on managing Tropical Race 4 of banana, developing an Agrobiodiversity Index, and valuing ecosystem services. In 2020, during the COVID-19 pandemic, I stepped down from Bioversity International. I briefly consulted for a Japanese company, and today I serve as Scientific Advisor to Indo-American Hybrid Seeds, Bengaluru. I also contribute actively to the scientific community – serving on Research Advisory Committees of several ICAR institutes and the Central Silk Board, and chairing the QRTs for the All-India Network Projects on Soil Arthropod Pests and Agricultural Acarology.

> *"Agriculture remains the backbone of our country—India needs its brightest minds to contribute."*

CMKS: Finally, what advice would you give young people aspiring to specialize in entomology?

NKK: Work hard – it always pays off. Never look back with regret, and avoid shortcuts. Master your basics – statistics, biochemistry, ecology –

Dr. C.M. Kalleshwaraswamy

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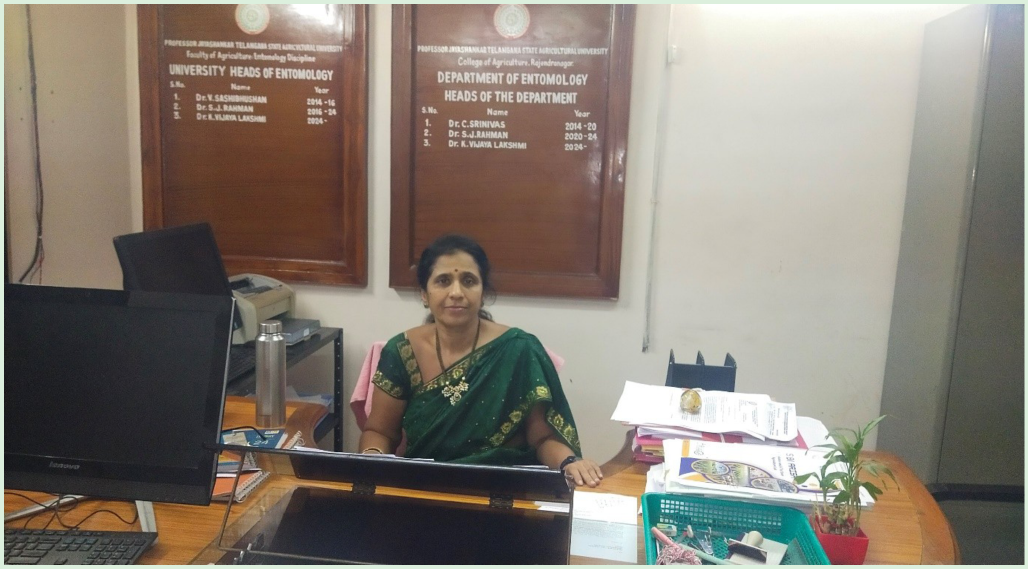
WOMEN IN ENTOMOLOGY

An Inspirational Dialogue with Dr. K. Vijayalakshmi: Trailblazing the World of Insects

Dr. K. Vijayalakshmi, an eminent entomologist, was born in Eluru, West Godavari district of Andhra Pradesh, into a family that valued education and service—her father, Sri Rama Rao, was a government employee, and her mother, Yasoda Devi, a homemaker. Her academic journey began at Kasturba Girls High School, Eluru, and she subsequently pursued intermediate education at St. Theresa's College for Women, Eluru. Her inclination towards agricultural sciences led her to enroll in a **Bachelor's degree in Agriculture at the Agricultural College, Bapatla under APAU then, PJTAU now** where she graduated with distinction. She excelled in her academic performance and developed a keen interest in Entomology during this foundational phase.



Dr. K. Vijayalakshmi, Former - Senior Professor & University Head, Department of Entomology, College of Agriculture–PJTAU, Rajendranagar, Hyderabad

Dr. Vijayalakshmi completed her **M.Sc. (Ag.) in Entomology** from the same college securing the **highest OGPA at the University level** and earning **two gold medals** for her exemplary performance. Her postgraduate research focused on *Lasioderma serricorne* (cigarette beetle) in turmeric, with emphasis on biology, varietal resistance, and integrated pest management strategies.

She went on to pursue her **Ph.D. at the College of Agriculture, Rajendranagar, APAU**, and was associated with **ICRISAT**, working under the guidance of the renowned plant virologist **Dr. D.V.R. Reddy** and eminent entomologist **Dr. J.A. Wightman.** Her doctoral research was supported through prestigious fellowships including **CSIR-SRF** and **ICRISAT-SRF**. Her work significantly advanced understanding the virus-vector interactions between *Thrips palmi* and **Peanut Bud Necrosis Virus (PBNV)**. She was the first to report *T. palmi* as a vector of PBNV in India. Additionally, she standardized laboratory protocols for the rearing of thrips and developed experimental techniques for conducting serial transmission studies.

Her professional journey began as a **Consultant at ICRISAT**, contributing to a Netherlands-funded project by Wageningen University (1992–1993), wherein she identified resistant peanut germplasm lines to

PBNV and *T. palmi*. She joined **APAU** (now PJTAU) in 1993 as **Assistant Professor**, and over the course of 33 years, served in various capacities across Agricultural Colleges in Bapatla, Aswaraopet, Palem, and Rajendranagar.

Dr. Vijayalakshmi is a distinguished educator with extensive teaching experience at both undergraduate and postgraduate levels. She has mentored **15 M.Sc.** and **6 Ph.D.** students as a major advisor and served on the advisory committees of over 50 students.

Her **research contributions** are substantial, particularly in the fields of Insect-virus interactions, biological control, host plant resistance, storage entomology, pest forecasting using weather-based models and ecological engineering for pest suppression. She has published over **120 research papers** in reputed national and international journals, authored **10 books and book chapters**, and contributed over **50 popular science articles**. Her outreach efforts include radio talks and TV programs focusing on crop pest management and agro-advisory services. She has successfully handled several **national and international projects** as Principal Investigator (PI) and Co-PI. Her international engagements include participation in workshops on **thrips taxonomy at the University of Vermont, USA**, and presenting more than **50 research papers** at various scientific conferences, including in the United States.

Dr. Vijayalakshmi has also worked as **Director (Plant Health Management), NIPHM**, where she coordinated national and international training programs on plant protection strategies; **Associate Dean, Agricultural College, Palem**, where she was instrumental in the establishment and accreditation of the college**; University Head, Department of Entomology, PJTAU**, where she led departmental research programs and guided faculty and students.

Her scientific and academic excellence has been recognized through numerous awards, including **State Best Teacher Award, Rythu Nestham Award, etc.**

Dr. Vijayalakshmi's illustrious career exemplifies a rare blend of academic brilliance, research innovation, and institutional leadership. Her unwavering dedication to the field of entomology continues to inspire future generations of scientists committed to sustainable pest management and agricultural advancement.

MR (Dr. M. Rajashekhar): Madam, could you briefly reflect on your academic journey and early inspirations—what initially drew you into the discipline of entomology?

KV (Dr. K. Vijayalakshmi): My fascination with insects started during my undergraduate studies in Agriculture, particularly due to their diverse role in ecosystem services which contributed their dominance as a species on earth. This interest led me to pursue post graduate studies in Entomology which focussed on storage beetle affecting turmeric, exploring its biology and control to mitigate post-harvest losses. I chose to carry out my Ph.D research at ICRISAT under the guidance of internationally renowned entomologist and virologist to investigate the transmission of Peanut bud necrosis virus by thrips. My research focussed on identification of thrips vector and the intricate virus-vector relationships in groundnut. The findings marked the first report of *Thrips palmi* as the vector of peanut bud necrosis virus from India paving the way for future research in this area.

MR: Over your distinguished career spanning Teaching, Research, and Extension, which of these domains do you consider the most fulfilling or impactful, and why?

KV: While all three domains have been rewarding, teaching has been the most fulfilling. It has given me a sense of purpose and fulfilment. By sharing my passion for entomology, I have had the privilege of mentoring thousands of students and watching them grow in to accomplished professionals. I have enjoyed guiding the students through research projects and academic pursuits, witnessing their growth and development. Teaching allowed me to inspire and empower the next generation of entomologists to address emerging challenges.

MR: Your specialized focus on thrips and understanding the virus vector relation both are rare and commendable. What motivated you to pursue this niche area, and how do you perceive its relevance in contemporary pest management?

KV: My interest in working with thrips stemmed from the challenges posed by their minute size and complex biology. I found it intriguing to study these tiny insects and their role in the transmission of viral diseases which are often overlooked despite their significant role they play as pest and vector of important viral diseases. Working on thrips requires meticulous attention, precision and patience. And I slowly started to enjoy working with thrips. Understanding the complex interaction between thrips and viruses is crucial for developing effective pest management strategies ultimately benefitting agriculture and food security.

MR: What were the major academic and professional challenges you encountered during your formative years as a student and later as a Professor, Director at NIPHM, University Head, and Associate Dean?

KV: Academic and professional challenges are an inevitable part of the journey. I am no exception, having faced many challenges throughout my career. However, I have learned to view these challenges as opportunities for growth, resilience and innovation which ultimately made me stand as a stronger professional. As a student balancing academic and research responsibilities is very crucial. During my Ph.D. research, I dedicated five years to study the thrips and their virus vector relationships. The complexity of the work necessitated meticulous experimentation and validation, often requiring repetition of work to ensure accuracy. This rigorous approach ultimately led to significant findings. Later as a professor, University head and Associate dean, though balancing teaching, research and administrative duties posed significant challenges, I ensured to offer quality education to students, facilitated research guidance to entomologists and navigated complex administrative tasks. As a Director at NIPHM, I ensured better resource management and policy implementation.

MR: Given your extensive experience, what do you think are the reasons behind the declining interest among students in classical taxonomy, particularly insect taxonomy, in the present era?

KV: Insect taxonomy is a complex subject which can be daunting to the students. There is notable shortage of expertise and decline in resources and competitive grants dedicated to taxonomic research making it challenging for students to pursue their work in this field. The focus on innovative research and publication matrix are over shadowing the importance of taxonomic work making the subject less appealing to the students.

MR: In your observation, why are a majority of budding agricultural graduates not showing enthusiasm toward Entomology, and what can be done to reverse this trend?

KV: Most of the students perceive entomology as a very difficult subject as it needs lot of hard work, dedication and interest to perform well which is deterring many students to pursue. Students are prioritizing other areas of agriculture which have brighter career opportunities. To create interest among the students towards the subject, emphasise the importance of entomology in addressing the practical issues of the farmers like pest management, role of pollinators in food security and entrepreneurship opportunities in sericulture, apiculture and entomophagy.

MR: In your opinion, what essential qualities or competencies should a young entomologist possess to emerge as a successful and impactful researcher or extension scientist?

KV: The entomologist should develop passion towards the subject. Stay tuned to the current and latest research across the globe, attend conferences and participate in online forums, network with colleagues and mentors to share knowledge and expertise, interact with farmers and stakeholders to understand real problems at field level.

MR: What, according to you, should be the future thrust areas of entomological research in the context of emerging challenges like climate change, invasive pests, and resistance management?

KV: Development of weather-based pest prediction models, promotion of IPM approaches, molecular characterization of invasive pests, exploring CRISPR-Cas and RNA interference-based pest control methods and investigating biotechnology enhanced genetic control like genetic modification of insects are some of the emerging research areas that can be explored for pest management.

MR: How can we strengthen the last-mile connectivity to ensure that advanced plant protection technologies developed through research effectively reach and benefit smallholder and resource-poor farmers?

KV: The advanced plant protection technologies can be effectively disseminated by fostering partnerships between research institutions, government agencies and private organizations. use of digital platforms like mobile apps, online forums and social media and by establishing robust extension services to communicate research findings among the farmers and stake holders.

MR: Looking back at your professional life, what legacy or message would you like to pass on to future generations of entomologists and agricultural scientists?

Pursue your passion in entomology, be curious to learn the subject, build relations with mentors and stake holders to share knowledge and expertise, stay up to date with emerging technologies of entomology to deal the complex challenges. *"Success is not about position or power, but the impact you make in people's lives and the planet's health."*

MR: Why many girl students perceive entomology as career option and what motivates them to pursue it?

KV: Entomology indeed requires lot of dedication and hard work. Many girl students are drawn to entomology due to their interest in insects. By combining passion, dedication and hard work, many girl students excel in entomology and making meaningful contribution to the field.

MR: What are the prospects for career growth and advancement in entomology for women globally?

Women in entomology have promising career growth prospects globally with opportunities in academia, Research, government, Industry, public health sectors, Biocontrol and seed testing laboratories. Growing demand for sustainable pest management during recent years in Agriculture is also opening doors for women in this field.

**(Interviewed by Mr. M. Rajashekhar,
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GENERAL ARTICLE

Insect Tourism: A Sustainable Approach to Ecotourism and Biodiversity Conservation

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Abstract

Persons interested in insect observation and their conservation strategies form the base of rapidly expanding insect tourism endeavours. Tourists who participate in this ecotourism learn about insect ecology together with supporting local economic growth and environmental conservation efforts. They also gain knowledge on insect conservation and understand their importance as bioindicators of environmental health. The combination of scientific information together with local public participation and tourism practices that prioritize responsibility enables insect tourism to protect the environment while supporting community welfare. Insect-based tourism stands as a distinctive travel sector that allows tourism expansion to proceed jointly with biodiversity conservation and environmental learning initiatives.

Introduction

Ecotourism is defined as "nature-based tourism focuses on exploring nature, where visitors learn about and appreciate the environment", (Donohoe and Needham, 2006). It mainly aims to benefit local communities and is designed to reduce negative impact on the environment. The term "ecotourism" was first coined by Hector Ceballos-Lascurain in 1983, who defined it as a responsible travel to natural areas that conserves the environment and improves the well-being of local people. This definition emphasized that ecotourism must be centered around the preservation of natural resources and the promotion of sustainability, while also providing visitors with enriching educational experiences. Over time, ecotourism evolved from a niche market to a major segment of the global tourism industry.

Ecotourism popularity continues to grow across the world although it finds its strongest acceptance in developing nations. Ecotourism is also referred to as sustainable tourism and responsible tourism, ethical tourism or ecological tourism, nature tourism, cultural tourism and heritage tourism. Ecotourism functions to overcome standard tourist antagonisms together with preserving biodiversity alongside community development, Weaver (2001).

The main goal of this ecotourism is to make tourists to observe insects by creating educational opportunities in wooded areas or grasslands and designated sanctuaries and wetlands. It involves building recognition on how insects fulfil fundamental ecological responsibilities in their environments together with participation in pollination, decomposition processes and predation cycles.

History and Evolution of Insect Tourism

Since time immemorial mankind has been fascinated by insects in addition to study them scientifically. Over many generations' naturalists together with entomologists, artists and travellers have studied insects because of their diversified ecological significance and their elaborate interesting behaviour. The Royal Entomological Society of the United Kingdom established in 1833 created one of the first organizational settings which allowed insect admirers to exhibit their scientific discoveries. In the 19^{th} century entomological tourism operated as a component of scientific exploration through which travellers studied unusual insect species (Kanaujia et al., 2022).

Insects an Artistic Inspiration

In addition to their scientific importance, insects have been a source of artistic inspiration. Entomologist cum artists such as Maria Sibylla Merian of the 18th century, along with her daughter, captured the beauty and intricacies of insect life in her detailed illustrations. Merian's work focused on the metamorphosis of insects, particularly caterpillars, butterflies and her paintings not only showcased the wonder of insects and also contributed significantly to the scientific understanding of their biology. Even before Charles Darwin, Merian embarked on voyage to suriram to study insects. Her work, "Metamorphosis Insectorum Surinamensium" (1705), is a famous example of how insects were celebrated in art, with illustrations that combined both artistic beauty and scientific accuracy. Merian's contributions helped to shape public interest in insects and set the stage for the later popularization of insect-themed exhibitions and collections. She may be considered as the first person to study insects in a distant land through scientific voyage.

Early Beginnings and Interest in Nature Observation

The conception of insect tourism began as part of nature tourism evolution together with human fascination toward insects' natural ecosystem functions. In the nineteenth century and throughout the eighteenth period the scientific community grew passionate about insects resulting in significant contributions from experts such as Carl Linnaeus and Charles Darwin towards understanding insect diversity. Butterfly observers and other insect enthusiasts represent a natural evolution of the 19^{th} century wildlife tourism growth that inspired upon the creation of national parks and wildlife reserves. The adoption of insects in wildlife tourism occurred slowly over time because scientists recognized their crucial ecological roles despite their initial concentration on observing mammals and birds (Weaver, 2001).

Butterfly Watching and Early Insect Tourism (Late 20^{th} Century)

The late 20^{th} century brought about the increasing popularity of butterfly watching which became a notable form of insect tourism. Scientists largely believe that the annual Monarch butterfly, Danaus plexippus migration along with its observations became the defining moment which made insect tourism appealing to public. Multitudes of Monarch butterflies leave northern Canada and the United States annually to reach the pine forests of Mexican state Michoacán for seasonal winter residence (Shapiro, 1988).

Tourism performed a key role in exhibiting how environmental education programs merge with wildlife preservation strategies by using the Monarch butterfly migration as a lesson model.

During the 1990s butterfly gardens and parks multiplied intensely in regions rich in biodiversity across European territory, US territory and Asian territory. The designated areas function as education centers to teach butterfly species alongside their lifecycle patterns and habitat protection necessities for developing an effective communication link between tourism and insect observation, (Mathew et al., 2011).

Expansion of Insect-Based Ecotourism (2000s - Present)

The early 2000s brought numerous additional insect-oriented recreational options to the entertainment market. At that time firefly watch events formed the key draw for tourists throughout Southeast Asia and Latin America. Japanese along with Malaysian and Thai tourists view firefly illumination in synchrony during night-time while visiting their river and forest areas because of their cultural connection dating back to ancient local traditions.

According to Buckley (2009) tourists regularly visit the Amazon Rainforest in South America alongside Costa Rican rainforests for insect-orientated vacations. The advancement of insect tourism as a commercial sector can mostly be attributed to activities related to beekeeping tours. Outside visitors can visit areas where honey is produced at beekeeping tours that operate throughout Europe along with specified locations in North America and New Zealand (Goulson, 2010). The financial contribution works in conjunction with the ecological value that bees and pollinators provide to tourism because these vital insects support food agriculture and species diversity.

Principles of Ecotourism

Conservation of Natural Resources

Ecotourism aims to preserve the environment, ensuring that tourism activities do not degrade or over-exploit natural ecosystems. By promoting sustainable use of natural resources, ecotourism helps protect biodiversity, wildlife habitats and landscapes for future generations (Fennell, 2003).

Minimizing Negative Environmental Impacts

Practices such as minimizing energy consumption, avoiding littering and encouraging the use of renewable resources are key to ensuring that tourism does not harm the environment. Additionally, tourists are encouraged to engage in low-impact activities, such as walking, cycling or using public transport, to reduce carbon footprints (Wearing and Neil, 2009).

Education and Interpretation

Ecotourism places a strong emphasis on educating tourists about the environment, local culture and the importance of conservation. Guided tours, nature walks and interpretive programs allow visitors to learn about the flora and fauna, conservation challenges and sustainable practices in this area (Packer et al., 2011).

Respect for Local Culture and Communities

Respecting and benefiting local communities are the fundamental principle of ecotourism. This principle promotes the preservation of local culture, traditions and heritage while ensuring that local people are treated with dignity and respect. It also encourages the use of local guides, businesses, and materials to promote economic sustainability for the community.

Economic Sustainability and Community Involvement

The tourism industry should provide a fair share of income to local communities, helping to reduce poverty and support local infrastructure and services. Economic sustainability is also about creating jobs that are not only economically beneficial but also respectful of local cultures and traditions. Moreover, the involvement of local communities in tourism planning, management and decision-making ensures that the development is in line with their needs and aspirations.

Promoting Responsible Travel Behaviour

The concept of ecotourism promotes sustainable tourism that teaches tourists to avoid harming ecosystems through actions that respect natural elements combined with cultural traditions in the host communities. Travellers must adhere to established tracks and refrain from bothering wildlife besides controlling their waste output through environmentally friendly materials and sustainable water and energy usage. Travellers need to show respect by understanding cultural traditions of local societies while providing support to sustainable local business operations.

Sustainability and Long-Term Planning

Sustainability in ecotourism involves long-term planning and development that considers future generations. It aims to create tourism models that balance environmental protection, social equity and economic prosperity. Ecotourism operators are encouraged to adopt sustainable practices that preserve the resource base for future visitors. This principle ensures that tourism does not exploit or deplete the resources it depends on, allowing future generations to experience and benefit from these resources (Buckley, 2009).

Importance of Insect Tourism

Population processes and spatial positioning with behavioural responses of insects enable scientists to measure environmental conditions. Insects hold important biological indicator value because they reveal changes in both habitat quality and pollution effects as well as ecosystem alterations thus serving as essentials for ecological monitoring. The presence of these insects in ecotourism operations enables them to teach basic principles about biodiversity conservation while focusing on environmental sustainability (Chung and Binti N, 2008).

Diversity records of insects along with their abundance changes help establish information on air quality and water status together with land resources and climate conditions. Certain species of insects demonstrate both pollution distribution and habitat damage through their absence or presence (Goulson, 2010).

Scientists have spent multiple years studying butterflies together with aquatic and beetle insects to identify their usage as bioindicators. Butterflies act as ideal indicators of climate change because their bodies strongly react to environmental temperatures and ecological conditions (Warren et al., 2001). Scientific assessments of freshwater ecological conditions depend on studying mayflies alongside caddisflies because these organisms demonstrate specific water pollution susceptibility in water bodies (Barbour et al., 1999). The correct operation of health assessments in ecosystems depends heavily on pollinators such as butterflies and bees because these insects perform key roles in pollination processes (Biesmeijer et al., 2006).

The numerous synchronized fireflies display indicates strong natural habitat health but reduced firefly populations suggest potential problems in wetland ecosystems (Stronza et al., 2019). At these designated ecotourism sites visitors gain the opportunity to study insect-environment relationships and contribute to habitat defense efforts that protect susceptible species.

Insect population decline across the globe exists as an urgent matter of environmental conservation. Scientists confirm that insects are decreasing in numbers because environmental scientists attribute this decrease to both habitat destruction and changes in climate as well as pesticide effects and pollution outcomes (Dirzo et al., 2014). The steep reduction of insect numbers impacts ecological stability because these organisms carry out vital ecosystem processes including pollination, waste cycle operations and soil nutrient management (Hallmann et al., 2017).

Local communities would experience economic rewards when they safeguard insect habitats which can occur through nature reserve creation together with sustainable pest-friendly agricultural practices (Lemelin, 2013).

Promoting Awareness About Endangered Insect Species Through Insect Tourism

Insects, despite their critical ecological roles, are increasingly threatened by factors such as habitat loss, pollution and climate change. Many species of insects, including bees, butterflies and fireflies are experiencing significant declines, which can have cascading effects on ecosystems. These insects are not only vital for functions like pollination, decomposition and soil aeration, but their presence also serves as a key indicator of ecosystem health (Goulson, 2010).

The direct economic impact from insect tourism allows for financial support of conservation efforts promoting the protection of endangered species along with their habitats. Tourists visiting insects can enable the revenue sharing between operators and local and international conservation organizations which supports environmental protection projects. Some butterfly parks together with insect reserves participate in community-based conservation initiatives that enable local people to protect habitats and regulate insect populations through measures against pesticide problems and fragmentation threats (Buckley, 2009).

Data and Statistics on Ecotourism Growth

- UNWTO, United Nations World Trade Organization (2018): The global ecotourism market was valued at $323 billion in 2017 and was expected to grow at an annual rate of 20 per cent. Ecotourism has become one of the fastest-growing segments within the travel industry
- TIES (2021): The International Ecotourism Society reports that ecotourism accounts for approximately 20-30 per cent of global tourism, with an increasing share of that market being dedicated to wildlife tourism and insect tourism

Conclusion

Tourism focusing on insects demonstrates sustainability alongside environmental education about insects through its promotion of conservation measures alongside economic assistance to local communities. The expanding insect tourism sector combines three key benefits that include environmental consciousness as well as local economic growth and sustainable practices maintenance. The decline of global insect populations makes insect tourism essential for conservation work because it provides financial value to preserve habitats. Insect tourism achieves sustainable ecological and economic growth through responsible behaviour implementation and scientific research integration. In the future insect tourism development will strengthen biodiversity preservation programs that benefit ecological systems as well as communities throughout the world.

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GENERAL ARTICLE

Space, Sight and Uzi Fly Parasitism in Muga Culture: A Conceptual Overview

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Abstract

Muga sericulture, an age-old tradition in Northeast India, is a vital cultural and economic practice, with Muga silk considered the most prized of all silks. However, outdoor rearing of Muga silkworms faces significant threats from the Uzi fly (*Exorista sorbillans*), an endoparasitoid whose infestations severely reduce crop yield. The parasitism strategies of tachinid flies are strongly influenced by host dynamics, including larval movement, density, and habitat conditions, as well as visual and olfactory cues. Studies reveal that female tachinids utilize movement, shape, and color cues in host detection, with preferences for moving larvae and specific visual contrasts. Habitat fragmentation and sparse host plant distribution further exacerbate parasitism risks in Muga ecosystems. This article explores heuristic approaches linking host behavior, larval aggregation, and habitat management with tachinid parasitism. Understanding these interactions provides valuable insights for developing eco-friendly, behavior-based pest management strategies to safeguard Muga sericulture against Uzi fly infestations.

Keywords: Muga, Uzi fly, Tachinid, Parasitism, Host–parasitoid interactions

Introduction

Muga culture, a traditional practice among the rural population of Northeast India, has been deeply intertwined with the region's society and culture for centuries. Muga silk, the most valuable of all silks, is a source of pride for the Indian state of Assam. However, the outdoor rearing of Muga silkworms makes them vulnerable to natural fluctuations, which can negatively affect crop yields. Among the major threats to Muga silkworms is the endoparasitoid, Uzi fly (*Exorista sorbillans* (Louis) (Diptera: Tachinidae). The infestations caused by Uzi fly typically begin in April and persist until October, primarily affecting 3rd, 4th and 5th instar Muga larvae. Tachinid flies exhibit intricate behaviors influenced by host movement and visual cues, which are crucial for their parasitism strategies. Several studies have shown that host location behaviour by female tachinids can be elicited by tactile-chemosensory cues associated with the host, and by the host's food plants (Stireman *et al.,* 2006). Females use chemosensors present on their front tarsi, which may function similarly to the chemosensors on the long antennae of many hymenopteran parasitoids. In addition to tactile-chemosensory cues, visual cues are also important in the final stages of the tachinid host location process, especially for species that use the direct strategy. In this article, a few heuristic approaches are presented to better understand the influence of host dynamics and visual signals on the parasitism rates of Tachinids, particularly the Uzi fly.

Host movement and parasitism

Tachinid flies, such as *Exorista japonica* (Tachinidae: Diptera), utilize a range of visual cues to locate their hosts. When encountering a host, *E. japonica* females display a sequence of behaviors: they initially exhibit 'fixation' by turning towards the host, then proceed to 'approach' by moving within 1 cm, and finally, they 'pursue' the crawling larva (Yamawaki *et al.,* 2002). The flies' 'examination' behavior involves facing and touching the host with their front tarsi (Nakamura, 1997). However, the pursuit of the host is primarily controlled by visual stimuli at close range (Yamawaki *et al.,* 2002). The stimuli may include movement, shape or colour of the object *per se* the host larva. In support, in one of the studies, females responded to moving artificial stimuli, such as a black rubber tube, suggesting that larval movement is a key attractant (Yamawaki and Kainoh, 2005). This preference for moving targets is not unique to *E. japonica*; for instance, *Drino inconspicua* females walk directly towards moving objects over distances of 9–10 cm (Dippel and Hilker, 1998). Similarly, *Compsilura concinnata* (Weseloh, 1980) and *Exorista mella* (Stireman, 2002) exhibit a behavioral preference for moving objects over stationary ones. Interestingly, *Drino bohemica* shows a preference for moving feathers in a Y-tube olfactometer, even when odors from larvae are present (Monteith, 1956). Field observations also reveal that *Bessa parallela*

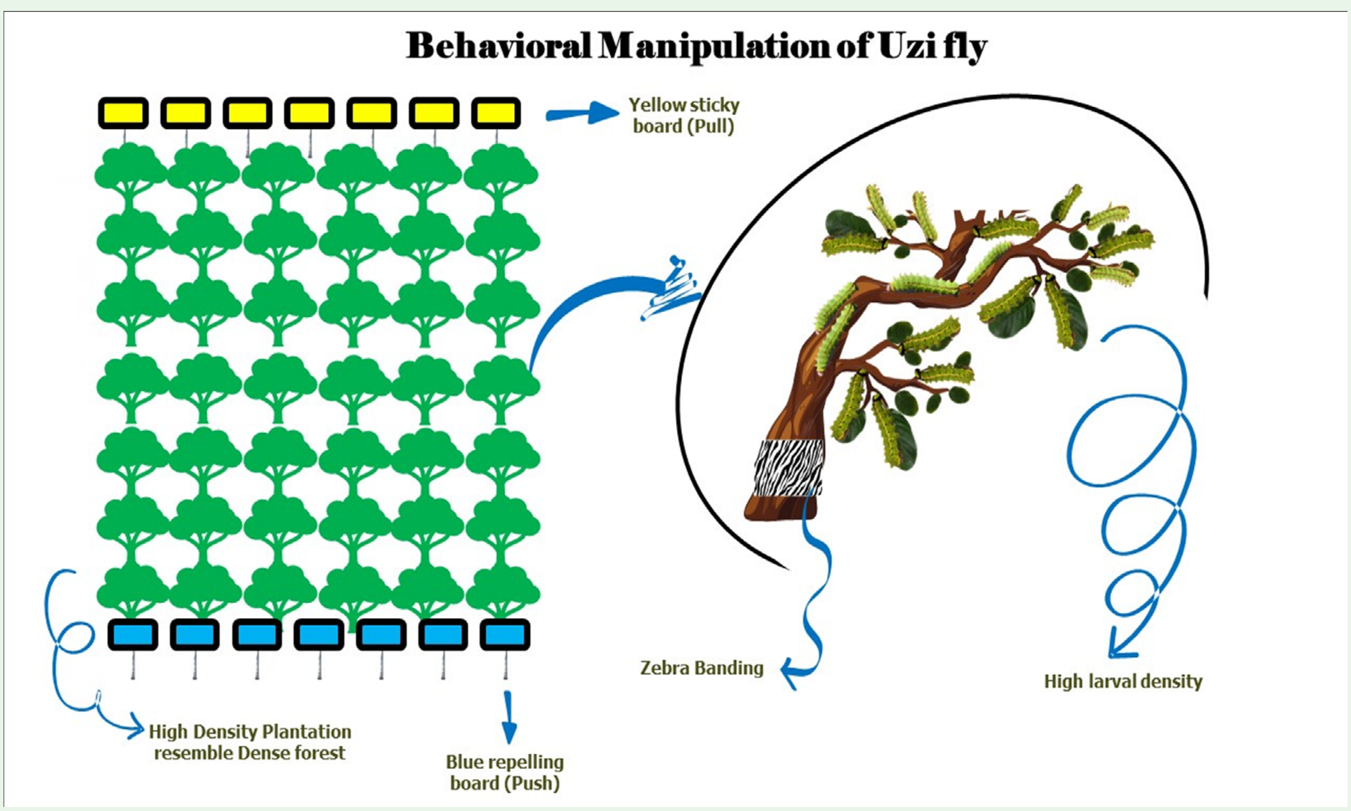

Figure 1. Behavioural alteration of Uzi flies via manipulating density and visual factors

prefers to lay eggs on actively moving larvae of the Euonymus leaf notcher, *Pryeria sinica* (Ichiki *et al.,* 2006). In the Muga ecosystem, the movement of larvae significantly increases during the later instar stages, which may lead to a higher likelihood of infestation by Uzi flies. However, this needs to be confirmed by conducting behavioural assay and field studies.

Parasitism in dense larval aggregations

The tachinids also show sophisticated temporal host preference based on the larval aggregation. In one of the investigations, flies were more likely to parasitize in areas with higher larval densities of western tussock moth, although the rate of parasitism per individual fly decreased with increasing larval numbers (Umbanhowar *et al.,* 2003). Flies tended to gather in dense patches, which helped maintain high levels of parasitism. However, it was unclear whether this clustering happened because more flies were arriving in those areas or because they were staying there longer. However, Roland and Taylor (1997) also revealed that parasitism by larger parasitoid flies was positively related to caterpillar density but exhibited negative delayed density dependence. This means that while parasitism increased with caterpillar numbers, the rates eventually declined as densities continued to rise. In the Muga ecosystem, the larval density during the later instar stages will be sparse as the larvae disperse across the trees in search of food. This dispersion may increase the likelihood of Uzi flies being attracted to them. Thus, increasing the larval density per tree and frequently transferring larvae from consumed foliage to fresh foliage may help reduce the risk of Uzi fly attacks (Fig. 1).

Impact of habitat fragmentation on parasitism

Nowadays, urbanization is advancing rapidly, which is having a devastating impact on biodiversity. This trend is also leading to significant forest fragmentation. As urban areas expand, natural habitats are increasingly divided into smaller, isolated patches. Roland and Taylor (1997) investigated the effects of forest fragmentation on parasitism rates of the forest tent caterpillar, *Malacosoma disstria* in central Canada. Their study highlighted that forest fragmentation significantly affected parasitism rates. Larger tachinid parasitoid species (*Patelloa pachypyga* and *Leschenaultia exul*) which lay eggs on leaves that are subsequently ingested by the larvae were more impacted by fragmentation across broader spatial scales, while smaller tachinid species (*Carcelia malacosomae*) which attack host larva directly performed better in fragmented patches. This suggests that habitat fragmentation can differentially affect parasitoid species, with larger species potentially struggling due to greater distances between habitat patches. In North-East India, where Muga sericulture is practiced extensively, Som and Soalu plantations are distributed sparsely. This sparse distribution can resemble forest fragmentation, which may contribute to an increased prevalence of parasitism by Uzi flies. The fragmented landscape disrupts the natural habitat and can make it easier for Uzi flies to locate and infest the larvae. To address this issue, it is important to explore strategies for more efficient plantation management such as high-density planting of Som and Soalu tree or others, and habitat conservation to reduce the impact of parasitism and ensure the sustainability of Muga sericulture (Fig. 1).

Visual cues for host location

In addition to olfactory cues, tachinid females also use various visual cues, such as the shape and color of the larvae or their associated habitat, to locate host-infested plants. These visual indicators help them identify suitable sites for oviposition. Ichiki *et al*. (2011) found that *E. japonica* females showed a significantly higher landing rate on green paper plant models (84.6%) compared to yellow (53.8%), blue (38.5%), or red (30.8%) models when host-infested plant odors were present. This preference indicates that visual cues such as plant color play a significant role in host detection. Furthermore, there is an intriguing evolutionary aspect related to the repellence of dipteran flies. The alternating white and black bands observed in some animals, such as zebras, appear to deter the landing of dipteran flies, including tabanids (Caro *et al.,* 2019; Chandrakumara *et al*., 2022). This effect is thought to be related to the polarization of light caused by the varying colors and the width of the bands. The hypothesis is that the contrasting bands disrupt the visual patterns that flies use to locate hosts. Incorporating such alternating banding patterns might also help deter Uzi flies from infesting Muga silkworms. However, studies are necessary to explore and confirm the effectiveness of this approach in practical pest management (Fig. 1).

Conclusion

Tachinid flies demonstrate complex behaviors influenced by visual and movement cues in their parasitism strategies. Considering these behaviors, alongside the impacts of environmental factors like habitat fragmentation, provides valuable insights into their ecological roles and informs pest management practices. Understanding these cues can enhance our ability to manage and mitigate infestations by improving monitoring and control strategies for pests, especially when the host is reared outdoors. All of the alternative strategies mentioned could potentially be effective in the Muga culture to mitigate the nuisance of the Uzi fly (Fig. 1). However, extensive studies are needed to confirm their efficacy and ensure their practical application in managing the pest. Further research will help determine which approaches are most successful and how they can be best implemented. Effective integration of both olfactory and visual cues into pest management practices could lead to more targeted and efficient control measures. Future research should also continue to explore these dynamics to further refine our understanding of parasitoid-host interactions.

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GENERAL ARTICLE

Insect Pollinators: Diversity, Role and Ecological Importance

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Abstract

Insect pollination is an eco-system function for agricultural food production, and it is crucial to the production of many fruits, vegetables, and field crops. Honeybees accounting for 80% of insect pollination, play a crucial role in global crop pollination. In addition to bees, other insects that pollinate at a considerable pace include beetles, wasps, butterflies, and moths. The seeds from a crossl-pollinated bloom have a higher chance of germination and qualityfruit. Successful pollination can shorten the interval between flowering and fruit set, lessening the chance of fruit being exposed to pests, diseases, unfavourable weather, and agrochemicals.

Keywords: Agriculture, insect, fruits, pollinators

Introduction

Interactions between plants and pollinators are important mutualistic relationships in agricultural food production and offer essential ecological services that sustain biodiversity worldwide. Animal pollinators are thought to be necessary for reproducing 87.5% of blooming plants (Ollerton et al. 2011). According to Klein et al. (2007), animal pollination is essential for 35% of worldwide crop output volumes and 87 of the world's most important food crops. Flowering plants and insect pollinators are mutually dependent. For pollinators, nectar and pollen are dietary incentives. Pollinators are an incredibly varied group of animals that help flowering plants spread their pollen. Fertilisation occurs after pollinators transfer pollen from anthers to stigmas. Pollination can be aided by interactions between pollinators and plants, particularly when the plants are self-incompatible. Numerous insect groups, viz., bees, butterflies, moths, beetles, wasps, and flies, act as pollinators of different types of plants. Insects are the most varied and prevalent pollinators; for example, the Lepidoptera are thought to have about 140,000 species, the Coleoptera (77,300 species), and the Hymenoptera (70,000 species) (Wardhaugh, 2015). Among all insect groups, bees are the most significant and efficient pollinators.

Diversity of Insect Pollinators

The most varied category of pollinators is insects, which include a large number of species with distinct ecological niches and behaviours. Among the significant groups are:

Bees (Hymenoptera)

Honeybees (*Apis spp.*): Commercial crop pollination was also accomplished by very efficient generalist pollinators. The western honey bee (*Apis mellifera L.)* is the most common pollinator species for crops globally and offers highly valued pollination services for a wide range of agricultural crops (Garibaldi et al., 2013).

Table 1: Different species of honeybees and their native habitat (Thapa, 2006)

Sr. No.	Scientific Name	Common Name	Native habitat
1	*Apis dorsata* Fab.	Rock Bee Asia	Asia
2	*Apis florea* Fab.	Little Bee	Asia
3	*Apis laboriosa* Smith.	Largest Bee	Asia
4	*Apis cerana* Fab.	Asiatic Hive Bee	Asia
5	*Apis andreniformis* Smith.	Smallest Bee	Asia
6	*Apis mellifera* Lin	European Bee	Europe
7	*Apis koschevnikovi* Enderlein	Red Bee	Malaysia
8	*Apis nuluensis* Lin.	Malaysian Bee	Malaysia

Bumblebees *(Bombus spp.)*: Specialists in buzz pollination, crucial for crops like tomatoes. Bumblebee pollination in polyhouses produces greater fruit set, larger fruit size, and higher yields than other pollination methods. Bumblebees can increase fruit form, firmness, and seed set rates, yielding higher-quality produce. Bumblebees are extremely efficient pollinators, visiting multiple flowers per minute and carrying more pollen.

Solitary Bees (e.g., Mason bees, Leafcutter bees): Important for niche ecosystems and specific crops like almonds and blueberries.

Butterflies and Moths (Lepidoptera)

Butterflies, such as monarchs, are day-active pollinators that prefer to visit brightly coloured flowers with ample nectar. Moths, such as hawk moths, are nocturnal and contribute to the pollination of pale or fragrant night-blooming flowers.

Dipterans

Other flies, including midges, play a role in cacao pollination, essential input for manufacture of chocolate.

Wasps (Hymenoptera)

Wasps, though less efficient than bees, contribute to pollination, especially for specific plants like figs in mutualistic relationships.

Beetles (Coleoptera)

Often referred to as mess and soil pollinators, they are critical for ancient plant lineages such as magnolias.

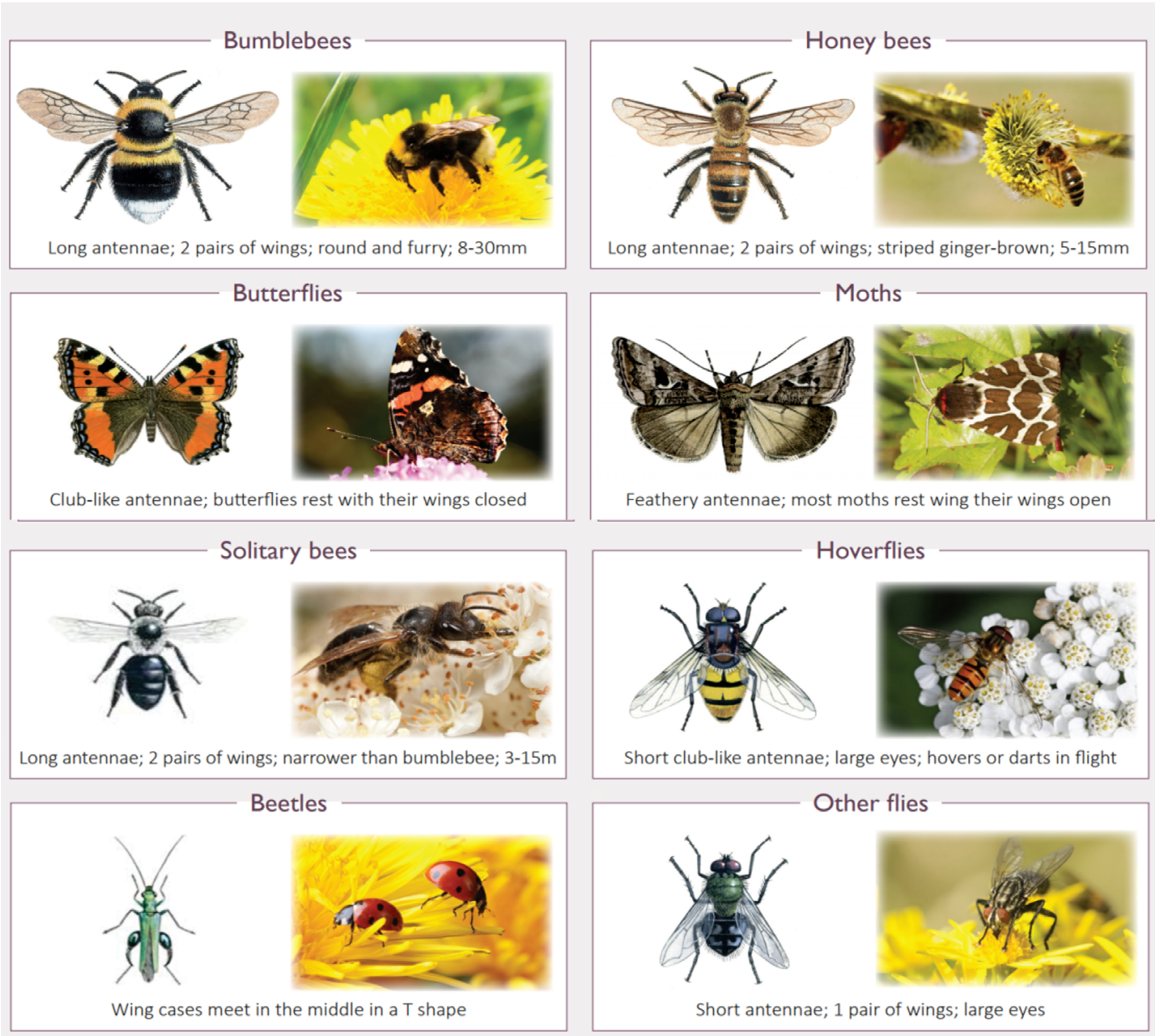
Roles in Ecosystems

As essential components of biodiversity, insect pollinators play a crucial role in:

Crop Pollination: More than one-third of the food and drink consumed depend on animal pollination to meet a variety of needs. Pollinators contribute to the production of primary food crops, medications made from plants, and other necessary goods. By resolving pollination deficiencies in cultivated regions, effective management of insect pollination services can reduce production risks and increase benefits. (Abson et al., 2011).

Wild Plant Pollination: For reproduction, almost 90% of blooming plants in wild depend on pollinators.

Ecosystem Stability: In order to maintain herbivores and higher trophic levels, pollinators encourage plant reproduction.



Diversity of Insect pollinators (Source: https://www.open.edu/openlearncreate/mod/book/view)

Threats to Insect Pollinators

Habitat Loss and Fragmentation: Reduces nesting sites and floral resources. Habitat loss and fragmentation, caused by urbanization, intensive agriculture, and deforestation, reduce the availability of suitable foraging and nesting resources for pollinators.

Pesticides: Pesticides are frequently employed in urban and agricultural systems, and they have both immediate and long-term negative impacts on pollinators. When pollinators are exposed to high levels of pesticides, toxicity may be severe.

Climate Change: Alters flowering times and pollinator activity patterns which significantly contribute to pollinators decline

Diseases and Parasites: Pathogens and diseases are affecting pollination population

Insects: biodiversity, threat status and conservation approaches

Habitat Restoration: Use a variety of flowering plants to create landscapes that are pollinator-friendly.

Integrated Pest Management: Adopting pollinator-safe practices and reducing the usage of pesticides are important.

Research and Monitoring: Increase knowledge about understudied pollinator groups.

Public Awareness: Encourage communities to build pollinator gardens and adopt more environmentally friendly habits.

Conclusion

Insect pollinators are essential component of both natural ecosystems and human agriculture. Flowers that are pollinated effectively produce quality fruit and seeds. However their population persistently threatened by habitat loss, pesticides use and climate change. To conserve their populations, global actions must be coordinated to address the risks they confront. The unique contributions of pollinators to various crops highlight their critical role in agriculture, influencing both economic and dietary results globally. We may ensure future generations' ecological responsibility by promoting biodiversity and sustainable activities.

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GENERAL ARTICLE

AI and the Bees: A New Era of Sustainable Beekeeeping

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Abstract

Artificial Intelligence (AI) is revolutionizing the beekeeping industry by emulating human intelligence to optimize hive management and enhance productivity. This technology has begun to address longstanding challenges faced by beekeepers, such as disease detection and environmental monitoring. Innovations like smart hives equipped with real-time sensors and software for identifying pests are improving operational efficiency and increasing honey production while promoting the health of bee populations. As the beekeeping sector grapples with disease management and climate variability issues, AI provides critical solutions that transform traditional practices.

Keywords: Artificial Intelligence, Bees, Beekeeping, Sustainability

Introduction

Beekeeping faces significant challenges, with colony decline as a primary concern. A significant contributor to this decline is colony collapse disorder (CCD), where bees abandon their hives. Although the exact causes of the disorder remain unclear, potential reasons include pesticides, pests, and malnutrition. Pesticides used in agriculture pose direct and indirect threats to bees, affecting both the insects and their food sources. Varroa mites spread viruses, and insufficient nutrition reduces bee vitality. Beekeeping, or apiculture, plays a crucial role in the agricultural sector, primarily for honey production and pollination services. Historically, beekeeping relied on traditional methods that required significant human labour and experience. However, technological advancements, especially in Instrumental bee breeding, Artificial Intelligence, are revolutionizing this age-old practice. AI facilitates automated, data-driven decision-making, allowing beekeepers to enhance hive management quality while minimizing human intervention. The integration of Artificial Intelligence (AI) in beekeeping marks a significant transformation in apicultural practices, aimed at improving efficiency, productivity, and sustainability.

Applications of AI in Beekeeping

1. Smart Hives: The Beehome System

Beehome is the world's first automated hive, developed by Israeli startup Beewise, is an autonomous apiary. It can house up to 40 hives of bees, or 2 million bees, and the system takes care of their health in every aspect; it even performs hive management and honey harvesting (Ecocolmena, 2020). This system monitors various environmental and health parameters to ensure optimal living conditions for bees. The technology's ability to automate routine tasks—

such as hive inspection, honey harvesting, and even pest management—enables beekeepers to monitor multiple hives remotely and decreases the risk of human error. Advanced computer vision and predictive analytics within the system contribute to effective hive management, resulting in increased honey production and healthier bee populations.

2. Disease Detection and Monitoring

A significant challenge in beekeeping is managing diseases that threaten bee colonies. Colony Collapse Disorder (CCD) and various viral infections can devastate hives, leading to economic losses (Nieto and Galan, 2018). To combat these issues, Jerry Bromenshenk and his team, have developed an AI application capable of analyzing the sound frequencies of buzzing bees. This technology serves as an effective early-warning system; by detecting changes in buzzing patterns, the application can alert beekeepers to potential health issues within the colony. Moreover, a remote monitoring device developed by students from the Universidad Tecnologica Nacional - Facultad Regional Buenos Aires employs IoT technology in combination with AI to monitor hives continuously (Anonymous, 2019). The device collects data on temperature, humidity, and weight, allowing beekeepers to assess hive health from afar. By automating this monitoring process, beekeepers can promptly identify and address conditions that could harm the hive.

3. Pest Management: Varroa Mite Detection

Pest management is another critical area where AI can significantly enhance beekeeping practices. The Varroa mite poses a severe threat to bee populations and is a common concern among beekeepers. Innovative image recognition systems using AI can identify and quantify the presence of Varroa mites within hives. A project focusing on image processing algorithms enables beekeepers to visually confirm the presence of mites through photos, facilitating timely treatment before infestations escalate. This level of precision and efficiency enhances hive management, potentially saving entire colonies from collapse.

The incorporation of AI into beekeeping presents transformative benefits. Not only does it improve operational efficiency and reduce labour costs, but it also enhances bee health and productivity. By adopting these technologies, beekeepers significantly minimize their risk of losing entire colonies due to diseases or pests. For the industry, this means more consistent honey production and better overall hive health. Furthermore, these innovations can lead to

Figure 1. Beehome the apiary with AI (Artificial Intelligence) and automated (Source: Ecocolmena, 2020)

sustainable practices by promoting interventions that do not harm bee populations. With the ongoing challenges posed by climate change, habitat loss, and declines in bee populations, integrating technology provides a path forward. As apiculture increasingly overlaps with tech sectors, there is potential for ongoing advancements that can elevate bee management practices.

Conclusion

The application of Artificial Intelligence in beekeeping signifies a remarkable shift in how apiculture is practiced. The beekeeping industry stands at the doorstep of a new era where data-driven techniques can significantly improve productivity and sustainability. As technology continues to advance, the future of beekeeping will likely involve even more sophisticated AI tools that ensure the health of bee populations and the economic viability of beekeeping operations.

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GENERAL ARTICLE

Tracing the Pollen: Unraveling Insect-Plant Interaction through Entomopalynology

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Abstract

The diversification of plants has been shaped by pollination; a fundamental ecological process crucial for the reproductive success of approximately 80% of angiosperms. Insects are important pollinating agents. Clarifying ecological linkages, maintaining biodiversity, and maximizing agricultural productivity depend on an understanding of pollen-insect interactions. The study of pollen linked to insects, or Entomopalynology, offers important information about pollination networks, pollinator food preferences, and ecological stability. Methodological developments like as network analysis, automated pollen identification, and pollen DNA metabarcoding have improved the precision of research on pollen-insect interactions. While structural assessments of pollination networks help to understand ecosystem resilience, investigations have shown that pollen particle size affects pollinator selection. Long-term evaluations of plant-pollinator dynamics are further made possible by field observations and the analysis of museum specimens. Through identification of keystone pollinators and the improvement of habitat management techniques, these studies aid conservation efforts. Future research should expand beyond and integrate interdisciplinary approaches for spanning ecology, genetics, and climate science. Given the increasing impact of anthropogenic changes and climate fluctuations on pollination systems, entomopalynology play a pivotal role in guiding adaptive strategies for biodiversity conservation and sustainable agriculture.

Keywords: Pollination, Entomopalynology, Pollen-Insect Interaction, Pollen DNA Metabarcoding, Pollination Networks, Biodiversity

1. Introduction

Pollination is a crucial ecological activity that has shaped the diversification of different seed plant families throughout evolutionary history (Ollerton et al., 2019; Asar et al., 2022). Gymnosperms and angiosperms demand pollination for sexual reproduction; around 80% of angiosperms depend on biotic pollinators, predominantly insects (Von Aderkas et al., 2018), to enable this process. Pollen-insect interaction studies are crucial for comprehending the intricate linkages that facilitate pollination, which is critical for the reproduction of several plants and the overall vitality of ecosystems. Robust pollinator populations enhance plant diversity, hence sustaining a multitude of other creatures within the environment which is essential for sustaining ecosystem services. In agriculture, numerous crops rely on insect pollination to optimize yield. Pollinators contribute substantially to the food supply (Van der Sluijs and Vaage, 2016); one in three bites of food we consume is directly associated with pollinator activity. Comprehending these connections aids in formulating ways to improve crop yield and guarantee food security. Examining pollen-insect interactions facilitates the identification of essential species and elucidates their functions within ecosystems. Targeted conservation strategies may be established based on these ideas. Considering these, entomopalynology, the study of pollen associated with insects, is gaining recognition for its significant contributions to understanding ecological interactions, particularly in pollination biology. This field not only enhances our knowledge of insect behavior and ecology (Sharma et al., 2023) but also has practical implications for agriculture (Saunders, 2018), conservation (Balasubramanian,

Table 1. Economic uses of pollen.

Sl no.	Details	References
1	**Pollen-Based Materials**	
	Pollen Paper: Scientists have developed a paper-like material derived from softened pollen grains that responds to environmental humidity changes. This material can be used in applications such as:	Zhao et al., 2020
	Green Analytical Chemistry: Sorbent for Solid-Phase Extraction (SPE): Pollen grains, due to their robust outer coating (sporopollenin), serve as low-cost, green sorbents for hydrophilic solid-phase extraction. They are used for separating organic acids and phenolic compounds, reducing reliance on silica-based sorbents, which have environmental and health risks. Pollen's natural adsorption ability makes it a promising material for miniaturized methodologies in analytical chemistry.	Li et al., 2021
2	**Functional Food and Feed**	
	Human Nutrition: Pollen is marketed as a dietary supplement in forms such as granules, capsules, powders, and tablets. It is rich in bioactive compounds like polyphenols, flavonoids, vitamins, and amino acids	Kostić et al., 2020
	Fermented pollen products improve nutrient bioavailability and antioxidant capacity, with potential health benefits like antitumor effects	
	Animal Feed: Pollen-based feed enhances animal growth, health, and meat quality. It is incorporated into bakery products, juices, and meat formulations to improve nutritional and functional properties	
3	**Therapeutic Applications**	
	Bee pollen is studied for its therapeutic potential in treating allergies, boosting immunity, and improving overall health due to its nutrient-rich composition	Khalifa et al., 2021
4	**Allergen Extracts**	
	Pollen is utilized in the production of allergen extracts for diagnostic and therapeutic purposes in allergy treatments	Codina et al., 2015
5	**Environmental Sustainability**	
	Pollen-based innovations reduce the ecological footprint by replacing synthetic materials with biodegradable alternatives. This aligns with global efforts toward sustainability	Şenol et al., 2023

2017), and forensic science (Alam et al., 2024). The current article focusses on the importance of entomopalynology, with its present implications and approaches to understanding the pollen–insect continuum.

Among diverse economic products of honeybees (Figure 1), apart from its role in pollination, bee pollen has various applications in the market, contributing to diverse industries such as materials science, food production, and green chemistry (Table 1). Below are the key areas where pollen is economically valuable:

2. Importance of pollen study in pollination ecology

Studying pollen-plant-insect interactions is critical for understanding ecological dynamics and ensuring the sustainability of both natural ecosystems and agricultural systems. The coevolution of these relationships highlights the intricate connections that have developed over time, emphasizing the need for continued research and conservation efforts in this area. The following are the crucial roles for understanding the pollen-plant studies.

2.1.Understanding pollinator interactions through pollen studies

Pollen studies play a crucial role in elucidating the complex interactions between pollinators and flowering plants. For example, the spring ephemeral *Corydalis ambigua* Cham. & Schltdl. is flowering earlier in mountain habitats due to earlier snowmelt, but the pollinators

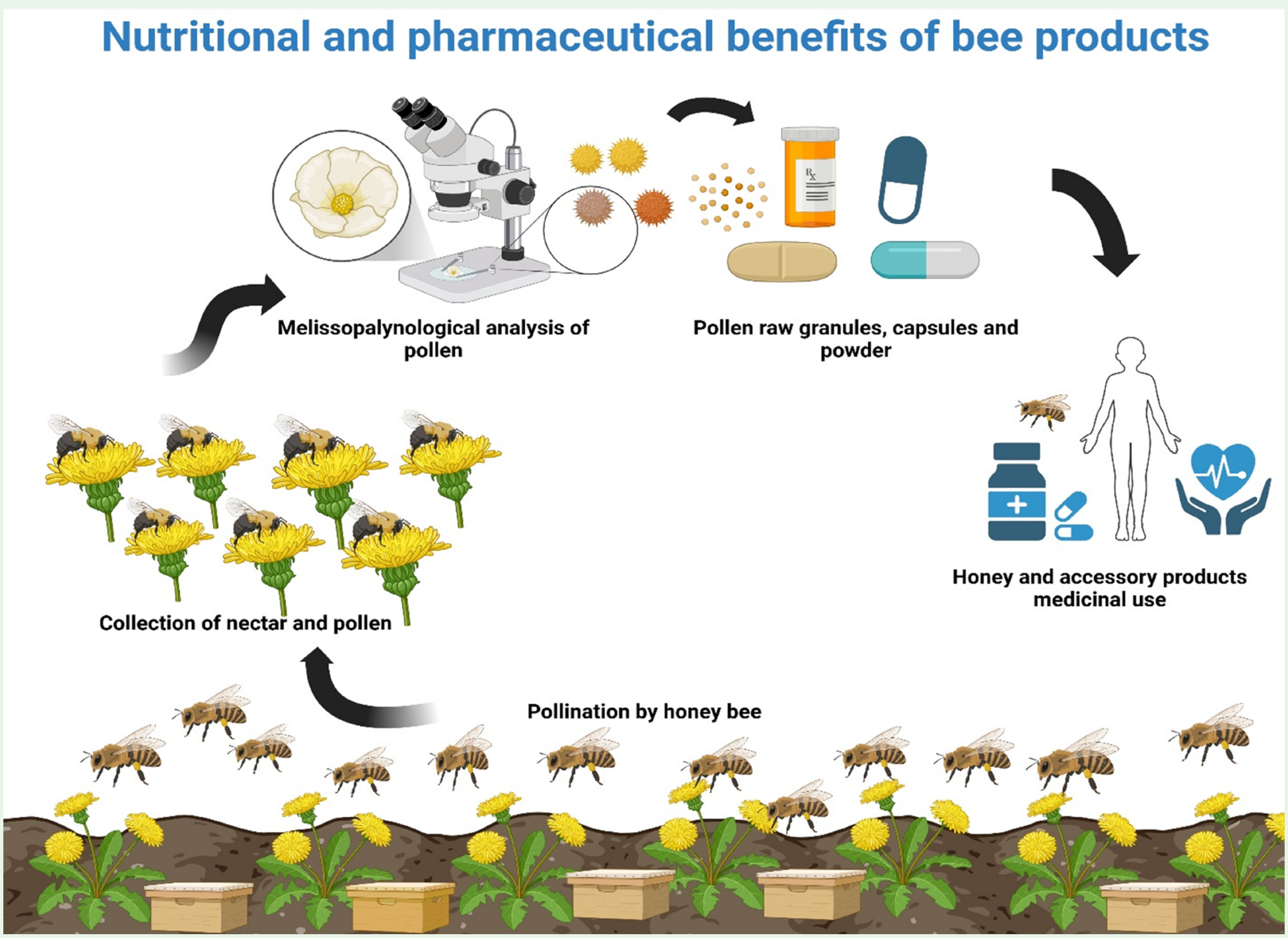

Figure 1. Nutritional and pharmaceutical benefits of bee products

(*Bombus hypocrita* and *B. hypnorum koropokkrus*), whose emergence is associated with soil temperature, are not always synchronized with flowering commencement, resulting in lower seed production (Kudo and Ida, 2013). By examining the pollen carried by various insect species, researchers can gather insights into the dynamics of these ecological relationships, which are vital for ecosystem health and agricultural productivity (Byers, 2017) (Table 2).

2.2. The role of pollen in pollination ecology

Pollen serves as a key component in the study of pollination ecology. Insects may interact with pollen in several ways: consuming it, passively carrying it, or actively transporting it to other plants. This interaction can reveal dietary preferences and patterns of floral visitation among pollinators. Analyzing pollen grains on the bodies of pollinators allows scientists to approximate pollen availability and track changes in plant-pollinator interactions over time, which is essential for understanding the impacts of environmental changes such as habitat loss and climate change (Galan et al., 2014). In particular, it is also observed that bees would prefer small (lipid-rich, starchless) pollen grains over large (starchy) grains because larger grains are envisioned as having relatively lower nutritional value (Hao et al., 2020).

Pollinator preferences are highly responsive to pollen nutritional profiles, floral trait integrity, and environmental volatility (Table 3). Climate change and habitat loss amplify these shifts, disrupting pollination networks. Conservation strategies must prioritize diverse, nutritionally rich floral resources and habitat connectivity to buffer against these dynamics.

2.3. Pollen-Insect Interaction Networks

Recent research has focused on constructing pollen-insect interaction networks, which provide a comprehensive view of how different species interact within an ecosystem. For instance, studies have utilized bipartite meta-networks to link specific pollen types with the insect species that carry them (Grass et al., 2018). For example, Hall et al. (2022) developed a bipartite meta-network across different land uses- remnant native forest, avocado orchard, dairy farm, and rotational potato

Table 2. Case studies of pollen mediated insect-plant synergism

Case/Study System	Insect(s) Involved	Plant(s) Involved	Synergism/Interaction Observed	Reference
Ant pollination in Proteaceae	Ants (various species)	*Conospermum*	Ants carry pollen with high germination rates (~80%), comparable to bees; ants significantly contribute to seed set	Delnevo et al., 2020
Tracking pesticide residues via pollen in honey bees	Honey bee (*Apis mellifera*)	*Spiraea spp.* (Rosaceae)	Entomopalynology traced highly toxic pollen loads to Spiraea, linking plant source to bee exposure risk	Soufbaf et al., 2018

Table 3. Plant factors affecting pollinator preferences

Sl no	Factor	Impact on Pollinator Preferences	Ecosystem Consequence
1	Optimal P:L ratios	Bees favor plants with ≈5:1 ratios; avoid lipid/protein extremes	Shapes plant community composition
2	Phenological shifts	Delayed flowering increases specialist pollinator efficacy; advances reduce generalist foraging	Alters seed set and plant reproduction
3	Habitat fragmentation	Reduces high-quality pollen access; intensifies selective foraging	Lowers pollinator diversity and abundance
4	Extreme weather	Destroys forage; forces range shifts (e.g., bumble bees moving northward/uphill)	Increases pollinator mortality and mismatch

crop- within a mosaic agricultural landscape. They found that agricultural sites like crops and dairy farms exhibited higher richness and strength of pollen–insect interactions compared to small forest patches and orchards. Notably, many interactions involved flies, wasps, and beetles, highlighting the ecological importance of often-overlooked pollinator groups. Additionally, bipartite meta-networks reveal that pollen-load data can uncover more interactions per individual insect than direct visitation observations, offering a more nuanced and comprehensive picture of pollinator roles and network structure. This dual perspective is essential for effective conservation planning, as it highlights both the generalist and specialist interactions that sustain pollinator communities across landscapes. This approach enables researchers to identify key relationships and assess how land-use types influence these interactions. The structural analysis of pollination interaction networks may provide key information on network stability and robustness under environmental change (Grass et al., 2018). By comparing interactions across various landscapes, such as agricultural fields versus natural habitats, scientists can determine which environments support the most diverse and robust pollinator communities. The study of historical pollinator specimens and associated pollen loads- central to entomopalynology- offers a unique window into how pollinator preferences have expanded or contracted over evolutionary timescales. Museum collections, some spanning over a century, are increasingly used to reconstruct past plant–pollinator networks and reveal the ecological and climatic drivers behind these changes (Table 4).

Further, obligate pollination mutualisms (Table 5) such as fig-fig wasp, yucca-yucca moth, and oil palm-oil palm weevil- represent some of the most specialized and ecologically significant plant–pollinator relationships. The availability and quality of pollen are central to the stability, reproductive success, and vulnerability of these systems.

3. Methodological Innovations and approaches to study pollen-insect interactions

Innovative methodologies have emerged to enhance the study of pollen-insect interactions.

Table 4. Evolutionary Shifts in Pollinator Preferences

Pollinator Group	Time Span (Specimens)	Observed Shift	Ecological Driver	Reference/Study Region
Bumble bees	1900–2020	Host range expansion	Habitat loss, exotics	UK, North America
Long-tongued solitary bees	1950–2015	Host range contraction	Floral partner decline	Mediterranean Europe
Monarch butterflies	1920–2020	Northward range shift	Climate warming	North America
Syrphid flies	1900–2000	Phenological shift (earlier)	Temperature rise	Central Europe

Table 5. Examples of obligate pollination mutualism and ecological factors affecting it

System	Pollinator	Plant Partner	Role of Pollen	Vulnerability Factors
Fig–Fig wasp	Fig wasp (Agaonidae)	*Ficus spp.*	Essential for wasp and seed development	Pollinator decline, habitat loss
Yucca–Yucca moth	Yucca moth	*Yucca spp.*	Required for fertilization and moth larvae	Climate shifts, pollen limitation
Oil palm–Oil palm weevil	Oil palm weevil	*Elaeis guineensis*	Key for fruit set and oil production	Weevil decline, poor pollen quality

The integration of museum specimens with field observations allows researchers to analyze historical data on insect-pollen networks across different spatial and temporal scales (Table 6). This approach not only enriches our understanding of current interactions but also helps reconstruct past dynamics, providing context for contemporary ecological changes (Balmaki et al., 2022). By identifying which insect species are effective pollinators for specific plants, conservationists can prioritize habitats that support these interactions. For example, findings indicate that certain land-use practices can enhance or diminish the richness and strength of pollen-insect interactions (Hall et al., 2022). Therefore, targeted management strategies at both field and landscape scales can significantly impact pollinator conservation outcomes.

3.1. Approaches to Study Pollen-Insect Interactions

The study of pollen-insect interactions employs a variety of innovative methodologies that enhance our understanding of these complex ecological relationships. Below are some key approaches currently being utilized in this field (Table 7).

3.2. The Role of Entomopalynology from an Ecotoxicological Perspective

Entomopalynology—the study of pollen carried by insects—offers unique and powerful tools for ecotoxicological research, particularly in the context of environmental contamination, pesticide exposure, and the health of pollinator communities.

Table 6. Pollen related Studies and their Implications

Sl no	Study Title	Targeted Crops	Implications	References
1	Land use and pollinator dependency drive global patterns of pollen limitation	Various wild plants	Highlights the impact of urbanization on pollen limitation in plants reliant on pollinators, emphasizing the vulnerability of ecologically specialized species.	Bennett et al., 2020
2	Review of European studies on pollination networks and pollen limitation	Wild plants in Europe	Quantifies the distribution of plant-pollinator network studies and identifies data gaps, stressing the need for more comprehensive research in Eastern Europe.	Bennett et al., 2018
3	Plants, pollinators and their interactions under global ecological changes	Various native and introduced plants	Discusses how urban pollinators forage from a wide range of plants, emphasizing the importance of understanding plant-pollinator communities for ecosystem management.	Bell et al., 2023
4	Evaluation of sampling effort required to assess pollen species richness	-	Provides insights into the sampling efforts needed to accurately assess pollen diversity associated with various pollinators, aiding in a better understanding of ecological interactions.	Nikkeshi et al., 2021
5	Pollen grain size associated with pollinator feeding strategy	Various flowering species	Confirms a link between pollinator behavior and pollen grain size, which can inform agricultural practices by highlighting effective pollinator species for crop types.	Hao et al., 2020

3.2.1. Tracking Pesticide and Pollutant Exposure:

Pollen collected by insects (especially bees) can serve as a bioindicator of environmental contamination. By analyzing pollen loads from insect bodies or within their digestive tracts, researchers can detect the presence and distribution of pesticides, heavy metals, and other toxicants in agricultural and natural landscapes. This approach helps identify specific plants or locations contributing to pollinator exposure, supporting targeted risk assessments and mitigation strategies (Mendonça et al., 2022).

3.2.2. Assessing Sublethal and Chronic Effects:

Entomopalynological techniques allow for the monitoring of both acute and chronic exposure to contaminants. For example, pollen collected from bee hives can be analyzed over time to reveal patterns of pesticide use, changes in residue levels, and potential links to declines in pollinator health or colony collapse. Such data are essential for understanding the long-term, sublethal impacts of agrochemicals on pollinator populations and ecosystem services (Stoner et al., 2019).

Table 7. Approaches employed to understand the pollen insect interactions.

Sl no	Approach	Description	Key Techniques	References
1	Museum Specimen Analysis	Utilizes historical insect specimens to analyze pollen loads, providing insights into past pollination networks and changes over time.	Pollen extraction from museum specimens, network analysis of pollen-insect interactions.	Balmaki et al., 2022
2	Field Observations and Sampling	Involves direct observation of floral visitation by pollinators, allowing for the collection of data on pollinator behavior and preferences.	Transect sampling, floral visitor counts, standardized sampling protocols.	Barker and Arceo-Gomez, 2021
3	Pollen DNA Metabarcoding	Employs DNA analysis of pollen to identify plant species consumed by pollinators, offering a molecular perspective on dietary intake.	DNA extraction from pollen grains, sequencing and bioinformatics analysis for species identification.	Bell et al., 2023
4	Pollen Transport Networks	Examines how pollen is transferred between plants by different insect species, providing a dynamic view of plant-pollinator interactions.	Network analysis to visualize and quantify interactions based on pollen transport data.	Barker and Arceo-Gomez, 2021
5	Experimental Manipulations	Involves controlled experiments such as flower bagging or enclosure studies to assess pollinator effectiveness and interaction outcomes.	Flower bagging experiments, exclusion experiments to test pollinator contributions.	
6	Automated Pollen Analysis	Utilizes machine learning algorithms to automate the identification of pollen taxa from samples, improving efficiency and accuracy in data collection.	Convolutional neural networks for pollen identification, and automated scanning of slides.	

3.2.3. Informing Integrated Pest and Pollinator Management:

By identifying the foraging patterns and pollen sources of beneficial insects, entomopalynology can guide the selection of floral resources that support pollinator health while minimizing exposure to harmful chemicals. This information is valuable for developing strategies that reduce pesticide use, enhance biological control, and promote sustainable agriculture (Biddinger and Rajotte, 2015).

3.2.4. **Supporting Environmental Forensics:**

In environmental forensic entomotoxicology, pollen found on or within insects can be used as evidence to trace the movement of toxicants through food webs, identify sources of contamination, and reconstruct exposure events. This is particularly useful when traditional environmental samples (soil, water) are unavailable or insufficient for detecting trace contaminants (Walker, 2014).

3.2.5. Techniques and Advantages

Pollen can be isolated from both external (legs, proboscis) and internal (gut, crop) insect tissues using relatively simple and cost-effective methods. Light microscopy and, when available, scanning electron microscopy are used for pollen identification and quantification. These approaches are less invasive and more accessible than many conventional ecotoxicological assays (Jones, 2012). Further, Entomopalynological data provide regulators and researchers with direct evidence of contaminant transfer from environment to pollinators, strengthening environmental risk assessments. They help in evaluating the effectiveness of regulatory measures and in designing more pollinator-friendly pest management protocols (Grímsson et al., 2021).

4. Future Prospects of Entomopalynology and Conclusion

Although major studies related to entomopalynology predominantly emphasize bees, there is an increasing interest in investigating other insect taxa, including Lepidoptera (butterflies and moths) and Diptera (flies). Broadening the scope of entomopalynology to encompass these groups may reveal distinct facets of pollen-insect interaction networks and their ecological functions. Improvements in molecular methods and microscopy are poised to augment the potential of entomopalynology. These tools will facilitate more accurate identification of pollen types and enhance comprehension of their ecological significance across temporal and spatial dimensions. As climate change increasingly affects global ecosystems, entomopalynology is essential for examining the influence of climatic fluctuations on pollinator behavior and plant-pollinator interactions. Comprehending these processes will be crucial for formulating adaptive management methods in agriculture and conservation initiatives. Future investigations in entomopalynology will be enhanced by interdisciplinary collaborations that amalgamate ecology, agriculture, genetics, and climate science. Collaborations can yield extensive research that tackles intricate ecological inquiries and guides policy decisions related to biodiversity conservation and agricultural methods.

By mapping pollen–insect interactions, entomopalynology can reveal the richness and strength of pollination networks in different agricultural landscapes. Sites with higher interaction diversity—such as those in crops and dairy farms—tend to have enhanced pollination services and greater resilience to disturbances. The diversity and abundance of pollen types collected by insects can serve as a proxy for pollinator visitation rates and effectiveness, helping to identify key pollinator species and their preferred floral resources. Reconstructing historical and current plant trait composition from pollen records allows for the identification of crop types and wild plants that contribute most to ecosystem services, such as pollination and soil health. Entomopalynological data, when combined with precision agriculture tools (e.g., remote sensing, sensor networks), can enable real-time monitoring of pollinator activity and pollen movement, supporting targeted management interventions.

Practical Implications

Present article has following practical implications like, optimizing Crop and habitat Management, temporal planning to constitute floral calender for year round non-migratory bee keeping, improving Integrated Pest and Pollinator Management (IPPM), and enhancement of yield. The integration of entomopalynology into extension services and policy frameworks can support evidence-based recommendations for pollinator-friendly farming practices and landscape planning.

Entomopalynology, through its ability to map, monitor, and analyze pollen–insect interactions, offers actionable insights for optimizing crop management, enhancing pollination services, and improving integrated pest and pollinator management. Its integration with precision agriculture and biocontrol strategies can help overcome current limitations, leading to sustainable increases in agricultural productivity and ecosystem resilience. The study of pollen not only sheds light on the intricate relationships between insects and plants but also informs broader ecological management strategies. As research continues to evolve, leveraging both modern techniques and historical data will be essential for understanding and preserving these vital interactions in an ever-changing environment. By fostering a deeper comprehension of how pollinators interact with their floral resources, we can better protect the ecosystems that rely on these essential relationships.

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GENERAL ARTICLE

Insect-Plant Chemical Ecology: Detection of Plant Volatiles and Their Roles in Ecological Interactions

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Abstract

Insect-plant chemical ecology examines the dynamic interactions between insects and plants, primarily mediated by volatile organic compounds (VOCs). This article explores how insects detect plant volatiles through specialized olfactory systems, leading to behavioural responses that impact pollination, herbivory, and natural pest control. Plant volatiles serve crucial ecological roles, including deterring herbivores and attracting beneficial insects, and their application in sustainable agriculture is promising, particularly through methods like push-pull systems and genetically modified crops. Future research should focus on the molecular mechanisms of volatile perception, field-based studies, and innovative agricultural strategies leveraging plant volatiles for effective pest management, which can ultimately enhance agricultural sustainability and ecosystem resilience.

Introduction

Insect-plant chemical ecology is a fascinating field that explores the intricate interactions between insects and plants, primarily mediated by volatile organic compounds (VOCs). These interactions are crucial for processes such as pollination, herbivory and pest control and have significant implications for agricultural practices. VOCs are emitted by plants in response to external stimuli, such as herbivore attacks or pathogen infections, acting as signals that can modulate insect behaviour and interactions among multiple trophic levels. This review delves into how insects detect plant volatiles, the ecological roles of these interactions and their practical applications in agriculture, with a focus on indigenous aromatic crops like spices and medicinal plants. Insects possess highly specialized olfactory systems that enable them to detect and respond to plant volatiles. These volatiles, which include terpenoids, phenylpropanoids and green-leaf volatiles, are emitted by plants in response to environmental cues, such as herbivore attacks or pathogen infections (Das *et al*., 2013) (Serdo, 2024).

Detection of Plant Volatiles by Insects

1. **Perception Mechanisms**: Insects use chemosensory proteins (CSPs) and odorant-binding proteins (OBPs) to perceive plant volatiles. These proteins bind to odorant molecules and facilitate their transport to odorant receptors in the antennae (Lei *et al*., 2024; Qian *et al*., 2024). For example,

in *Bactrocera dorsalis*, a highly invasive fruit fly, the antennae-enriched CSP, BdorCSP3 plays a critical role in detecting host plant volatiles like methyl eugenol and β-caryophyllene (Lei *et al*., 2024).

2. **Behavioural Responses**: Once detected, these volatiles elicit specific behavioral responses in insects, such as attraction to food sources, mates or oviposition sites. For instance, the fall armyworm (*Spodoptera frugiperda*) is repelled by certain volatiles emitted by *Desmodium* species, which are used in push-pull strategy in agriculture to manage pest populations (Odermatt *et al*., 2024).
3. **Environmental Influences**: Environmental factors, such as temperature, humidity and wind, can influence the emission and perception of plant volatiles. These factors often determine the effectiveness of volatile-mediated interactions in natural settings (Serdo, 2024; Qian *et al*., 2024).

Ecological Roles of Plant Volatiles

Plant volatiles play a pivotal role in mediating interactions between plants, insects and other organisms, thereby contributing significantly to ecological balance and agricultural productivity. Floral volatiles, particularly terpenoids and benzenoids serve as key attractants for pollinators such as bees, butterflies and moths, often functioning synergistically with visual cues like flower color and morphology to guide pollinators to nectar sources (Das *et al*., 2013; Faheem *et al*., 2004). In addition to facilitating pollination, plants emit herbivore-induced plant volatiles (HIPVs) upon herbivore attack, which can directly deter herbivores or indirectly attract their natural enemies, including parasitoids and predators (Zhou and Jander, 2021). For instance, maize plants damaged by fall armyworm infestation release HIPVs that attract parasitoid wasps, enhancing biological control.

Beyond these direct and indirect defences, plant volatiles also mediate complex tri-trophic interactions, recruiting beneficial insects that help suppress herbivore populations through the release of compounds such as β-ocimene and β-caryophyllene (Niu *et al*., 2024). Furthermore, volatiles facilitate plant-to-plant communication; undamaged plants can perceive airborne signals from neighboring damaged plants and pre-emptively activate their own defense responses, a phenomenon known as “priming” (Das *et al*., 2013; Arimura and Uemura, 2024). Collectively, this sophisticated chemical signalling mechanisms not only bolster individual plant defense but also strengthen the resilience of entire ecosystems.

Practical Applications in Agriculture

The understanding of plant volatile-mediated interactions has led to the development of innovative strategies for sustainable agriculture. These strategies aim to reduce reliance on chemical pesticides and promote eco-friendly pest management practices.

1. Push-Pull Agriculture

Push-pull systems utilize plant volatiles to repel pests and attract their natural enemies. For example, intercropping with *Desmodium* species repels the fall armyworm (*Spodoptera frugiperda*) and attracts parasitoids that prey on the pest (Odermatt *et al*., 2024) (Figure 1). This approach has been successfully implemented in maize cultivation to reduce herbivory damage.

2. Genetically Modified Crops

Genetic modification of crops to alter their VOC emission profiles is another promising strategy. Crops with enhanced VOC emissions can attract beneficial insects or repel pests, providing a

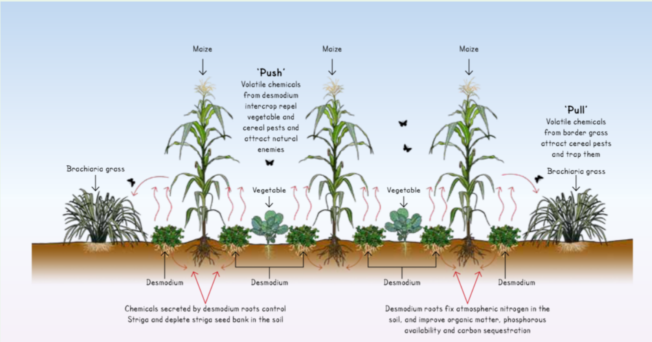

Figure 1. Push-Pull strategy against fall armyworm (*Spodoptera frugiperda*) (Sobhy *et al.,* 2022)

sustainable alternative to conventional pest control methods (Maurya, 2020; Arimura and Uemura, 2024).

3. Volatile-Based Pest Control

Plant volatiles can be used as attractants or repellents in pest control. For instance, synthetic formulations of plant volatiles can be used in traps to capture pest insects or disrupt their mating behaviours (Maurya, 2020; Qian *et al*., 2024). This approach is particularly effective for managing invasive pests like *Bactrocera dorsalis* (Lei *et al*., 2024). Several examples of plant volatiles and their associated herbivores are listed in Table 1.

4. Indigenous Aromatic Crops

Indigenous aromatic crops, such as spices and medicinal plants are rich sources of bioactive volatiles. These compounds have been used for centuries in traditional agriculture to repel pests and attract pollinators. Modern research has validated the efficacy of these traditional practices, providing a scientific basis for their integration into contemporary agricultural systems (Teranishi *et al*., 1993; Makhlouf *et al*., 2024).

Insights into Ecological Relationships

The study of plant volatile-mediated interactions has provided valuable insights into the ecological relationships between plants and insects, which are critical for understanding the complex dynamics of agricultural ecosystems and developing sustainable management strategies. The chemo diversity of plant volatiles is shaped by evolutionary pressures, including herbivore pressure and environmental conditions, with domestication and coexistence with herbivores significantly influencing the volatile profiles emitted by plants (Thompson *et al*., 2024). Understanding these evolutionary forces is crucial for breeding crops with enhanced resistance to pests.

Plant volatiles also mediate multitrophic

Table 1. Plant volatiles and their associated herbivores

Plant Volatile	**Associated Herbivore**	**Notes**
β-Caryophyllene	*Agrotis segetum*	Attracts the parasitoid *Microplitis mediator*, enhancing pest control (Li *et al.,* 2022).
Linalool	Various herbivores	Emitted in response to herbivore attack, serving as a deterrent (War *et al.,* 2011).
Green Leaf Volatiles	*Manduca sexta, Tupiocoris notatus*	Elicit predator responses, varying with time of day (Joo *et al.,* 2018).
Nonanal	*Agrotis segetum*	Part of the volatile blend that attracts natural enemies (Li *et al.,* 2022).
Terpenoids	Various herbivores	Serve as chemical defenses and attract parasitoids (Rani and Sulakshana, 2017).

interactions across different trophic levels, influencing the behaviour of herbivores as well as their natural enemies. For instance, terpenoids such as α-pinene and β-myrcene have been shown to attract predators and parasitoids that help regulate pest populations (Niu *et al*., 2024). Additionally, eco-evolutionary factors like plant domestication and long-term herbivore coexistence can either enhance or diminish volatile diversity, thereby affecting the ecological effectiveness of plant defences (Thompson *et al*., 2024; Makhlouf *et al*., 2024).

Multitrophic semiochemical interactions

Multitrophic semiochemical interactions among plants, insects, and associated microorganisms are complex and pivotal in shaping ecological dynamics. These interactions involve chemical signals that influence herbivore behaviour, plant defence mechanisms, and the roles of microbial communities. Plants emit volatile organic compounds (VOCs) that attract or repel herbivores and their natural enemies, influencing foraging and oviposition behaviours. Microbial associations can modify these chemical cues, enhancing or diminishing plant attractiveness to herbivores. Plant-associated microorganisms can induce significant phenotypic changes in plants, affecting their quality as hosts for herbivores. Some insects utilize plant secondary metabolites for prophylactic and therapeutic purposes, enhancing their resistance to pathogens (Shikano, 2017). Understanding these multitrophic interactions can inform the development of biotechnical control methods, such as using semiochemicals to manage pest populations effectively (Gross *et al.,* 2019). The integration of microbial and entomopathogenic interactions into pest management strategies can enhance plant fitness and agricultural sustainability (Shikano, 2017).

Future Directions and Research Gaps

While significant progress has been made in understanding plant volatile-mediated interactions, several research gaps remain that must be addressed to advance the field and foster innovative agricultural practices. Further investigation is needed into the molecular mechanisms underlying volatile perception and signalling, particularly concerning the role of chemosensory proteins in insect olfaction and the molecular pathways involved in volatile biosynthesis (Lei *et al*., 2024; Qian *et al*., 2024). Moreover, most current knowledge is derived from controlled laboratory studies, highlighting the urgent need for more field-based research to capture the complexities and variability of volatile-mediated interactions in natural ecosystems (Makhlouf *et al*., 2024). Additionally, the development of sustainable agricultural practices leveraging plant volatiles remains an underexplored area; promising strategies include the application of microbial volatiles and the use of genetically modified crops engineered to enhance volatile organic compound (VOC) emissions for improved pest management (Maurya, 2020; Makhlouf *et al*., 2024).

Conclusion

Insect-plant chemical ecology is a vital area of research with significant implications for agriculture and ecosystem management. Plant volatiles play a central role in mediating interactions between plants and insects, influencing processes such as pollination, herbivory, and pest control. By understanding these interactions, researchers can develop innovative strategies for sustainable agriculture, such as push-pull systems and volatile-based pest control. However, further research is needed to address existing gaps and unlock the full potential of plant volatiles in agricultural applications.

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GENERAL ARTICLE

Pest Forecasting in Agriculture

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Abstract

Pest forecasting, which is based on data obtained through pest surveillance, involves predicting pest outbreaks that may require control measures or identifying the optimal timing for interventions to achieve maximum protection. Mathematical and computer-based models are used to anticipate the future activity of biotic agents that negatively impact crop production. The integration of insect body temperatures into these models stems from in-depth research on thermoregulation behaviour, habitat selection across developmental stages, and biophysical modelling using weather parameters.

Keywords: Forecasting, Prediction, Population dynamics, Modelling

Introduction

Pest forecasting is essential for timely pest management and includes several key types. Climatic forecasting uses weather data to predict pest outbreaks based on favourable conditions. Phenological forecasting links pest activity to specific crop growth stages. Population-based forecasting analyzes past and current pest densities to forecast future trends. Degree-day forecasting calculates heat accumulation to predict pest development stages. Remote sensing and GIS forecasting track pest-prone areas using satellite imagery and mapping. Model-based forecasting uses computer simulations and decision support tools to predict pest behavior accurately. The development of accurate pest forecasting models relies heavily on data related to weather conditions, pest populations, natural enemies, and crop phenology. Near real-time pest incidence data, when combined with remote sensing and GIS technologies, enables early warnings of potential pest outbreaks. Collection and analysis of weather data from affected regions also serve as crucial inputs for these forecasting models. Computer-based systems have enhanced the speed, accuracy, and cost-effectiveness of pest forecasting. This allows farmers to take timely action by applying bioagents and pesticides, making pest forecasting a vital tool for precision farming.

Forecasting in Lepidoptera

Jha et al. (2016) reported that during the 32nd Standard Meteorological Week (SMW), each degree rise in maximum temperature increased the odds of a high infestation of *Helicoverpa armigera* (pod borer) pest attack by a factor of 8.6. In comparison, a one percent increase in morning relative humidity raised the odds of a high or medium pest attack by 6.4 times. The maximum severity of *Spodoptera litura* moth catches (numbers per trap per week) was analyzed in relation to the mean weather variables across individual SMWs (26–44) during the Kharif seasons over a 25-year period. Vennila et al. (2011) conducted a study using a quantitative model to examine the factors influencing the population dynamics of *Pectinophora gossypiella* (commonly known as the pink bollworm). Their findings revealed that higher evening relative humidity levels during the two weeks prior had a negative impact on the pest's population. Additionally, the study identified several climatic thresholds associated with increased pest severity. Specifically, a maximum temperature exceeding 34 ºC during the 40th standard meteorological week, a minimum temperature dropping below 17 ºC during the 44th standard week, and both morning and evening relative humidity levels falling below 33% were found to be key indicators predicting the severity of *P. gossypiella* infestation. Furthermore, the aggregate model highlighted negative correlations between pest severity and minimum temperature, as well as both morning and evening relative humidity, with evening humidity being a particularly significant factor.

Forecasting in Diptera

Bactrocera dorsalis Hendel is a major fruit pest causing substantial global economic losses. Though mainly distributed in Asia, data on its density trends in Sri Lanka remain limited. A study conducted by W. M. C. D. Wijekoon et. al (2024) assessed its current (2020–2022) and projected (2023–2025) densities across Sri Lanka's bioclimatic zones using trap data from 40 random locations. The SARIMA model was used for forecasting, and QGIS was employed to map density trends. Findings revealed a year-round seasonal pattern and an increasing trend, with the arid zone showing the highest rise (37%) by 2025. This is the first SARIMA-based forecast and spatial mapping for B. dorsalis in Sri Lanka, aiding strategic pest management.

Forecasting in Hemiptera

According to the findings of Bana et al. (2021), mango hopper populations exhibited two major peaks during the crop cycle. The first surge occurred at the new flush stage, while the second and more intense peak was recorded during the flowering and fruit-setting stage of mango plants. Their study also explored the relationship between weather conditions and hopper activity, revealing that maximum temperature and relative humidity had a significant impact on hopper population trends. During the rainy season, the hopper population was at its lowest, likely due to unfavorable climatic conditions for their survival and reproduction. Conversely, the highest infestation levels were observed during the flowering stage, a critical period for mango development, followed by the vegetative stage. These insights highlight the role of climatic factors in pest population buildup and emphasize the need for stage-specific pest management strategies in mango cultivation.

Conclusion

Pest monitoring combined with weather data plays a crucial role in enhancing pest forecasting, leading to more efficient and sustainable agricultural practices. By tracking pest populations and integrating real-time weather parameters—especially temperature, humidity, and rainfall—forecasting models can accurately predict pest emergence, life cycles, and outbreak intensity. Tools like Degree-Day (DD) models quantify insect development based on accumulated heat units, while Decision Support Systems (DSS) and Expert Systems (ES) use this data to guide timely interventions. Software such as CIPRA leverages hourly weather data to simulate pest development and crop conditions, improving precision in management strategies. These advancements reduce pesticide overuse, cut production costs, protect crops from severe infestations, and ultimately safeguard environmental and public health. Thus, pest forecasting grounded in weather and monitoring data significantly boosts agricultural productivity and sustainability.

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GENERAL ARTICLE

Consequences of Human Activity on Monarch Butterfly Survival and Long-Term Population Trends

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Abstract

The monarch butterfly (*Danaus plexippus* L.) is an iconic species renowned for its transcontinental migration and dependence on milkweed (*Asclepias* spp.) as a larval host. However, human activities have drastically reduced its populations through habitat destruction, widespread pesticide use, and deforestation of overwintering sites. Transgenic crops and neonicotinoid exposure impair larval development, adult survival, and reproduction, while logging in Mexican and Californian overwintering habitats threatens critical refuges. Climate change further exacerbates population declines by altering migration timing, nectar availability, and milkweed distribution. Natural enemies and pathogens such as *Ophryocystis elektroscirrha* also contribute to mortality, particularly in non-migratory populations where transmission persists. Despite these threats, coordinated conservation efforts—including habitat restoration, reduced pesticide use, and transnational initiatives—offer pathways to safeguard monarchs. Understanding the synergistic effects of anthropogenic pressures is essential for developing long-term strategies to ensure the persistence of monarch butterfly populations.

Keywords: Monarch butterfly, habitat loss, pesticides, climate change, conservation

Introduction

Monarch butterflies (*Danaus plexippus L.*) are familiar herbivores of milkweeds of the genus *Asclepias*, and most monarchs migrate every year to relocate these host plants across North American ecosystems now dominated by agriculture. Eastern migrants overwinter in high-elevation forests in Mexico, and western monarchs overwinter in trees on the coast of California.

Causes for mortality of Monarch butterfly

The Monarch butterflies face threats such as loss of milkweed resources for larvae due to genetically modified crops and pesticides, degraded overwintering forest habitats due to commercially motivated deforestation, and other economic activities. Secondary threats to monarch population viability include climate change effects on the distribution and abundance of milkweed host plants and the dynamics of breeding, overwintering habitat, and migration (Malcolm, 2018). Hansen and Obrycki (2000) investigated the levels of *Bt* corn pollen on *Asclepias syriaca* L. placed within and adjacent to plots of transgenic corn and found that the range of deposition of transgenic corn pollen grains on milkweed were up to three meters from the field edge, which had negative effect on the larvae of *Danaus plexippus* L. feeding in and adjacent to *Bt* corn field. Prouty *et al.* (2023) studied the effect of neonicotinoids on the survival, reproduction and flight performance of monarch butterflies

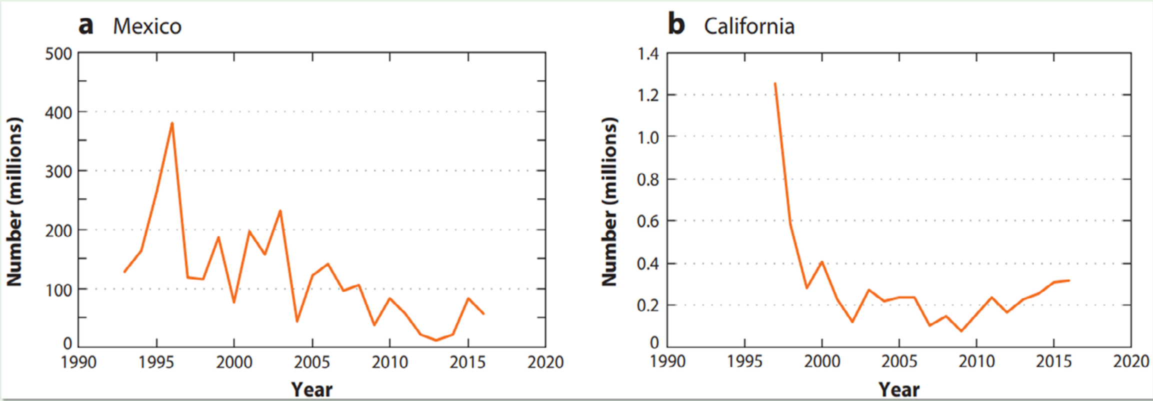

Figure 1. (a) Number of monarch butterflies overwintering in Mexico since the winter of 1993/94. **(b)** Number of monarch butterflies overwintering in California since the winter of 1997/98. (Source: http://www.westernmonarchcount.org)

and the results revealed that upon feeding with 20 per cent honey solution containing imidacloprid and clothianidin at different concentrations the number of matings and fecundity was reduced. When the adults were fed with high concentrations of clothianidin the amount of food intake, response time and flight ability were reduced. Calvert *et al*. (1983) studied the effect of freezing temperature on flight ability of Monarch butterfly and found that the butterflies lying on the ground

Figure 2. Pathogenicity of Ophryocystis elektroscirrha in monarch butterfly (https://ecology.uga.edu/wp-content/uploads/2024/02/Monarch-butterfly-infected-with-Ophryocystis-elektroscirrha-Jaap-de-Roode-Copy-2_web.jpg)

and near to the vegetation were flight impaired compared to those which congregated on trunk and bough region. Rafter *et al*. (2013) studied the feeding behaviour and consumption rates of *Tenodera sinensis* Saussure when fed with larvae of monarch butterfly, European corn borer and Greater wax moth to mantids. Their observation revealed that mantid degutted the larvae of monarch butterfly completely and consuming only the remaining larval tissues. The endangered eastern migratory population of *D. plexippus* is at risk due to climate change. Monarchs rely on nectar from late-season flowering plants in their breeding range in Canada to fuel their migration south to Mexico. A recent study (Peel, 2024) investigating the indirect effects of warming on *D. plexippus* as mediated by changes in nectar quality found that warming-induced nectar responses led to a decrease in the fat mass of monarchs who fed on the nectar of warmed plants.Satterfield *et al*. (2015) investigated the pathogenicity of *Ophryocystis elektroscirrha* in different monarch butterfly populations. They found that infection prevalence was significantly higher in monarchs from year-round breeding sites compared to migratory monarchs at overwintering sites. The study suggests that migration may act as a natural defence by reducing parasite loads. In contrast, non-migratory populations may allow the parasite to accumulate and spread more easily over time.

Conservation Measures

Monarch butterfly conservation involves several key programs aimed at preserving their populations and habitats. Notable programs include the Monarch Joint Venture, Monarch Watch, Monarch Habitat Exchange, The North American Monarch Conservation Plan and Journey North etc. These initiatives collectively aim to ensure the long-term survival of monarch butterflies.

Conclusion

Human activities pose a major threat to the survival and long-term viability of monarch butterfly populations. Habitat loss driven by urbanization and agriculture deprives monarchs of vital breeding and overwintering sites. Additionally, the widespread use of pesticides, particularly neonicotinoids, has led to a significant decline in their numbers, as these chemicals harm both larvae and adult butterflies. The destruction of these habitats and the direct impact of pesticide use contribute to a troubling trend in population decline. Compounding these challenges, climate change disrupts monarch migration patterns and alters the availability of host plants essential for their survival. As temperatures fluctuate and seasons shift, the timing of migrations and the growth cycles of crucial plants become misaligned, further stressing butterfly populations. To counteract these threats, conservation efforts must prioritize habitat restoration, reduced pesticide use, and strategies to mitigate the effects of climate change, ensuring the continued existence of these iconic butterflies.

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GENERAL ARTICLE

Buzzing Benefactors: The Carpenter Bees

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Abstract

Carpenter bees (*Xylocopa* spp.), belonging to the family Apidae, are efficient, large-bodied pollinators with significant ecological and agricultural relevance, particularly in solanaceous and cucurbitaceous crops. Their foraging behaviours-buzz pollination, traplining, and occasional nectar robbing-facilitate effective pollen transfer, especially in floral structures inaccessible to honey bees. Nesting in wooden substrates and bamboo, they exhibit solitary, tunnel-building behavior. *Xylocopa* spp. have demonstrated potential for managed pollination in protected cultivation systems through the use of trap-nesting techniques. However, habitat degradation, loss of nesting sites, and declining floral diversity due to anthropogenic activities threaten their populations. Conservation and promotion of carpenter bees are imperative for sustaining pollination services and agroecosystem resilience.

Keywords: *Xylocopa*, pollination biology, buzz pollination, trap-nesting, solitary bees, agroecology, pollinator conservation

Introduction

Carpenter bees, also known as large black bees, are robust bees belonging to the largest family, Apidae, within the super family Apoidea of the order Hymenoptera. They are also known as wood-boring bees. Carpenter bees are broadly classified in two different genera: Ceratina represented by small carpenter bees and, Xylocopa consisting of large carpenter bees. The genus Xylocopa comprises approximately 469 species (Michener, 2000) grouped in 31 to 51 subgenera. *Xylocopa* shows a cosmopolitan distribution over most continents, mostly in tropical and subtropical climates and rarely in temperate areas (Hurd and Moure, 1963). Large carpenter bees are among the largest bees in the world, often measuring over 3 cm in length. The females are easily distinguished by their striking black, blue, or yellow metallic coloured bodies, often speckled with lighter-coloured pubescence. Males are smaller than females and their entire body is coated with light brown, light green, yellowish green, or yellow pubescence in some species. The male and female carpenter bees show noticeable sexual distinctions, including the number of antennal segments (males have thirteen segments, whereas females have twelve), the number of abdominal segments (males have more than seven, but females have only six), the size and prominence of the tibial scale (larger and more prominent in females but barely

Figure 1. Carpenter bees (*Xylocopa* spp.) foraging (Left: on Marigold Flower; Right: on Clay Sage Flower)

noticeable in males), and the number of spines on the posterior tibia (females have two, but males have only one). The abdomen is pilose and well-punctured, especially on the sides. The abdominal dorsum is bare. Unlike honey bees, the hind legs of carpenter bees are devoid of well-differentiated pollen baskets. Many *Xylocopa* species are effective pollinators of diverse plants, including agricultural crops around the world (Table 1). Hence, they are already being utilized for managed pollination purpose in various countries. In natural habitats, *Xylocopa* forages on a wide variety of flowers and can remain active up to 40ºC, making them excellent pollinators. Carpenter bees possess several advantages as potential crop pollinators compared to other non-*Apis* bees. They are contributing most to crop pollination when honey bees are ineffective especially in cucurbitaceous and solanaceous plants. Carpenter bees exhibit various foraging behaviours such as buzzing, traplining, territorial, and opportunistic. These foraging behaviours greatly benefit plants that are obligate outcrossers. Some species of *Xylocopa* even exhibit nocturnal activity and forage on night-blooming flowers, which are not accessible to honey bees and other pollinators that are active during daylight. Since they are relatively large pollinators, they can carry more nectar than any flower visitors and they visit more flowers or plants on their foraging trips. This enhances their efficiency as pollinators. By their legitimate foraging mode on flowers resulting inefficient transfer of pollen from anthers to stigma of the flower, thereby playing a significant role in crop pollination. Some plant species that are obligate outcrossers are exclusively dependent on pollination by carpenter bees.

Foraging behaviour

In carpenter bees voltinism is determined by ambient temperature and the availability of floral resources. Flowers are major source of food and required water for carpenter bees. Both male and female carpenter bees collect nectar. The floral arrangement, structure and size of the flowers

Table 1. Crop pollination by various carpenter bee species around the World

Carpenter bee species	Crop	Country	References
Xylocopa mordax Smith	Passionfruit (*Passiflora edulis* Sims. f. *flavicarpa* Deg.)	West Indies	Cobertand Willmer, 1980
Xylocopa varipuncta Patton	Passion fruit (*Passiflora edulis*f. *flavicarpa* Degener)	Hawaii	Nishida, 1963
Xylocopa spp.	Passionfruit (*Passiflora edulis* Sims. f. *flavicarpa* Deg.)	Philippines	Barrera et al., 2021
Xylocopa pubescens Spinola	Honeydew melons (*Cucumis melo* L.)	Israel	Sadeh, et al., 2007
Xylocopa calens Lepeletier	Runner bean(*Phaseolus coccineus*)	Cameroon	Pando et al., 2011
Xylocopa (Lestis)	Tomato (*Solanum lycopersicum* L.)	Australia	Hogendoorn et al., 2000
Xylocopa varipuncta Patton	Cotton (*Gossypium hirsutum* L.)	U.S.A	Waller et al., 1985
Xylocopa sp.	Alfalfa (*Medicago sativa* L.)	U.S.A	Ball et al., 1929
Xylocopa olivacea Fab.	Pigeon pea (*Cajanus cajan*) [L.])	Cameroon	Fohouo et al., 2014
	Cowpea (*Vigna unguiculata* [L.])	Cameroon	Mineo et al., 2024
	Sponge gourd (*Luffa aegyptiaca* [Mill.])	Ghana	Mensah and Kudom, 2011

play an important role in carpenter bee foraging. Carpenter bees select flowers that are compatible with their size and can hold them while they collect nectar. The positions of the reproductive parts of the flowers also determine the pollination efficiency and the amount of pollen grains the bee gets. Carpenter bees normally collect nectar from the flowers in a permitted manner by landing on the flowers and sometimes entering within the flowers. However, in some cases, *Xylocopa* species exhibit an illegitimate way of collecting nectar called “nectar robbing” or “nectar theft.” This behavior is common when flowers have long, slender corolla tubes that make the nectar inaccessible to the bees. Carpenter bees make small holes at the base of the sepal or petal wall adjacent to the nectaries using their hard maxillary galeae and obtain nectar easily. However, the nectar robbing in some plant species does not hamper the legitimate visits by the other pollinators and proportion of the nectar robbing varies from 5 to 15% of the total flower visits. Carpenter bees also collect pollen grains along with the nectar. The nectar and pollen are stored in their brood cell for their upcoming generation. Before laying eggs, female carpenter bees provision the brood cell with enough nectar and pollen so that the newly emerging larvae of carpenter bees can utilize the reserved floral resources until they disperse from the cell.

Nesting behaviour

The nesting habit of the carpenter bee stands out as an exceptional behavior in the entire insect group. The name carpenter bee is derived from their nesting habits and often considered as structural pests in some countries but the benefits as pollinators outweighs the structural damage caused by the bees. Carpenter bees are solitary bees that make their nests in old wooden logs and bamboo stems by creating tunnel-like holes. These tunnels may be branched or unbranched according to the different species of carpenter bees. Carpenter bees select nesting areas based on various external factors. They choose nesting areas where building materials are abundant and usually avoid regions with frequent disturbances, especially anthropogenic activities. Being solitary and territorial in nature, they are cautious about the presence of other carpenter bees before selecting a nesting area. They usually make elliptical-shaped tunnels as nests, with the entrance hole only marginally broader than the bee's diameter and narrower than the tunnel's width. The process of digging is essentially nonstop and can extend into the night, taking a few days or being completed in sessions spread over several days. Tunnelling can begin on the substrate's damaged or sliced surface, as well as on its vertical or horizontal surfaces. Carpenter bees usually avoid polished or painted areas on the wooden logs. Once the nest is made, the female carpenter bees lay eggs inside the cells provisioned with mixture of nectar and pollen and prioritize guarding the eggs and cells. Carpenter bees usually brood eggs two to four times per year, from February to November, or this may be limited to particular months according to the availability of floral resources. Their breeding period varies on different continents. The nests can be reused multiple times after a generation emerges unless the nesting area is disturbed or destroyed.

The efforts are made to domiciliation of carpenter bees and utilize them for augmented pollination of crops in open field and protected conditions. The carpenter bee *Xylocopa fenestrata* prefers the bamboo nodes of 1.5 to 1.7 cm diameter for the construction of their nests when placed in angled position under shadow/shade for protection from sunlight or rain. Frames made from bamboo nodes are used for trap nesting of *X. fenestrata* and then they can be used for the pollination of the crops like cucumber and ridge gourd under protected conditions. The farmers' practices in north eastern states like providing the bamboo supports in the cultivation of cucurbitaceous crops in help in conserving and augmenting the population of the carpenter bees. However, the more detailed studies on the foraging behaviour under protected conditions are required to have a recommendation on the augmentation of carpenter bees for pollination of solanaceous crops in protected conditions.

Carpenter bees exhibit an enormous interdependent relationship with various plants. Some plants provide them with pollen and nectar, while others are excellent options for lodging their nests. At the same time, carpenter bees are an important example of pollinators on the planet. They play a significant role in the pollination of various plants, including beneficiary crops. Frequent habitat loss and lack of food resources are major threats to their survival. Extensive collection of wooden logs, previously utilized by carpenter bees as their nests, by fuel wood collectors has caused significant habitat loss in the carpenter bee community. Such disturbances caused by anthropogenic activities pose a major threat to their existence. These insects also play a role in the decomposition and recycling of underutilized woods. Hence, it is necessary to conserve these valuable creatures for the sake of a sustainable future and for our ecosystem.

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GENERAL ARTICLE

Zoopharmacognosy – Self medication behaviour in insects

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Abstract

Self-medication in insects, a fascinating aspect of zoopharmacognosy, demonstrates how these small yet complex organisms utilize environmental resources to combat pathogens and parasites. Despite their small size, they exhibit complex behaviours like consuming toxic plants or using anti-microbial resins to prevent or treat infections. Two primary forms of self-medication exist: *prophylactic* (preventive) and *therapeutic* (curative), which may benefit individuals or their kin. Examples include fruit flies ingesting ethanol to kill parasitoids, monarch butterflies choosing antiparasitic milkweed for eggs, and ants adding anti-microbial resins to nests. These behaviours meet self-medication criteria, such as deliberate substance use and fitness benefits. While insect immune defences (e.g., cuticules, melanization) is their first defence, self-medication acts as a secondary strategy. Research highlights its ecological and evolutionary importance, revealing intricate species interactions. Protecting these "tiny pharmacists" and their habitats is crucial for ecosystem health.

Keywords: defence, insects, parasites, self – medication, zoopharmacognosy

Introduction

Humans in the world are suffering with different kinds of diseases and even fatal sometimes. We came up with ways to protect ourselves from these diseases through drugs and vaccines. However, this ability isn't unique to humans; numerous animals, including elephants, chimpanzees, dogs, and even insects, exhibit self-medication behaviours by consuming or applying natural substances to prevent or treat illnesses. While evidence remains largely observational, such practices are widespread across the animal kingdom, often in unexpected ways. This phenomenon, termed zoopharmacognosy (from Greek: zoo = animal, pharmacon = drug, gnosy = knowledge), refers to animals' innate ability to self-medicate (Ashwini & Patel, 2022). The concept was first introduced in 1978 by Daniel H. Janzen, an evolutionary ecologist at the University of Pennsylvania (Raman & Kandula, 2008). From mammals to insects, these behaviours highlight nature's remarkable adaptability, demonstrating how even the simplest organisms leverage their environment for survival and health management.

Criteria for self – medication

In order to consider the behaviour performed by an animals is a legitimate self-medication, there are four important criteria that must be followed. The first three were proposed by

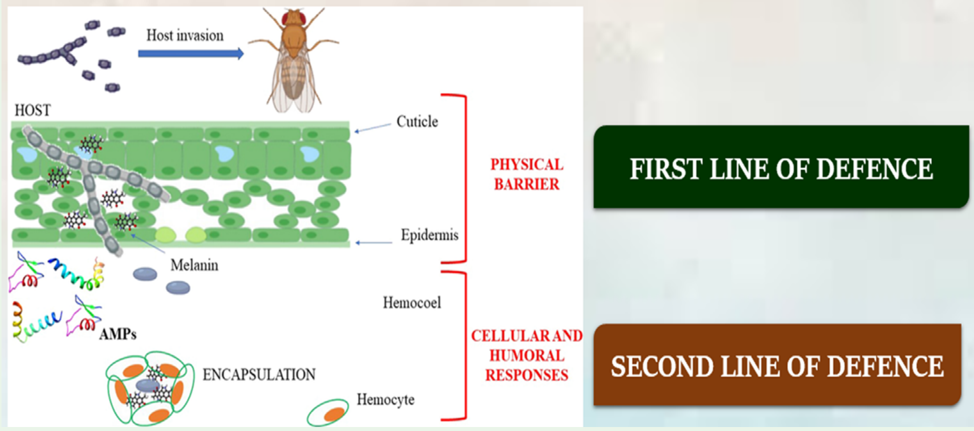

Figure 1. Two lines of insect defence systems (Manniello et al., 2021)

Clayton and Wolfe (1993):

1. The substance in question must be deliberately contacted.

2. The substance must be detrimental to one or more parasites.

3. The detrimental effect on parasites must lead to increased host fitness.

4. The substance must have a detrimental effect on the host in the absence of parasites (Singer *et al.*, 2009)

Modes of self – medication

Self-medication can be classified into four categories according to the mode of contact: ingestion, absorption, topical application and proximity.

a. Ingestion: Nicotine ingested by the tobacco hornworm (*Manduca sexta*) reduces colony growth and toxicity of *Bacillus thuringiensis*, leading to an increase in the survivorship of the hornworm (Krischik *et al.*, 1988).

b. Absorption: Absorption of medicinal substances across skin or mucous membranes is another potential mode of self-medication. Chimpanzees massage *Aspilia* leaves with the tongue for up to 25 seconds before swallowing the leaves which may facilitate absorption of Thiarubrine A, a potent antibiotic to treat their gastric acidic conditions (Clayton and Wolfe, 1993).

c. Topical Application: A better known example is 'anting' behaviour of birds, during which bird grasps an ant in its bill and rubs it frenetically through its plumage. The fact that birds ant exclusively with ants that secrete acid or other pungent fluids suggests that anting may play some role in ectoparasite defence (Ehrlich *et al.,* 1986).

d. Proximity: Gall-wasps developing galls benefit indirectly from tannin-rich oak leaves, showing reduced fungal attacks and higher survival rates. Tannin levels vary among oaks, influencing gall density and wasp diversity. This suggests wasps depend on host tannins for fungal defence, despite no direct contact with the compounds (Taper *et al.,* 1986).

Evidence of Zoopharmacognosy in Insects

An insect has two lines of defence system. First, its cuticle acts as a barrier to keep pathogens away, and second, their immune systems can combat infection if the pathogen penetrates this layer which includes melanisation, encapsulation, and the production of antimicrobial peptides that comes into play (Fig 1). When neither of these defence systems is effective, an insect can look to its habitats for compounds that will aid to fight against infections then self-medication may be an alternative (Ashwini and Patel, 2022).

Insects do performed self – medication through various which includes:

- ✓ Change diet composition
- ✓ Ingest antiparasitic toxins
- ✓ Alter nutritional intake
- ✓ Change ovipositional sites
- ✓ Collection and storage of antimicrobial substances (Singer *et al.,* 2009).

Types of Insects Zoopharmacognosy

By using the four criteria listed above, we can distinguish true self-medication behaviour from other related phenomena such as prophylactic consumption or compensatory diet choice. The key factor in distinguishing self-medication from other actions is whether the substance involved is harmful to the consumer, as outlined in criterion 4. Dose-dependency plays a crucial role here as many compounds that are safe or even beneficial in small amounts can become toxic at higher doses. Another useful way to categorize these behaviours is based on timing: whether the substance is taken before or after infection. While not explicitly included in the original criteria, substances consumed to prevent infection (prophylaxis) may differ from those used to treat an active infection (therapeutic medication) (de Roode *et al.,* 2013). Combining these two factors creates a matrix of four related categories, all of which may affect parasite resistance or tolerance - but only two of these qualify as true self-medication. (Fig 2).

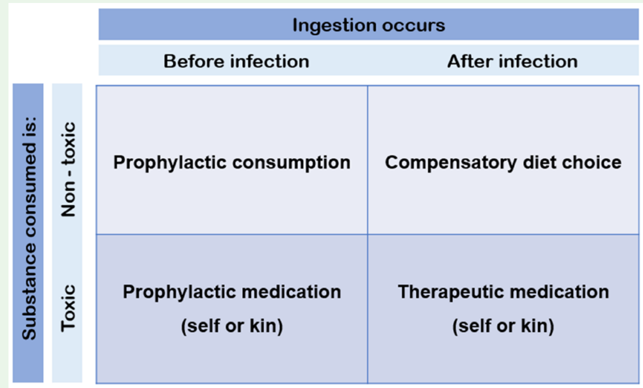

Figure 2. Diagrammatic representation on types of self-medication (de Roode & Hunter, 2019)

a. Non-toxic substances that are consumed prophylactically

This category is quite broad, as it could encompass nearly any food that enhances general health or immune response. For instance, one study showed that alkaloids in nectar can lower pathogen levels in bumblebees (*Bombus terrestris*) without harming them (Manson *et al.,* 2010). When infected with the trypanosome parasite *Crithidia bombi*, bees that had previously consumed nest-mate faeces developed significantly milder infections compared to control groups.

b. Non-toxic substances that are consumed therapeutically

When infected individuals consume specific substances without apparent costs, this represents compensatory diet choice. For instance, infected individuals of the beetle (*Tenebrio molitor*) increased protein consumption relative to uninfected individuals, allowing them to offset costs of infection. Notably, higher protein consumption did not negatively affect the fitness of healthy beetles (Ponton *et al*., 2011).

c. Prophylactic self-medication

Ants and bees exhibit prophylactic self-medication by gathering antimicrobial or antifungal resins to shield their colonies from bacterial and fungal infections. However, the timing of resin collection varies between these insects. For example, wood ants (*Formica paralugubris*) practice social prophylaxis by harvesting antimicrobial resin from conifers, which helps prevent bacterial outbreaks within the colony (Castella *et al.,* 2008).

d. Therapeutic self-medication

The best example for this is seen in fruit flies. In their natural habitat, these flies encounter fermenting foods that produce alcohol. Uninfected flies avoid high-ethanol foods, as alcohol consumption reduces their fitness. However, when parasitoid wasps are present in them, consuming alcohol-producing food is a smart decision because it aids in the killing of wasp larvae. In this case, "drunk" flies actually outlive their "sober" counterparts. (Milan *et al.,* 2012) (Fig 3).

Targets of Zoopharmacognosy

Therapeutic and prophylactic medication can be further divided depending on the target of medication: Self – medication and kin medication. "Self-medication" refers to when an insect actively seeks out substances that help them combat diseases or parasites in them. Example, Fruit Flies (*Drosophila melanogaster*) when infected with parasites, fruit flies seek out ethanol-rich (fermented) food, which helps reduce parasite loads. "Kin medication" refers to the application or ingestion of substances to prevent their offspring or their genetic kin, which may be prophylactically or therapeutically. Example, parasite-infected monarch butterflies (*Danaus plexippus*) can protect their offspring against high levels of parasite (*Oprhyocystis elektroscirrha*) growth and virulence by laying their eggs on antiparasitic milkweed (transgenerational therapeutic medication) (Lefèvre *et al.,* 2012).

Self-Medication Behaviours & Metabolic Adaptations in Insects

Zoopharmacognosy in insects involves the deliberate consumption or use of bioactive

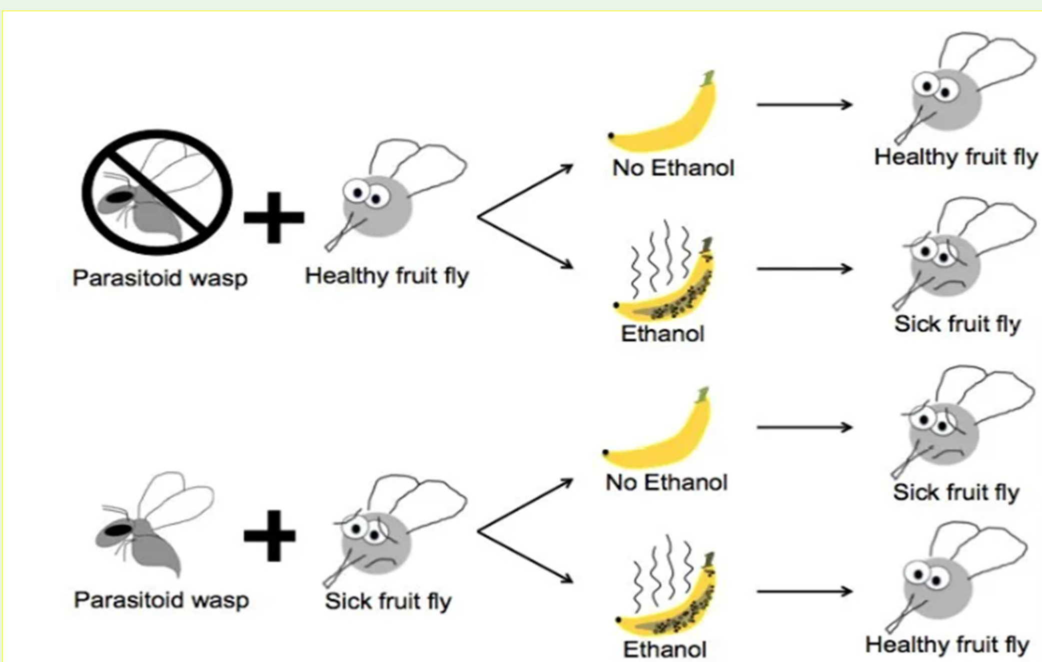

Figure. 3. Parasitized fruit fly used Ethanol for self – medication (Milan et al., 2012)

substances to prevent or treat infections, parasitism, or toxins. These behaviours are often linked to specific metabolic adaptations that allow insects to process, detoxify, or sequester these compounds. Below are key examples and mechanisms:

a. **Detoxification & sequestration of plant toxins:** Monarch Butterflies (*Danaus plexippus*) feed and lay eggs on milkweed, which contains toxic cardenolides. They have evolved modified Na^{+}/K^{+}-ATPase enzymes that resist cardenolide binding, alongside cytochrome P450s (CYPs) to metabolize excess toxins. This adaptation allows them to sequester cardenolides for defence against predators or parasitoids (Petschenka *et al.,* 2018).

b. **Ethanol consumption to combat parasitoids:** Fruit Flies (*Drosophila melanogaster*) self-medicate by consuming ethanol when infected by parasitoid wasps. They metabolize ethanol using alcohol dehydrogenase (ADH), which intoxicates and kills the parasitoid larvae inside them (Milan *et al.,* 2012). This behaviour increases survival rates among parasitized flies.

c. **Antimicrobial use of plant resins and propolis:** Wood Ants (*Formica paralugubris*) collect antimicrobial tree resin and incorporate it into their nests. The resin's terpenoids inhibit fungal growth, and ants may metabolize these compounds via CYP450s (Chapuisat *et al.,* 2007). Honey Bees (*Apis mellifera*) use propolis to line hives. Their gut microbiota and detox enzymes (GSTs, UGTs) help process these compounds, providing protection against bacterial and fungal infections (Mao *et al*., 2013).

Why should we study about insect self - medication?

a. Evolutionary Insights into Medicinal Behaviour: Insects, like other animals, have evolved behaviours to combat pathogens and parasites. Studying self-medication in insects (e.g., parasitoid-infected flies consuming ethanol or monarch butterflies using anti-parasitic milkweed) helps us understand the origins of medication behaviours in animals (de Roode *et al.,* 2013).

b. Potential for Novel Drug Discovery: Scientists have looked at everything from traditional native remedies to marine microorganisms in their search for novel drugs. Despite the numerous differences between humans and insects, there have already been cases in which compounds present in human drugs have also been used by insects. Cardenolides used by the insects, have been utilized to treat both cancer and heart failure. Insects use bioactive plant compounds to self-medicate, which may inspire new antimicrobial or antiparasitic drugs for humans (e.g., honeybees using resinous propolis to inhibit fungal infections) (Simone-Finstrom and Spivak, 2012).

c. Ecological and Conservation Implications: Understanding self-medication helps assess how environmental changes (e.g., pesticide use or habitat loss) disrupt insect health by limiting access to medicinal plants (Singer *et al.,* 2009).

d. Comparative Studies on Animal Cognition and Immunity: Insect self-medication challenges assumptions about "simple" organisms and reveals complex host-parasite interactions (Abbott *et al.,* 2014).

Conclusion

Identifying deliberate self-medication in animals or insects can be challenging since many food plants also have medicinal qualities and the boundaries between food and medicine can at times be hazy. In their natural habitats, animals select beneficial plants, possibly to treat health issues. Studying this behaviour can accelerate drug discovery, especially in ecosystems at risk. Just as human medicine learns from indigenous knowledge, animal self-medication offers valuable insights. To confirm self-medication, researchers must assess whether a behaviour reduces parasites and improves host fitness, then determine how the substance works. Insects, though small and seemingly simple, demonstrate remarkable medicinal behaviours that could inspire new human treatments. Their ability to self-medicate highlights nature's untapped potential for drug development. Future breakthroughs may even stem from compounds first used by insects, proving that these tiny creatures hold big promise for the discovery of new medicines.

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FIELD NOTE

In the Shadow of Ants: Asian Weaver Ants and their Mimics

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Abstract

The mimicking of Asian weaver ant (*Oecophylla smaragdina*) workers by other species to gain survival advantage is seen among different arthropod lineages in nature. Here we report five entirely different mimics of Asian weaver ants based on the observations from the Thrissur district, Kerala, India. The observations include nymphal instar of mantis (*Hapalopeza nilgirica*), broad-headed bug (*Riptortus* sp.) and adult of stilt-legged fly, Micropezidae, Crab spider (*Amyciaea* sp.) and jumping spider (*Myrmaplata* sp.)

Keywords: Mimicry, *Oecophylla smaragdina*, convergent evolution, spider, mantis

The Asian weaver ant (*Oecophylla smaragdina*, Fabricius, 1775) is found in almost all of tropical Asia, extending from India to the Solomon Islands and northern Australia (Wetterer, 2017). Asian Weaver ants are documented as one of the most successful biocontrol agents for pests affecting eight tropical tree crops and six forest trees, over 100 pest species belonging to eight orders and 26 families are known to be controlled by *Oecophylla* ants, so they have been propagated both naturally and artificially in Thailand and other Asian countries (Divyangi and Nikunj, 2022).

The term 'mimicry' in ecology refers to the phenomenon where a species changes over time to resemble other species or objects in their environment for survival benefits. The resemblance may be of different types, including optical, auditory, chemical or behavioural, which deceives different senses or a combination of different senses (Haug et al., 2020). The strong territorial behaviour and potent chemical defence make *O. smaragdina* a model species mimicked by different arthropod lineages.

Here, we discuss five examples of optic imitation, where different species have evolved to visually resemble Asian weaver ants, all of them from different lineages. These mimics are also potential predators which play the role of pest management in the shadow of Asian weaver ants, except *Riptortus* sp, which is a potential pest of many leguminous plants.

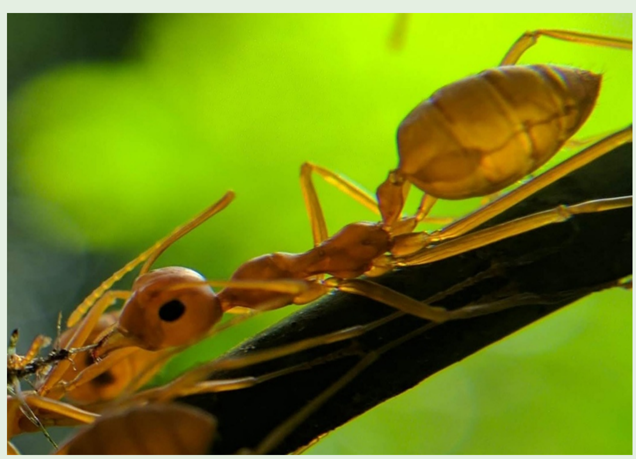

Figure 1. Asian weaver ant worker

Opportunistic observations from various habitats of Thrissur district, Kerala, from January 2022 to April 2024 are discussed here. Since there is no strictly formulated theoretical framework regarding the criteria of optical mimicry, we used simple criteria such as similarity in size, outline and colour following Haug et al. (2020).

Mimic 1: *Hapalopeza nilgirica* Wood-Mason, 1891 (Mantodea: Insecta)

Hapalopeza nilgirica (Gonypetidae) are small colourful species distributed over the states of Karnataka, Kerala, Maharashtra and Tamil Nadu in India (Kamila and Sureshan, 2022). Their nymphs are reddish brown and similar in size to the Asian weaver ant, and were found near the Asian weaver ant colony. A white band was observed at the end of long antennae, which is thought to produce visual truncation, making them more ant-like (Jackson and Drummond, 1974). Nymphs were smaller and lack wings compared to their adults so they are more vulnerable to predation, hence they mimic more aggressive Asian weaver ants to escape from predators (Batesian mimicry). A total of four nymphs were observed foraging on the leaves of *Chassalia curviflora* to mimic the foraging ants, as they become adults, they lose their red-brown colouration and are more often seen on the inflorescence to catch the floral visitors.

Figure 2. *Hapalopeza nilgirica*: (A) Nymph mimicking Asian weaver ant; (B) Fully grown adult.

Mimic 2: *Riptortus* sp. Stål, 1860 (Hemiptera: Insecta)

Genus *Riptortus* (Family: Alydidae), also called broad-headed bugs. Currently, there are more than 25 described species worldwide (Aukema and Rieger, 1995) and three species are known to be reported from India, namely *Riptortus linearis* (Fabricius, 1775) *Riptortus pedestris* (Fabricius, 1775) and *Riptortus strenuus* Horvath, 1889. Many are potential pests of economically important crops like soya beans and other leguminous plants (Zhang et al., 2022). Their nymphs showed transformational mimicry by mimicking two ant species during their hemimetabolous development. In the initial stages, they were small-sized and resembled small black-coloured ants. On reaching near adulthood, they were the size of Asian weaver ants. During their final stage of development, their colour changed to reddish brown. Butler (1921) identified this form of transformational mimicry for the first time. These Batesian mimicry by their weaker developmental stages will help them avoid predation before the development of wings. They did not show any active foraging behaviour like Asian weaver ants, but the nymphs are found communally on the bean pods by waving their antennae. As adults, they stop mimicking and develop colours to camouflage with their surroundings.

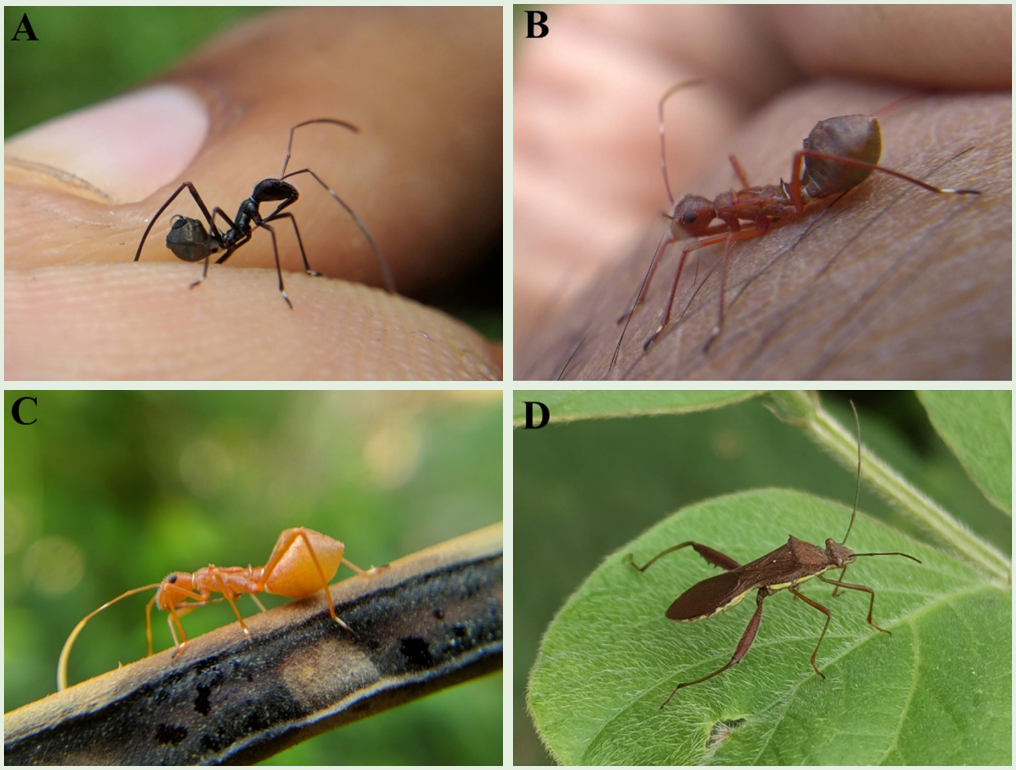

Figure 3. *Riptortus sp.* (A, B & C) Different nymphal stages; (D) Fully grown adult

Mimic 3: Micropezidae Loew, 1862 (Diptera: Insecta)

Commonly called stilt-legged flies, Micropezidae are one of the least studied Diptera family with only eight species reported from India, most of which are known only from single records, and only a single species *Mimegralla (Grammicomyia) coeruleifrons* Macquart, 1843 is known from Kerala (Mitra et al., 2015). Many species of the family have evolved to mimic different models such as ants and wasps to escape from their predators by exhibiting Batesian mimicry. They showed striking resemblance to Asian weaver ants in their body colour and size. Interestingly, they were seen above the leaves foraging like these ants. Three to six individuals were found together; they seldom flew, and if they flew, they covered only a short distance only.

Figure 4. Micropezidae flie on grass blades mimicking Asian weaver ants

Mimic 4: *Amyciaea* sp. Simon, 1885 (Araneae: Arachnida)

Genus *Amyciaea* (Family: Thomisidae) are commonly called crab spiders. Unlike other crab spiders, *Amyciaea* lack distinctive large forelegs; instead, they have simple and slender forelegs which they raise in the air to mimic the antennae of Asian weaver ants. Only a single species, *Amyciaea forticeps* (O. Pickard-Cambridge, 1873) is known from India (Sen et al., 2024). The observation was made near the Asian weaver ant colony. Their reddish-brown

Figure 5. *Amyciaea sp.* crab spider with a catch of Asian weaver ants

Figure 6. *Myrmaplata sp.* jumping spider mimicking Asian weaver ants.

colouration and body size were exactly similar to a typical Asian weaver ant. In addition, two black spots on the posterior side of the abdomen mimic the eyes of the Asian weaver ant. The genus is well known for its aggressive mimicry, in which the mimic resembles sufficiently that enable them to approach their prey closely. Asian weaver ants are the most common prey of these spiders. In our observation, we noticed that they capture at neck region of the ant, which avoids the powerful mandibles of the ants and then inject their venom to paralyse it before consuming. Mathew (1954) has given a detailed explanation of the aggressive mimicry and predation behaviour of *Amyciaea forticeps.*

Mimic 5: *Myrmaplata s*p. MacLeay, 1839 (Araneae: Arachnida)

Genus *Myrmaplata* (Family: Salticidae), commonly called ant-mimicking jumping spiders. During our observation, they were found near the Asian weaver ant colony in the nutmeg plantations in Thrissur district. They mimicked the reddish-brown colour, size and some behaviours, including foraging on plants or tree foliage. They often raised and waved their front pair of legs to mimic the antennae of these ants. Pedipalps of the male *Myrmaplata* sp. were enlarged and often resembled Asian weaver ants carrying dead ants, which is also an interesting behaviour among the Asian weaver ants.

Discussion

The oldest known fossils of weaver ants are from the Eocene epoch (Archibald et al., 2024). They are one of the most successful insects with two extant species, *O. longinoda* (Latreille, 1802) and *O. smaragdina* (Fabricius, 1775). Weaver ants are aggressive, territorial and are the most abundant arboreal ant fauna in many localities (Dlussky et al., 2008). Due to their aggressive and territorial behaviour, most of the predators avoid them. To take advantage of these peculiarities, many arthropod lineages have evolved to mimic these ants.

Among the five different mimics of Asian weaver ants discussed here, four of them are Batesian mimics, namely the initial stages of *H. nilgirica, Riptortus* sp. and adult Micropezidae, and *Myrmaplata* sp., whereby they avoid predators by mimicking these aggressive or unpalatable model. *H. nilgirica* and *Riptortus* sp. mimic in their immature stages before wing development, when they are more vulnerable to predation. *Amyciaea* sp. showed aggressive mimicry in which mimicking facilitates a closer encounter with the target prey.

Ant mimicry is well-studied in many spider groups. Many species of other insects remain be studied on myrmecomorphy so as to understand the interactions between them.

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FIELD NOTE

First Report of Tropical Sod-Webworm Moth, *Herpetogramma phaeopteralis* (Guenée) (Lepidoptera: Pyraloidea: Crambidae: Spilomelinae) from Rajasthan, India

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Abstract

The tropical sod-webworm moth (*Herpetogramma phaeopteralis*) distribution has been previously reported in different parts of the country, including Meghalaya, Karnataka, Delhi, and Uttarakhand. The present study documented the occurrence of Tropical Sod-webworm moth species from Rajasthan. It is characterized by a wing span of approximately 20 mm, with a medium-brown head, thorax, abdomen, and forewings. Forewing markings are subdued compared with other *Herpetogramma* species. At rest, adults hold their wings flat, unlike other North American webworms that fold their wings around their bodies.

Keywords: Tropical Sod-webworm, moth, Rajasthan

Moths and butterflies belong to the order Lepidoptera and the phylum Arthropoda, respectively. According to van Nieukerken *et al.* (2011), approximately 1,57,424 lepidopteran species have been identified globally. In India, almost 13,500 moth species occur in different parts of the country (Chandra, 2011). Various studies have been conducted in Rajasthan state to assess moth diversity, and Koli and Prajapati (2021) documented 154 moth species belonging to 18 families from different districts of southern Rajasthan. Additionally Savita and Trigunayat (2023) observed 65 moth species belonging to 13 families from the city area of the Jaipur district, Rajasthan and Jain and Verma (2023) observed 43 species from 9 families in the Jhalawar district of Rajasthan.

Herpetogramma phaeopteralis is found in the United States, America, Oriental region, and the Ethiopian region. The 'Moths of India' and 'iNaturalist' websites were referred to verify reports of this moth species from various states across the country, and found that it has been observed in a few states of the country, including Meghalaya, Karnataka, Delhi, and Uttarakhand (Sondhi *et al.,* 2025). It is a small moth with a wing length of less than 11 mm and a wingspan of approximately 20 mm, with a medium-brown head, thorax, abdomen, and forewings. Forewing markings are subdued compared with other *Herpetogramma* species. At rest, adults hold their wings flat, unlike other North American webworms that fold their wings around their bodies.

On 21.09.2024, we first observed *Herpetogramma phaeopteralis* in Rajasthan, India (Tilak Nagar, Bhilwara) (Figure 1). The Nikon

P500 camera was used to take photos. Various turf-grasses are common host plants for this moth species. This moth species feeds on grass leaves. The species has been previously reported in different states of the country, including Meghalaya, Karnataka, Delhi, and Uttarakhand (Sondhi *et al.,* 2025). Therefore, the present study provides the first record of *Herpetogramma phaeopteralis* from Rajasthan.

Figure 1: Tropical sod-webworm moth, *Herpetogramma phaeopteralis* reported from Bhilwara, Rajasthan, India

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MINI REVIEW

Viruses Infecting Honey Bees: Emerging enigmatic threats

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Abstract

Honey bees play an important role in pollinating crops and promoting biodiversity. Globally, where apiculture provides thousands of livelihoods and different ecosystems, viral infections are posing a significant threat to bee health. This article insight the viruses that infect honey bee species, their transmission patterns and the effects on colony strength, production and survival. Major honeybee pollinators viz., *Apis cerana indica* and *Apis mellifera*, are the two most commonly managed species received special attention. Over 20 viruses have been identified in honey bees worldwide, with several being closely associated with colony losses, reduced productivity, and compromised immunity. In recent years, reports of viral infections have increased in Indian apiculture, which is centred on *A. cerana indica*, *A. mellifera*, and *A. dorsata*. Though Varroa infestation was previously absent in native bees, its proliferation through *A. mellifera* colonies poses a significant alarm.

Introduction

Honey production and pollination services have increased dramatically as a result of beekeeping with *A. mellifera*. However, this development has raised challenges, particularly the introduction and spread of viral diseases, which are frequently vectored by the Varroa mites. India is home to a varied range of honey bee species, including the native *A. cerana indica*, wild species such as *A. dorsata* and *A. florea*, and the introduced European honeybee, *A. mellifera*. Presently, honeybees are facing severe threat from various bee pathogens globally (Fig. 1). Viral diseases that were previously considered latent or subclinical are now posing a severe threat to bee colonies across the country.

Honey bees can get infected with various viruses. Sacbrood virus was the first bee-infecting virus identified in the scientific literature in 1913, and approximately more than twenty different viruses were later described based on bee symptoms. With new molecular biology technologies, DNA can currently be utilised to identify viruses infecting bees, even when there are no symptoms. A recent screening of honey bees gathered in Pennsylvania revealed that they were infected with multiple viruses, including Deformed wing virus (DWV), Black queen cell virus (BQCV), Sacbrood virus (SBV), two Paralysis viruses and others (Grozinger et al., 2023). More than 20 viruses have been reported to infect honey bees worldwide, generally from Dicistroviridae and Iflaviridae families, such as ABPV (Acute Bee Paralysis Virus), BQCV (Black Queen Cell Virus), KBV (Kashmir Bee Virus), SBV (Sacbrood Virus), CBPV (Chronic Bee Paralysis Virus), SBPV (Slow Bee Paralysis Virus), IAPV (Israeli acute paralysis virus), and DWV (Deformed Wing Virus) are

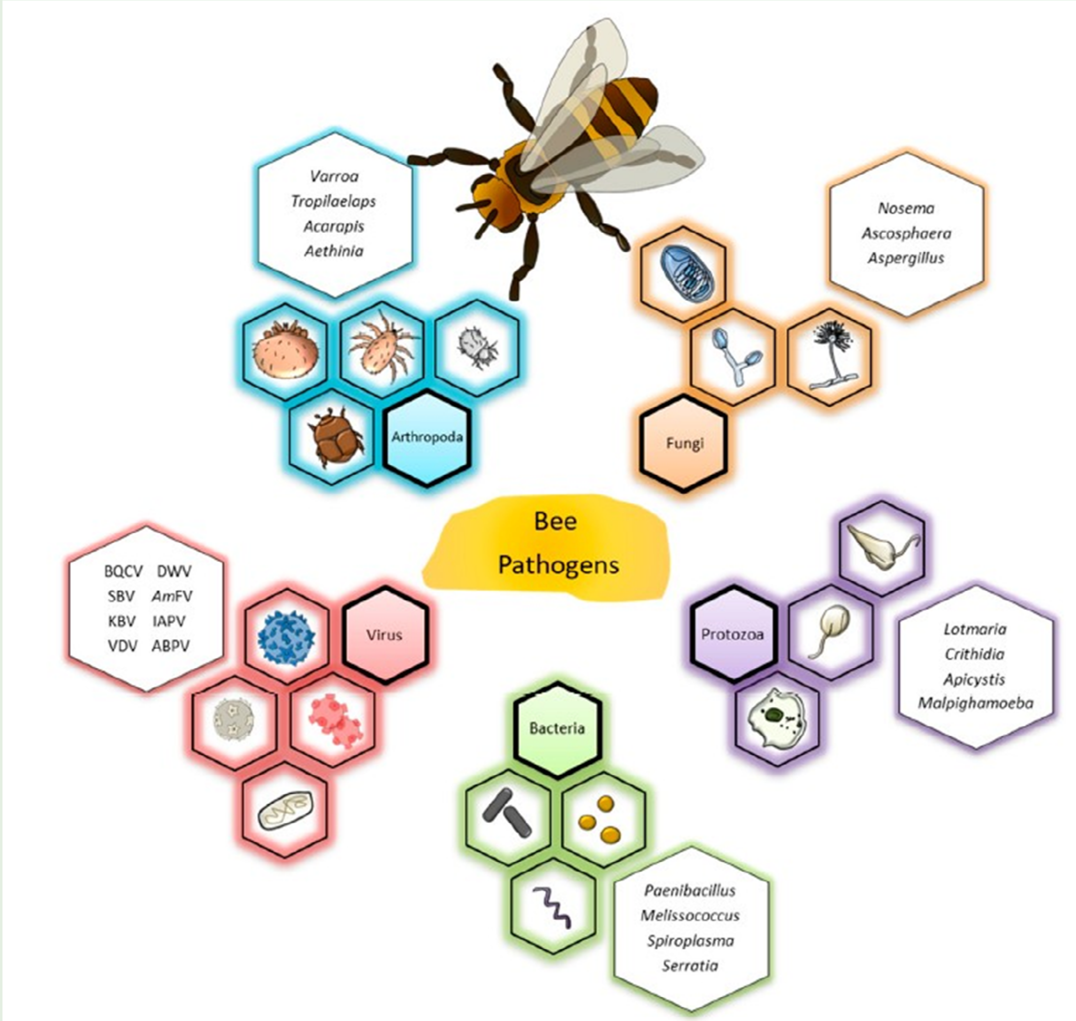

Figure 1. Major bee-pathogens infecting *Apis mellifera* (Lannutti et al., 2022)

prominent (Fig.2) and cause infections harmful to honey bee colonies (Ullah et al., 2021).

Honey bees are primarily infected with RNA viruses. These viruses are often composed of small icosahedral particles (17, 30, or 35 nm) with a positive-sense, single-stranded RNA genome. After attaching and penetrating their host cells, these viruses typically multiply by injecting RNA straight into the cytoplasm. The host machinery will then transcribe and generate new viral proteins, which will be assembled into a viral particle, released from the infected cell, and starts infecting new cells. Recently, RNA viruses with a negative-sense, single-stranded genome, which are normally more difficult to propagate in vivo, have been discovered in *Apis mellifera* (Levin et al., 2019). In addition, a few viruses with DNA genomes have been found in honey bees. The replication mechanism of DNA viruses differs from that of RNA viruses. After getting into their host cells, DNA viruses are transported to the nucleus for transcription and translation (Beaurepaire et al., 2020).

RNA viruses impact honey bee health and contribute to elevated colony loss rates worldwide. Deformed wing virus (DWV) and the closely related Varroa destructor virus-1 (VDV1), are the most widespread honey bee viruses. VDV1 is known to cause high rates of overwintering colony losses in Europe, however, it was unknown in the United States (U.S.). Using next generation sequencing,

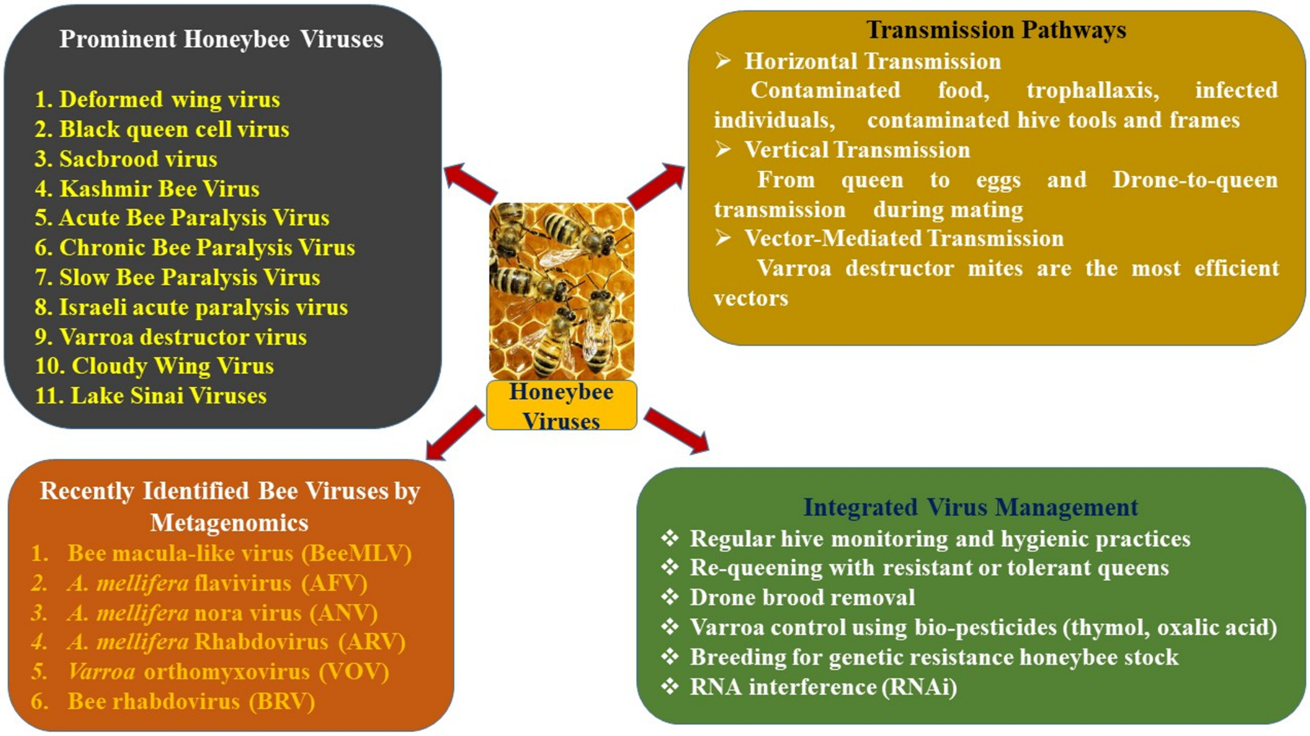

Figure 2. Highlights on honeybee viruses and their management

Ryabov et al. (2017) identified VDV1 in honey bee pupae in the U.S. They tested 603 apiaries in the U.S. in 2016 and found that VDV1 was present in 66.0% of them, making it the second most prevalent virus after DWV, which was present in 89.4% of the colonies. VDV1 had the highest load in infected bees compared to other tested viruses, with DWV second.

Diversity of Honey Bee Viruses

Honey bee viruses are primarily positive-sense, single-stranded RNA viruses, mostly classified under the families Dicistroviridae, Iflaviridae, and Nodaviridae. Key viruses include:

- ❖ Deformed Wing Virus (DWV)
    - Family: Iflaviridae
    - Symptoms: Deformed wings, shortened abdomen, impaired flight
    - Transmission: Vertical, horizontal, and vectored by Varroa destructor
    - Impact: Major contributor to winter losses and colony collapse
- ❖ Acute Bee Paralysis Virus (ABPV)
    - Family: Dicistroviridae
    - Symptoms: Sudden death of adult bees, trembling, hairless thorax
    - Often fatal when linked with Varroa infestation
- ❖ Israeli Acute Paralysis Virus (IAPV)
    - Associated with CCD in the U.S.
    - Symptoms: Paralysis, disorientation, rapid collapse
- ❖ Chronic Bee Paralysis Virus (CBPV)
    - Symptoms: Chronic paralysis, trembling, hairless appearance
    - Typically spreads in crowded colonies
- ❖ Kashmir Bee Virus (KBV), Black Queen Cell Virus (BQCV), Sacbrood Virus (SBV)
    - BQCV and SBV mainly affect larvae
    - BQCV linked with *Nosema* infections
    - SBV causes larval death with sac-like appearance
- ❖ Lake Sinai Viruses (LSVs)

- Newly discovered group
- Prevalent worldwide but often asymptomatic
- Potentially significant under stress conditions

Deformed Wing Virus

When a colony is heavily infected with Deformed wing virus (DWV), it shows the classic diagnostic symptom of bees with deformed wings. When this symptom is seen, the colony often also shows many other symptoms that make up Parasitic Mite Syndrome (PMS). PMS includes a spotty brood pattern, larvae sunken in cells, cappings removed from some cells containing pupae that have been chewed, and a dwindling adult population. An alcohol wash for Varroa mites may or may not show that there is a large mite population, depending on the stage of the infection. Varroa mites have been shown to transmit DWV from one bee to another and to cause the virus to reach damaging levels. So, even if the mite population is not high when deformed wings and PMS symptoms are seen, both mites and DWV were probably involved.

Sacbrood Virus

Sacbrood (SBV) is characterized by the uncapping of brood in the stretched larva stage. If you remove the capping and the larva, it appears to be inside of a sack. Sacbrood virus is caused by a virus from the Iflavirus family. The virus primarily affects worker larvae, although it can also infect adult honeybees. Sacbrood virus results in an uneven brood pattern, with discoloured, sunken, or punctured cappings distributed throughout. Larvae are thought to become infected after consuming brood food contaminated with Sacbrood virus. The virus then grows among the infected larvae, causing them to sit in the cell with their heads up and eventually die shortly after capping. The larvae's skin progressively changes to a fluid-filled sac. Sacbrood virus can survive in dead larvae, honey, or pollen for up to four weeks.

Kashmir bee virus

The Kashmir bee virus (KBV) is a potentially fatal honey bee virus that has lately gained recognition as one of numerous viruses linked to colony collapse caused by varroa mite infestation. KBV, like most honey bee viruses, is considered to remain as an undetectable infection within the bee community until stress or an alternate vector (such as varroa) causes it to spread and become fatal. The geographic and host origins of KBV are unknown. It was found in 1974 as a contaminant in preparations of *Apis iridescent virus* from the Asian hive bee (*Apis cerana*), which grew rapidly when injected or given to adult *Apis mellifera* bees. Although it was suspected that KBV originated in *A. cerana* and SE Asia, the discovery of KBV or its serological relatives in natural populations of *A. mellifera* from all over the world, as well as *A. cerana* from India, bumble bees (*Bombus* spp.) from New Zealand, and European wasps (*Vespula germanica*) from Australia, has made this difficult to prove.

Acute Bee Paralysis Virus

The three viruses viz., Acute Bee Paralysis Virus (ABPV), Kashmir Bee Virus (KBV), and Israeli Acute Paralysis Virus (IAPV) are very similar and, despite significant genetic changes, are regarded a complex. They are all connected with varroa infestation, as is the Black Queen Cell Virus, a member of the Dicistroviridae family. Because of this, controlling varroa is the most effective strategy to minimise these infections. ABPV was discovered in 1963. At first glance, ABPV is easily mistaken for Chronic Bee Paralysis Virus (CBPV) type 1. Bees that have died or are dying can be spotted at the hive entrance. It is most commonly spotted in the apiary during the summer and autumn. The two primary differences are that it starts extremely suddenly. Indeed, it could be part of colony collapse disorder (CCD). The second distinction is that, unlike CBPV, ABPV is transmitted by the varroa mite. The only way to know for sure is to perform polymerase chain reaction (PCR) on DNA of a dead bee's body. The virus is usually found in colonies as a hidden low titre infection. When it develops into a clinical illness, it spreads horizontally in crowded hives via the cytoplasm of damaged cuticle hair. It spreads vertically by feeding larvae.

Lake Sinai virus

Lake Sinai virus (LSV1) and LSV2 were discovered in honey bee samples obtained from a migratory commercial beekeeping operation with sites near Lake Sinai, South Dakota. These viruses were the most abundant pathogens detected in a 10-month honey bee pathogen monitoring study carried out in the U.S. in 2008-2009. In that sample cohort, LSV2 was the most abundant virus with peak levels in April and January, whereas LSV1 infections peaked in July (Runckel et al., 2011). While the pathogenicity of LSVs is not well understood, LSV1 and LSV2 loads were higher in Colony Collapse Disorder (CCD) affected colonies, as compared to unaffected colonies (Cornman et al., 2012). Since the discovery of LSV1 and LSV2, the LSV group has been expanded to include LSV3 (Cornman et al., 2012), LSV-Navarra (Granberg et al., 2013), LSV4, LSV5 and several LSVs discovered in Belgium (Ravoet et al., 2015). LSVs have been detected in the U.S., Spain, Belgium and Turkey etc.

Slow bee paralysis virus

Slow bee paralysis virus (SBPV) causes paralysis of the front two pairs of legs of adult bees a few days before death following an inoculation (Bailey and Woods, 1974). The virus is linked and transmitted by *Varroa destructor* (Bailey and Ball, 1991). Despite its relationship, SBPV is rarely found in bee colonies. SBPV can also be found in larvae and pupae, however it induces no symptoms (De Miranda et al., 2013).

Cloudy Wing Virus

Cloudy Wing Virus (CWV) symptoms consist of opaque wings of severely infected adult bees, with lower titers resulting in asymptomatic infected bees (Bailey and Ball, 1991). It cannot be propagated in larvae or pupae. It has an unpredictable incidence, no regular associations with other pathogens or pests. Like chronic bee paralysis satellite virus, it has a small particle and very small genome, but they are serologically unrelated and their single capsid proteins are of different size (De Miranda et al., 2013).

Recently Identified Bee Viruses by Metagenomics

The development and optimization of high-throughput sequencing technologies enables the sequencing of the genetic material of a host's entire viral community, even without prior knowledge of viral genome sequences. This approach is referred to as viral metagenomics analysis. Metagenomics improves viral diversity characterization and accelerates the detection of new viruses that impact honeybees and other pollinators (Galbraith et al., 2018). By this approach, more than 30 additional, previously unrecognized, viruses could be identified. Although they were classified as honeybee viruses, many of them infect a wide variety of insect hosts. This is particularly important under the perspective of the pollinator network, since the presence of multi-host pathogens favours interspecies virus transmission.

Recent investigations have identified other honeybee-infecting positive-sense ssRNA viruses, such as the bee macula-like virus (BeeMLV), *A. mellifera* flavivirus (AFV) and *A. mellifera* nora virus 1 (ANV). Furthermore, high-throughput sequencing has led to the discovery of the first negative-sense ssRNA viruses in the Rhabdoviridae family: A. mellifera rhabdovirus-1 (ARV-1) and A. mellifera rhabdovirus-2 (ARV-2) (McMenamin and Flenniken, 2018).

Novel metagenomics pipeline for the rapid and inexpensive screening of bee viruses that included purification of encapsulated RNA/DNA viruses, sequence-independent amplification, high-throughput sequencing, integrated assembly of contigs, and filtering, to identify contigs specifically corresponding to viral sequences. Besides common bee viruses, new viral agents could be identified, including: (i) seco-like virus sharing sequence homology with Secoviridae, (order Picornavirales); (ii) a novel (+) ssRNA virus within the family Nodaviridae, (iii) a tymo-like virus, (iv) A. mellifera Rhabdovirus 1 (ARV-1) (family Rhabdoviridae), (v) a partiti-like virus (family Partitiviridae), and (vi) a circo-like virus (family Circoviridae) (Galbraith et al., 2018).

Viromes from the Western honeybee subspecies *A. m. ligustica*, *A. m. syriaca*, *A. m. intermissa*, and *A. cerana* and their respective *V. destructor* mites, were analyzed by RNA metagenomics to compare the composition of their viral populations. In this study, two novel viruses: Varroa orthomyxovirus-1 (VOV-1) in *A. mellifera* and *V. destructor*, and a Hubei like-virga virus-14 homolog in *V. destructor* were reported, as well as some recently described viruses: ARV-1, BRV-1, VDV-2, and VDV-3 (Levin et al., 2019). It can be expected that novel viruses will be identified in the honeybee by applying metagenomics approaches in the near future.

Routes of Transmission

Viruses can be readily transmitted within and between honey bee colonies, and can also be transmitted among other bee and insect species in the area. Transmission can occur from drone to queen during mating, from queen to egg, from nurses to larvae during feeding, and between workers during trophallaxis, or through the environment, particularly when bees feed on contaminated food, such as contaminated honey stores in the colony or contaminated flowers in the field.

DWV infections are closely associated with Varroa destructor mite parasitization. DWV is transmitted by varroa mites, and this transmission generates very high prevalence (many workers in the colony are infected), high virulence (individual workers have high levels of the virus), and high pathogenicity (severe symptoms in infected workers). It is thought that varroa mites impair the immune function of honey bees by removing haemolymph, and mite transmission may also select for more virulent strains of DWV. Intriguingly, the number of offspring a varroa mite female can produce is higher on pupae infected with DWV. DWV reduces wound healing in honey bees, and this may allow for their offspring to obtain more food from the infected pupae through the slit the mother mite cuts into the cuticle.

Knowledge of the spreading mechanism of honey bee pathogens within the hive is crucial to understanding bee disease dynamics. The aim of Ribiere et al., (2007) was to assess the presence of infectious chronic bee paralysis virus (CBPV) in bee excreta and evaluate its possible role as an indirect route of infection. Samples of paralyzed bees were (i) produced by experimental inoculation with purified virus and (ii) collected from hives exhibiting chronic paralysis. CBPV in bee heads or faeces (crude or absorbed onto paper) was detected by reverse transcription-PCR. CBPV infectivity was assessed by intrathoracic inoculation of bees with virus extracted from faeces and by placement of naive bees in cages previously occupied by contaminated individuals. CBPV RNA was systematically detected in the faeces of naturally and experimentally infected bees and on the paper sheets that had been used to cover the floors of units containing bees artificially infected with CBPV or the floor of one naturally infected colony. Both intrathoracic inoculation of bees with virus extracted from faeces and placement of bees in contaminated cages provoked overt disease in naive bees, thereby proving that the excreted virus was infectious and that this indirect route of infection could lead to overt chronic paralysis. This is the first experimental confirmation that infectious CBPV particles excreted in the faeces of infected bees can infect naive bees and provoke overt disease by mere confinement of naive bees in a soiled environment (Ribiere et al., 2007).

Diagnosing and Managing Viral Infections

The potential methods for identifying viral infections are limited. As previously stated, several viruses exhibit distinct symptoms that can be utilised to diagnose their existence. Molecular techniques, such as polymerase chain reaction (PCR) are required for identifying infections in colonies that do not exhibit symptoms, confirming the existence of a specific virus, and assessing virus prevalence or levels. This service is not accessible to the general public and local beekeepers.

Options for dealing with viral infections are also limited since there is no specific treatment for viral infections in honey bees. However, beekeepers can take steps to minimize viral transmission and reduce exposure to other stressors, such as parasites, pesticides, and nutritional deficiencies. Stress can reduce the bees' ability to manage viral infections. Pesticide exposure can reduce immune responses. For example, exposure to neonicotinoids, organosilicons, and KATP channel agonists can all result in increased viral titers. Additionally, treatment with a chemical miticide to control varroa mite populations, such as amitraz, can cause bees to be less tolerant of virus infections. However, providing bees with high-quality diets with pollen from diverse plant species can help bees have lower viral levels.

IPM for Bee-virus control

Beekeepers are encouraged to follow the Integrated Pest Management Approaches to Control viruses of bees and heir vectors. Grozinger and co-workes from Penn state university provided one IPM pyramid for virus control (Fig. 3). Integrated Virus Management by controlling Varroa using bio pesticides (thymol, oxalic acid) and drone brood removal, regular hive monitoring and hygienic practices and re-queening with resistant or tolerant queens can effectively manage viruses. Novel control strategies like, breeding for genetic resistance, RNAi and biocontrol research should focus on prevention and management of bee viruses and their vectors.

1. Cultural Approaches

Use Varroa mite-resistant honeybee stocks. These include Russian, Varroa-sensitive, and ankle-biter/leg-chewer stocks. Russian and Varroa sensitive hygiene stocks have been demonstrated to be effective in suppressing virus populations.

Reduce Between-Colony Transmission

Viral infections tend to be higher in areas with a higher density of honey bee colonies.

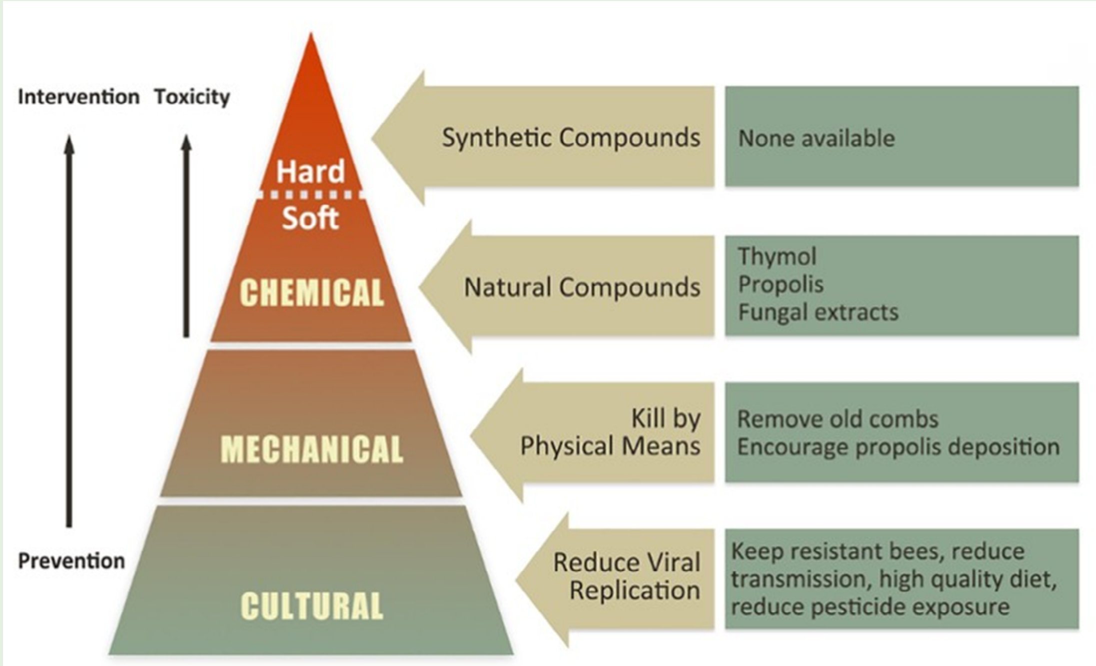

Figure 3. The IPM pyramid for virus control (Image: Nick Sloff; Grozinger et al., 2023)

Beekeepers can reduce transmission between colonies by limiting the number of colonies in an apiary, orienting the colonies to reduce drift of infected bees. Colonies can be spaced farther apart by facing different directions or different markings, not moving frames from a colony that is exhibiting symptoms of virus infection to another colony, cleaning hives tools or other equipment with alcohol after inspecting a colony showing symptoms of viral infection, providing bees with high-quality diets etc.

Reduce Pesticide Exposure

Beekeepers needs to enquire regularly from the neighbouring farmers about when a pesticide spray is scheduled in their farm. It should also be noted that exposure to acaracides used to control Varroa mites (such as amitraz) may exacerbate viral infections.

2. Mechanical Methods

Remove old combs

To remove viruses and other hive pollutants that accumulate as wax comb ages, replace old combs on a regular basis. It is recommended to change approximately ⅓ of the frames in each colony annually. The old combs should be destroyed.

Encourage Propolis Deposition

Hive equipment can be designed with a rough interior surface to encourage bees to cover it with propolis. This can be accomplished by creating equipment with rough wood on one side or by scratching the interior hardwood surface. Furthermore, the use of cotton duck cloth as an interior cover encourages bees to collect and deposit propolis. Propolis has been demonstrated to boost immune gene expression in honey bees and reduce viral levels.

3. Chemical approaches

There are no commercially available chemical treatments to treat viral infections in honeybee colonies. Several investigations have shown naturally produced (soft) compounds that may lower viral loads, although they are not yet commercially available. Treatment with 0.16 ppm thymol reduced DWV levels in emerging bees when they were fed and returned to their colonies. However, the effect of thymol was not consistent with other therapeutic techniques, necessitating more investigation. Applying a propolis solution to the interior of honey bee hives and feeding extracts of two fungus species (*Ganoderma resinaceum* and *Fomes fomentarius*) can lower levels of DWV and Lake Sinai virus.

Conclusions and Future Directions

Most virus infections in honey bee colonies are not problematic if the honey bee colony is healthy and does not experience chronic stress. However, high levels of varroa mites can lead to hive levels of DWV, which can lead to severe symptoms and colony death. In an IPM approach, beekeepers should rely heavily on cultural and mechanical practices to reduce the transmission of viruses and levels of viruses in colonies, as well as for managing varroa mite populations. Understanding the biology of bee-virus interactions and considering all the available options for managing viral infections will help in improving well-being of honey bee colony. Viruses have emerged as significant hidden killers of honey bee colonies, frequently operating in tandem with mites, pesticides, and nutritional stress. A thorough understanding of their ecology, pathophysiology and transmission dynamics is critical for safeguarding apiculture. Integrated pest and disease management, supported by molecular diagnostics and worldwide surveillance, is essential. Future study should concentrate on virus-host coevolution, resistance breeding, and environmentally friendly control strategies such as RNAi.

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OBITUARY

Professor Samiran Chakrabarti
January 5, 1946 – July 18, 2025

Professor Samiran Chakrabarti, Emeritus Fellow (UGC) and former Professor of Zoology at the University of Kalyani, West Bengal, left for his heavenly abode on July 18th 2025, at the age of 79. He was brought up with affection and discipline in Bira, the North 24 Parganas district in West Bengal by his school teacher father. He completed his schooling at Gobardanga Khantura High School, and earned B.Sc. (Hons.) from Bangabasi College, Kolkata and M.Sc. in Zoology from the University of Calcutta in 1966 and 1968, respectively. In 1973, he obtained his Ph.D. under the mentorship of Professor D. N. Raychaudhuri, on aphid (Hemiptera: Sternorrhyncha: Aphidoidea) taxonomy.

He joined the University of Kalyani as a faculty member in 1972, before completing his Ph. D., and served with distinction for over 38 years, retiring on 31st January, 2011 at the age of 65 years. In recognition of his academic excellence, he was awarded the prestigious UGC Emeritus Fellowship in 2011 and received a research grant through it until 2021.

As Principal Investigator, he led 16 major research projects funded by UGC, CSIR, DST, INSA, ICAR, and MoEFCC and supervised 34 Ph.D. students.

Professor Chakrabarti made significant contributions to the biosystematics of mites and aphids. His primary research focused on gall mites (Eriophyoidea) in northeastern India and aphids in the northwestern and western Himalayas. His work also explored the ecology of various insect groups, including those associated with the Sal tree (*Shorea robusta* Roth), mulberry whiteflies and their parasitoids, aphid natural enemies, elaterid and scolytid beetles, oribatid mites, and anopheline mosquitoes. He conducted biochemical studies on insect-induced plant galls and their effects on aphids and eriophyid mites biology.

A meticulous taxonomist, Professor Chakrabarti described 255 new species, erected 18 new genera, and recorded 117 species new to India. Notably, he discovered 70 gall-inducing aphids from the Himalayas, many of which he studied extensively at the Joshimath field station, which he established and maintained from 1981 to 2007.

He was a Fellow of five academic societies and held leadership roles in the Zoological Society, Kolkata, and the Aphidological Society of India. He served on numerous scientific committees, editorial boards, and traveled widely for academic purposes across Asia, Europe, Australia, and North America.

His national and international reputation was affirmed by numerous honors, including:

- S.P. Basu Medal (1975), Zoological Society, Kolkata
- UNESCO Fellowship (1978–79) at the Czechoslovak Academy of Sciences
- Visiting Young Scientist, Wilhelm-Pieck University, Rostock (1979)
- INSA delegate to the Aphid Symposium in Poland (1981)
- Indo-Czech Cultural Exchange Program member (1985)
- British Council visitor (1985, 1990), University of East Anglia and Natural History Museum, London
- Visiting Scientist, USDA, Maryland, USA (1990)
- Aphidological Society of India Award of Honor (1994)
- Plaque for ongoing eriophyid research from *International Journal of Acarology* and Taylor & Francis (2010)
- Visiting Professor, Nanjing and Nanning Agricultural Universities, China (2013)
- Biodiversity Excellence Award, North Bengal University (2015)
- Lifetime Achievement Award (2019) and T.V. Ramakrishna Ayyar Award (2020), B.V. David Foundation
- Honored as "Eminent Aphidologist" at the 11th International Aphid Symposium, Poland (2022)
- Honored with 'Life Time Achievement Award' by Zoological Society of India, Kolkata (2024)

A man of quiet routines and deep cultural roots, he began each morning with a cup of Darjeeling tea and the soulful strains of Rabindra Sangeet. An avid reader of Desh, the Bengali magazine known for its literary and political commentary, he enjoyed thoughtful conversation as much as he did the comfort of a simple fish curry or a bowl of rice pudding. His love for the films of Satyajit Ray reflected his enduring appreciation for subtlety, intellect, and art.

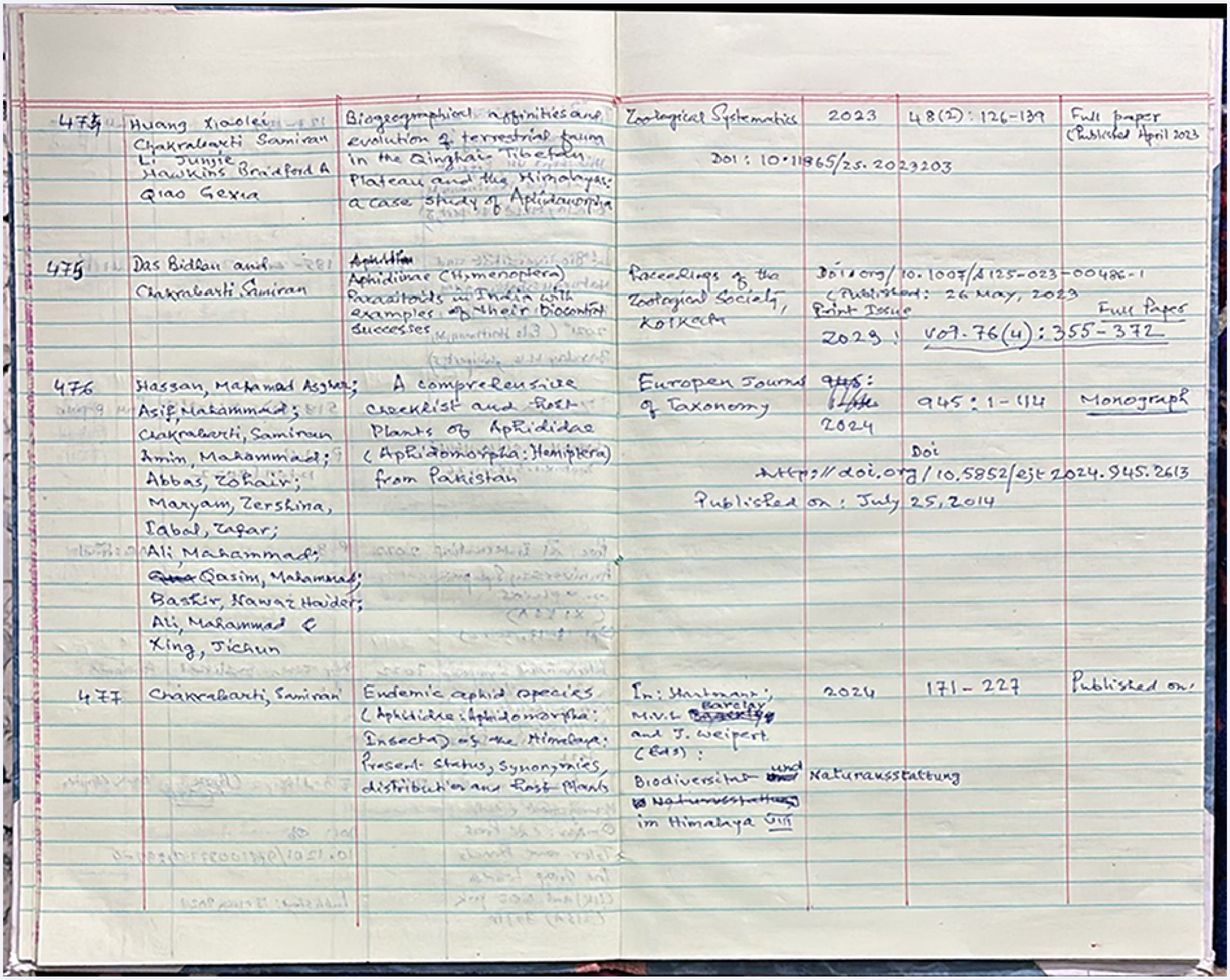
In his personal life, he was a generous and respectful partner to his wife, Dr Sibani Chakrabarti, whom he first met during their days at Ballygunge Campus, Calcutta University. Their disciplines—Zoology and Botany—though distinct, intertwined in conversations that blurred the lines between science and life, bringing them closer until marriage felt like a natural extension of their companionship. Over the decades, their relationship remained a partnership of equals, marked by quiet support and a deep respect for each other's intellectual space. Now a retired professor of Botany, Dr Sibani's name appeared in the acknowledgments of several of his papers. His belief in intellectual freedom was not confined to the academic sphere, but it was a principle he lived by at home. With their son, Saurav, he was an encouraging and non-imposing guide, offering counsel but never dictating choices, allowing him to chart his own course in studies and career. In this way, his home became a place where

Where Botany meets Zoology, and love meets a lifetime-
Mughal Garden, 2023

minds could grow without constraint, nourished by trust and mutual respect.

I remember our first meeting in 2001, graphically, at the canteen of the University of Agricultural Sciences, Bengaluru. I was asked by my guide Dr C. A. Viraktamath, to meet him there and interact with him. I was impressed by his tall figure, well-defined facial features, strong bone structure, and prominent Adam's apple, which would move to the rhythm of his words pronounced in a flat baritone. He listened to me cautiously, looking at me through his narrow, bright but kind eyes, as if peering through a microscope. With concern, he enquired about my work and, on examining my aphid slides, he said, 'Your slides are okay, but your aphid collection is poor. Forget Ph.D., this much collection is not enough for awarding M.Sc.' This motivated me to add several additional aphids to my collection. It was this rare combination of honesty, precision, and deep engagement with students that made him not just a rigorous educator but also a counsellor whose words would stay with the students longer than they expected. Aphids from South India often elicited his curiosity; he would call them "intriguing." He had repeatedly retrieved specimens of the species *Paoliella* (*Paoliella*) *nirmalae* (David, 1969) from me, which he was particularly affectionate to. He held Dr. Kanakaraj David, the noted aphidologist from South India, in high regard and would often speak about his work. His kindness and generosity often shone through in quiet yet thoughtful ways. Once, he went to the trouble of having two enormous volumes of *Catalogue des Aphididae* by Remaudière & Remaudière painstakingly photocopied, bound, and sent to me from Kalyani, through his son, who was then studying at the Ramaiah Institute of Technology in Bengaluru. It was a gesture that spoke not only of his helpful nature but also of the deep value he placed on sharing knowledge. We remained in touch ever since our first acquaintance,

Where others saw a pest, he saw beauty -
Paoliella (*Paoliella*) *nirmalae* (David)



474	Huang Xiaolei; Chakrabarti Samiran; Li Junjie; Hawkins Bradford A; Qiao Gexia	Biogeographical affinities and evolution of terrestrial fauna in the Qinghai-Tibetan Plateau and the Himalayas: a case study of Aphidomorpha	Zoological Systematics; Doi: 10.11865/zs.2023203	2023	48(2): 126-139	Full paper (Published April 2023)
475	Das Bidhan and Chakrabarti Samiran	Aphidiinae (Hymenoptera) Parasitoids in India with examples of their biocontrol successes	Proceedings of the Zoological Society, Kolkata	Doi.org/10.1007/s12595-023-00486-1 (Published: 26 May, 2023); Print Issue 2023:	Vol. 76(4): 355-372	Full Paper
476	Hassan, Mahamad Asghar; Asif, Mahammad; Chakrabarti, Samiran; Amin, Mahammad; Abbas, Zohair; Maryam, Zershina; Iqbal, Zafar; Ali, Mahammad; Qasim, Mahammad; Bashir, Nawaz Haider; Ali, Mahammad & Xing, Jichun	A comprehensive checklist and host plants of Aphididae (Aphidomorpha: Hemiptera) from Pakistan	European Journal of Taxonomy; Doi https://doi.org/10.5852/ejt.2024.945.2613; Published on: July 25, 2014	945: 2024	945: 1-114	Monograph
477	Chakrabarti, Samiran	Endemic aphid species (Aphididae: Aphidomorpha: Insecta) of the Himalaya: Present status, synonymies, distribution and host plants	In: Hartmann, M.V.L. Barclay and J. Weipert (Eds): Biodiversität und Naturausstattung im Himalaya VIII	2024	171-227	Published on:

A scholar's journey, handwritten in ink - A page from the register maintained by Dr Chakrabarti since his college days.

though our exchanges were always very formal and focused only on sharing our research findings. Most of our conversations revolved around enquiring about ongoing work, requesting research literature, or arranging the loan of slides. Whenever I published a new species or report on aphids (something that became less frequent after 2010), he would promptly request the slides for re-examination. I am certain those slides now rest safely in his collection, preserved with the same care he gave to all his scientific materials. After 2020, our interactions became rarer, yet he never failed to send me his warm Durgotsava greetings each year. His last email, dated 15 April 2025, was to inquire about a copy of my paper on *Tuberaphis xinglongensis* (Zhang). Along with his request, he had attached his own published work, *Endemic aphid species (Insecta: Aphidomorpha: Aphididae) of the Himalaya: Present status, synonyms, distribution and host-plants*, which had appeared in *Biodiversität und Naturausstattung im Himalaya VIII*. It was a final gesture that perfectly reflected him—ever the meticulous researcher, ever the generous colleague.

I met him in person for the last time on 21st February 2024, at the University of Agricultural

Sciences, during the Entomology Student Conclave. He greeted me with that familiar sweet smile, dressed in a navy-blue safari suit—simple, dignified, and unmistakably him. That image is etched in my memory like a still frame. Now, whenever I think of him, the same picture comes to my mind.

Throughout his career, Dr Chakrabarti published 477 research articles (which include 15 books, several monographs, and numerous book chapters), each a testament to his methodical mind and commitment to his field. His 478th manuscript, sadly left incomplete, was in progress at the time of his passing. True to his lifelong habits, he maintained a handwritten, tabular record of each of his publications in a ruled register- a practice he began in his college days and continued faithfully until the end.

His legacy lives on not only through his students and work but also in the two genera named after him: *Chakrabartiaphis* Remaudière, 1997 (Aphididae) and *Chakrabartiella* Amrine & Stasny, 1994 (Eriophyidae), as well as several species named in his honor by scientists in India and abroad.

Professor Chakrabarti was not only an outstanding researcher but also a deeply respected teacher and mentor. His passing leaves an irreparable void in the fields of zoology and entomology. For his former students—spread across India and far beyond—his name will always evoke memories of patient guidance, generous sharing of knowledge, and his unfailing willingness to assist in species identification and scientific pursuits. His influence will continue to live on in the researchers whose careers he helped shape. His name, Samiran (breeze) remained a fitting metaphor for his demeanor. He moved through life with calm grace, bringing comfort, encouragement, and clarity to those around him, leaving behind a refreshing touch of wisdom.

He is survived by his wife and son, daughter-in-law, grandson and granddaughter, who, along with his many students, colleagues, and friends, will cherish his memory, the legacy of scholarship and generosity he leaves behind.

Acknowledgements

The author is thankful to Dr Sivani Chakrabarti, Mr Saurav Chakrabarti, Dr Bijan Kumar Das, and Dr Sanjoy Sarkar for various inputs on the life of Dr Samiran Chakrabarti.

Sunil Joshi

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BUG STUDIO

12TH 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 presentedwith the photograph, caption, description and technical specifications.

The following are the winner for 12th Indian Entomologist photo contest:

- The first place was won by Raghuram Annadana (20133, Tower 20, Prestige Ferns Residency, Harlur Road, Bengaluru 560102), who captured incredible photo of Parasitic wasp ovipositing into the freshly laid eggs of the Banana Skipper (*Erionota thrax*).
- The second place was won by Vinod Kumar V. K (c/o Nirmala teacher, Basaveshwara Extn, Near Angel wings dance school, Kushalnagar, Kodagu, Karnataka), for his incredible close up photo of Parasitic wasp larvae developing inside a caterpillar.
- The third place was won by Anand Sharma (C-100, Badarpur, New Delhi-110044) for capturing a photo of Mating Robber flies.

Congratulations to the winners, and we acknowledge all the participants who took an interest in 12th Indian Entomologist photo contest and sent their entries!!

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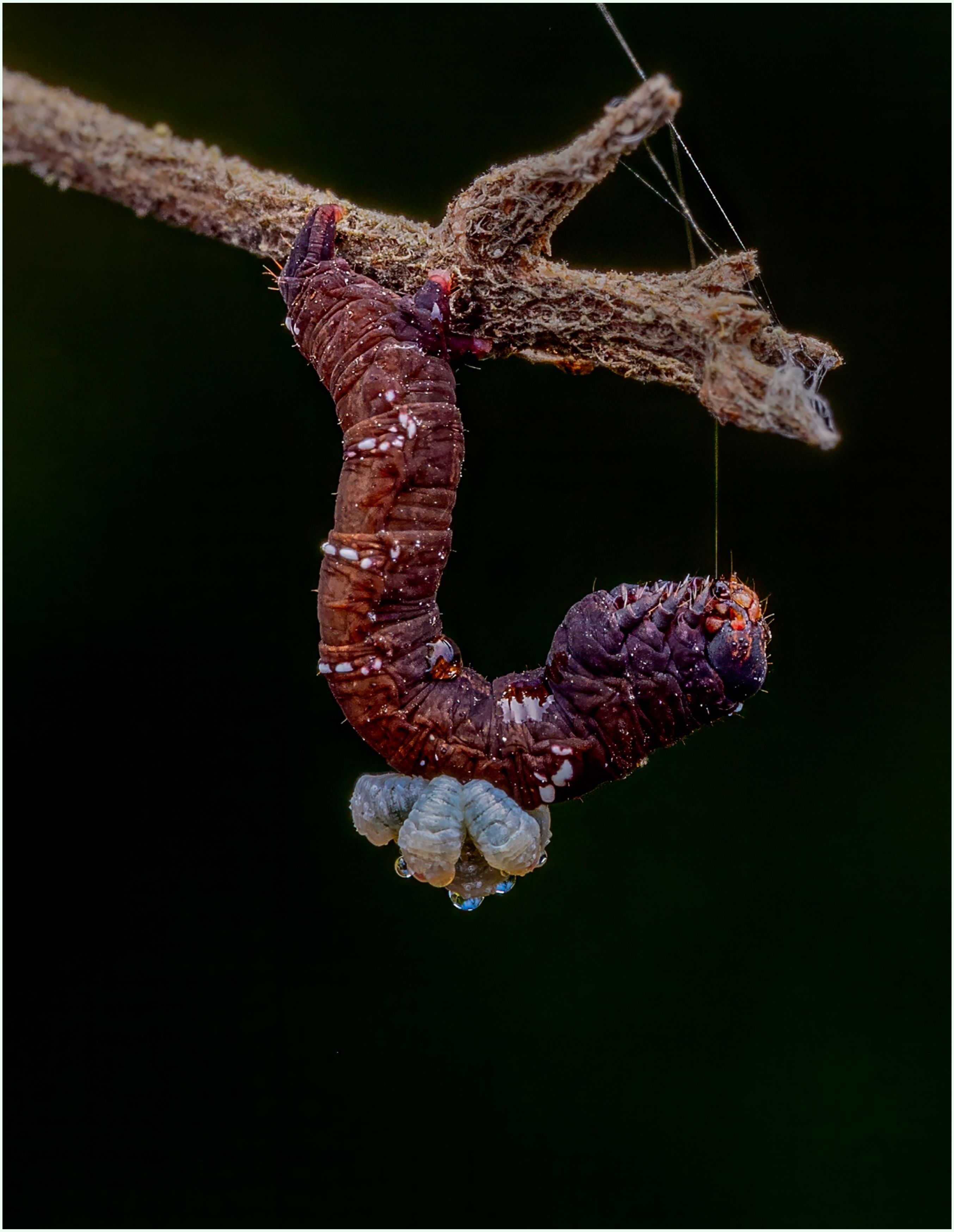
New Delhi-110 012

First place: Parasitic wasp ovipositing into the freshly laid eggs of the Banana Skipper (*Erionota thrax*) submitted by Raghuram Annadana from Bengaluru, Karnataka.



Second place: A close up shot of parasitic wasp larvae developing on caterpillar by Vinod Kumar V.K from Kushalnagar, Kodagu, Karnataka.

Third place: Mating Robber flies by Anand Sharma Badarpur, New Delhi.

STUDENT CORNER

Saravanan Selvam

Saravanan Selvam is currently pursuing his Ph.D. programme in Entomology on "Semiochemical-based management strategies for insect pests" under the chairmanship of Dr. P.S. Shanmugam, Associate Professor, Agricultural Entomology, TNAU, Coimbatore, and Co-chairmanship of Dr. Kesavan Subaharan, Principal Scientist, ICAR-NBAIR, Bengaluru. This research demonstrated that behavior-modifying chemicals effectively disrupt the mating and feeding behaviors of insect pests, leading to reduced pest populations and minimized crop damage. This approach offers an eco-friendly alternative to traditional pest control methods. He wants to become a ARS scientist and She strongly stated that his research findings benefit to farmers' level. He did his masters from the College of Agriculture, Central Agricultural University, Iroisemba, Imphal, Manipur and research on "Eco-friendly Management of *Plutella xylostella* (Linnaeus) with Reference to Bio-insecticides and Planting Dates under Cabbage-Crop-Ecosystem of Manipur valley" under the guidance of Dr. Kh. Ibohal Singh, Professor, CAU, Manipur.

Anithaa Velmurugan

Anithaa Velmurugan is currently pursuing her Ph.D. programme in Entomology on "Standardising the mass rearing protocol for Black Soldier Fly (BSF), *Hermetia illucens* Linnaeus and utilisation of its byproducts" under the chairmanship of Dr. C.P. Mallapur, Professor of Entomology, Head of PRT & QAL, UAS, Dharwad. She has been awarded with PM fellowship for Doctoral Studies funded by ANRF-CII. Her doctoral research is focused on optimising the rearing conditions for each life stage of the black soldier fly, intended for better protein yield and waste valorisation. My research will also highlight the potential of byproducts from BSF rearing. This will be helpful for the companies involved in waste management using BSF to improve their productivity and also for the policymakers (regulations for using insect products and byproducts) in the future, as the maximum number of research articles on BSF are from outside India. She wishes to build her career as an Agriculture Research Scientist where she can use insect science to achieve sustainability in all possible, as well as productive ways.

N. Shreya

N. Shreya, a Ph.D. scholar (Entomology) from University of Agricultural and Horticultural Sciences, Shivamogga is pursuing her research on the Taxonomy of tribe Empoascini (Hemiptera: Cicadellidae: Typhlocybinae) from economically important crops in South India. She is carrying out her study under the guidance of Dr. C. M.

Kalleshwara swamy, Professor UAHS, Shivamogga and Dr. C.A. Viraktamath, former emeritus professor, UAS, GKVK. She aims to determine the species composition, host association and distribution pattern of the Empoascini leafhoppers and also to develop an identification key that is suitable for their easy identification. She received her master's degree from University of Agricultural Sciences, Bangalore where she worked in the field of insect ecology where she compared two different light traps in an organic farming system. The outcomes of her M.Sc. research revealed that deployment of any type of light trap for the sole purpose of pest management is not a tenable option as it leads to potential harm to the local beneficial fauna and a consequent damage to the balanced agro-ecology. Shreya has been awarded with the UAHS, Shivamogga merit fellowship and has also qualified ASRB NET.

Airneni Sunny Rao

Airneni Sunny Rao is presently pursuing his Ph.D. in Entomology from Indira Gandhi Krishi Viswavidyalaya (IGKV), Raipur. Under the guidance of Dr. Dhanendra Kumar rana, professor, IGKV, Raipur and Dr. Gandhi Gracy, Pr. Scientist, ICAR-NBAIR, he is working on the identification and validation of target genes to develop RNAi based pest management for Cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: Pseudococcidae). This research can demonstrate the feasibility of RNAi as a targeted, sustainable pest management strategy against cassava mealybug. He has completed his M.Sc. degree from IGKV, Raipur where he worked on rice breeding lines for identification of resistance to Asian rice gall midge, *Orseolia oryzae.* His research identified the presence of key resistance genes in several resistant entries, offering promising resources for breeding ARGM-resistant rice varieties. Sunny has been awarded with the ICAR-NTS fellowship during his masters. After completing his doctoral program, he plans to continue research in the field of insect molecular biology and pest management.

Khaba Moirangthem

Khaba Moirangthem is currently pursuing his Ph.D. in Entomology at CPGS-AS, CAU (I), Umiam, Meghalaya, under the guidance of Dr. Kennedy Ningthoujam. His research focuses on the diversity of termite species in Meghalaya, their gut microbiome and the biorational management of pestiferous species. The work aims to discover endemic species of termites in Meghalaya. He completed his M.Sc. in Entomology from G.B. Pant University of Agriculture and Technology, Pantnagar, under the mentorship of Dr. Renu Pandey, where he screened soybean germplasm against *Spodoptera litura* and assessed the efficacy of entomopathogenic fungi. His study revealed

Beauveria bassiana to be more effective than *Metarhizium anisopliae* against *S. litura*. A recipient of the ICAR-NTS Fellowship during his undergraduate studies, he aspires to advance research in Agricultural Entomology.

Sanhita Chowdhury

Sanhita Chowdhury is currently pursuing her Ph.D. in Entomology at Punjab Agricultural University, Ludhiana, under the supervision of Dr. Anureet Kaur Chandi, Professor. Her research focuses on the sublethal and transgenerational effects of insecticides on fall armyworm (*Spodoptera frugiperda*), aiming to generate valuable insights into how sublethal doses of insecticides affect the pest across generations, contributing to improved pest management strategies. She completed her M.Sc. in Entomology from Dr. Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar, working on the efficacy and residue dynamics of a combi formulation against yellow mite in chilli under the mentorship of Dr. Sanjay Kumar Sahoo. A recipient of the ICAR-JRF (2021–23) and currently a Jawaharlal Nehru Doctoral Fellow, she aspires to contribute to agricultural research and education as an Assistant Professor or through Agricultural Research Services (ARS).

Bimal Kumar Sahoo

Bimal Kumar Sahoo is currently pursuing his Ph.D. programme in Entomology on "Decontamination of Pesticide Residues in Fruits and Vegetables by Microbial Agents" under the supervision of Dr. A. Suganthi, Associate Professor, Agricultural Entomology, TNAU, Coimbatore. He did his master's from the CPGS-AS, Central Agricultural University (Imphal), Umiam, Meghalaya, working under Dr. Mahesh Pathak on "Synergistic impact of chemical insecticides with *M. anisopliae* for managing sucking pests of rice". The outcomes and practical utility of his master's work emphasized identifying the microbial agents for degradation of pesticides. A DST-INSPIRE Fellow, he aspires to become an Assistant Professor and contribute to sustainable crop management for farmers' welfare.

The Vector War

Akansha Goldi

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Control, ICMR-RMRIMS, Patna

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Click here

At contemporary, vectors so-called transmitting agents of diseases have been re-introduced as a dynamic concern contributing towards a significant 17 percent of the infectious disease pool where more than 80 percent of the global population lies under the threat. Now and then, there have been several instances extending towards emergence and re-emergence of VBDs and zoonoses despite the sustained measures taken under multiple persevered national and sub-national level programmes. Public health as an expression for achieving the mainstay targets of disease control and elimination also prioritizes prevention, so to say!

With obvious reasons, the Integrated Vector Management Programme intensely focusses on Entomological Surveillance and Vector Control devising plans for optimal use of tools and interventions; still, there have been an epiphany of management considering individual based and community level participation to “Fight the Bite”.

Yes! There are plans, there is commitment, there seems resource allocation with an equivocal effort on community participation for personal protection measures, source reduction described far beyond IRS and fogging for control of vector borne diseases. Use of long-lasting insecticidal nets/ insecticide treated bed nets for regions showing malarial endemicity is just an example note-as depicted above!

A preventive approach begins with a sense of responsibility and comprehensive acts-leads towards a better outcome for both; individual and the collective.

It is not about achieving health at once but it ought to be-being healthy for-ever!

References:

Website URL: - https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases

Website URL: - https://ncvbdc.mohfw.gov.in/Doc/Guidelines/Manual-Integrated-Vector-Management-2022.pdf

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.

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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.

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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. indianentomologist.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 indianentomologist@gmail.com

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