

Buzzing wonders: a comprehensive review of stingless bee biology and behaviour

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Summary

Stingless bees, despite lacking a venom mechanism, play a vital role in ecosystems and economies due to their intricate colonies and diverse hive products, including honey, pollen, propolis, and beeswax, which possess significant medicinal and economic value across various industries. Beyond pollination, stingless bees produce a distinctive variety of honey that has been highly valued for centuries by indigenous communities in their respective habitats. This honey boasts a unique flavor profile and is esteemed for its medicinal properties, garnering increasing popularity among consumers seeking alternative honey varieties. Despite their significance, these bees confront threats such as habitat loss, pesticide exposure, and competition from other bee species. Hence, conservation endeavors aimed at preserving their habitats and fostering awareness regarding their ecological importance are imperative for their sustained existence. Stingless bees emerge as remarkable creatures pivotal for ecosystem balance and agricultural productivity. Their intriguing biology, intricate social dynamics, and pivotal contributions to pollination and honey production underscore the critical need for their conservation. By comprehending and safeguarding stingless bees, we uphold the health and resilience of our natural world.

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Introduction

Stingless bees, members of the Hymenoptera order and Apidae family, are relatives of orchid, bumble, and honeybees. Also known as sugar bag or sweat bees, they are small, eusocial insects with residual stings, ranging from 2 to 16 mm in size. These bees use dammer resin and wax to build nests in hidden locations. They are characterized by a reduced sting, a penicillium (a collection of hairs on the hind tibia), and weakened wing venation, lacking a functional venom mechanism (Singh & Khan 2019; Khambhu et al. 2021). Stingless bees are mainly classified into the genera *Trigona* and *Melipona*, with *Trigona* being the largest and most widespread (Camargo et al. 1988). In India, notable species include *Trigona laeviceps* and *T. iridipennis* (Singh & Khan 2019; Rahman et al. 2015; Haldhar et al. 2021a). The practice of meliponiculture highlights the economic value of their hive products—honey, pollen, propolis, and beeswax—which are prized for their antioxidant, antibiotic, and nutritional properties (Campos et al. 2008; Kwapong et al. 2010). Stingless bee honey, known for its unique composition, is used in wound healing and immunity boosting. The diverse medicinal uses of this honey across species emphasize its therapeutic potential. Recent studies suggest that commercial meliponiculture, particularly with *T. iridipennis*, holds promise for sustainable beekeeping and economic growth (Devanesan et al. 2022).

Morphology

The external morphology of stingless bees is divided into three main body sections: the head, the thorax, and the abdomen. Key features of the head include antennae, mandibles, and both complex and simple eyes (ocelli). The thorax supports three pairs of legs and two pairs of wings. Stingless bee workers have modified corbicular hind legs for pollen collection and transport. The abdomen, the third body section, contains a non-functional "stinging" system (Kwapong et al. 2010; Haldhar et al. 2021b). The stingless bee, *Lepidotrigona arcifera*, first reported in northeast India, is a pollinating insect of the tropical and subtropical regions of the world. Phylogenetic analysis shows that Tibetan *L. arcifera* is grouped with the other stingless bee species and is most closely related to the stingless bee, *L. flavibasis*. The genetic distance between Tibetan *L. arcifera* and the other stingless bee species is approaching those between pairwise bee species belonging to other such bee genera as *Bombus* and *Apis* (Yuxin Yao et al. 2024). The dorsal view of the bee demonstrates the following traits: the body length is approximately 4 mm; the back of the thorax is roughened by an incredibly dense tessellation (yellow scales); the reddish-brown metasoma; a completely black head, antenna, and mesosoma. The wings are bright and iridescent. The width of the head is approximately 1.8 mm, and tiny teeth grow on the mandible. The basitarsus of the hind leg is brown, and the hair fringe on the back of the hind tibiae is plain and not branching or plumose. The forewing length is around 4.5 mm. The hind wings have six hamuli (Yuxin Yao et al. 2024). *Trigona* species are small and slender, measuring 2 to 8 mm, while *Melipona* species are larger and more robust, ranging from 8 to 15 mm. *Melipona* bees have long, dense pubescence,

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whereas *Trigona* bees exhibit shorter, sparser pubescence. In *Melipona* spp., the forewing is relatively short, not extending beyond the abdomen, and the pterostigma is poorly developed. Conversely, *Trigona* spp. have long forewings that extend past the abdomen, with a broad, rounded pterostigma (Wille 1983).

In *T. laeviceps*, the queen lays a single egg per brood cell, pre-filled with honey and pollen, which worker bees seal with resin and wax. The eggs are smooth, cylindrical, and light cream-colored, with an incubation period of 4.80 to 6.40 days. Upon hatching, larvae are creamy white, legless, and C-shaped, lasting 10.40 to 12.00 days before becoming pupae with a pupal period of 31.00 to 33.40 days. Newly emerged adults of *T. laeviceps* have a light yellowish-brown body with blackish-brown abdomens and black heads with white hairs. Their compound eyes are reddish, and their forewings are uniformly colored, while their hind wings are semi-transparent with dark brown venation. The hind tibiae are short, with pear-shaped corbiculae covered with setae. The adult worker's lifespan is about 46.50 days (Khambhu et al. 2021).

Biology

The queen of a stingless bee colony, acting as the matriarch, regulates colony activities through pheromones that influence worker behaviors and colony dynamics. These chemical signals include suppressing worker bee egg-laying abilities. Female worker bees develop from fertilized eggs, initially fed royal jelly and later worker jelly, and assume various colony roles such as foraging, nest maintenance, defense, and larval care. Drones, the male bees, are essential for reproduction, mating with virgin queens from other colonies to enhance genetic diversity. They develop from unfertilized eggs and are characterized by lighter coloring (Kwapong et al. 2010).

Two distinct male behaviors in stingless bees have been observed:

1. Nest-associated aggregation: Drones gather near the nest entrance to increase their chances of mating with a virgin queen during her nuptial flight.
2. Non-nest-associated aggregation: Drones gather at environmental landmarks, attracted by visual cues or pheromones, to encounter virgin queens away from the nest. This behavior broadens mating opportunities and increases genetic diversity (Slaa et al. 2006; Zuben & Garcia 2017).

Studies on *Trigona* species have provided insights into their development. Roopa et al. (2015) reported on *T. iridipennis* in Karnataka, with an egg period of 5.75 days, a larval period of 12.70 days, and a pupal period of 35.30 days, totaling a life cycle of 53.30 days. Khambhu et al. (2021) investigated *T. laeviceps* in Navsari, noting an egg period of 5.37 days, a larval period of 11.20 days, and a pupal period of 31.83 days, with a total life cycle of 48.77 days. Shaikh et al. (2023) studied *T. nr. Pagdeni* in Maharashtra, observing an egg period of 6.3 days, a larval period of 15.1 days, and a pupal period of 18.7 days, resulting in a total development period of 38.2 days. These studies enhance our understanding of the developmental stages and life cycles within the *Trigona* genus.

Nest structures

The materials utilized in the construction of nests by *Meliponini* species are diverse and encompass various natural substances. One such material, cerumen, is a blend of wax and propolis. Cerumen can exhibit a range of characteristics, from soft and light brown, likely wax-dominated, to rigid and sometimes brittle, appearing dark brown or black. Propolis, another substance, consists of resins and gums collected from the environment and brought back to the nest by the bees. Wax, an essential component, is produced by the bees themselves through secretions. Mud is utilized by certain species, albeit less commonly, possibly mixed with propolis or cerumen, for constructing plates or occasional entrances Pavithra et al. (2013). Additionally, plant fibres and chewed leaf material find application in the construction process, primarily in the outer layers of batumen for exposed nests. Gums and resins, collected by stingless bees, originate from a variety of sources, including natural secretions of plants. These diverse materials contribute to the structural integrity and functionality of the nests, highlighting the resourcefulness and adaptability of *Meliponini* species in utilizing available resources for nest construction (Choudhary et al. 2021)

Nest architecture

Meliponinae, a subfamily of stingless bees, predominantly nest in hollow trees, a behavior documented by Wille & Michener (1973). Hollow trees offer several benefits: protection from weather and predators, insulation for stable temperature and humidity, and space for constructing complex nests. These nests include chambers for brood rearing and food storage, with camouflage aiding in predator evasion.

In *T. iridipennis* nests, brood cells are small, oval chambers constructed on wax pillars. Workers build these cells to raise larvae, which mature and emerge as adults, shedding their cell walls. Newly emerged adults are brown to black, while larvae are creamy white. Food storage includes larger honey and pollen pots arranged in clusters. Brood involucrums, often absent in *T. iridipennis*, are layers of propolis, resin, and plant components that facilitate movement around the brood area. Batumen, made of mud, resin, and wax, seals excess cavity space and maintains internal conditions. The nest entrance, varying in shape and size, is made from soil, resin, and plant materials, offering protection and aiding in colony management. Stingless bees generally prefer medium-sized entrances (Charan et al. 2023).

Nesting character

Roopa et al. (2015) conducted a study in Karnataka focusing on the nesting characteristics of *T. iridipennis* within whole cavities. Through the examination of 15 *Trigona* nests, they recorded various dimensions (in millimeters) of nest characteristics. These dimensions included cavity diameter (260 mm), entrance length (12 mm), brood cell height (2.5 mm), pollen pot height (5.5 mm), honey pot height (6.5 mm), and honey pot width (5.8 mm). Karthick et al. (2018) conducted research in India to explore different nesting sites of *T. iridipennis*. They observed that the majority of nesting sites were found in cavities within buildings (83.84%), while underground

cavities accounted for the least number of nesting sites (2.36%). Shaikh et al. (2023) conducted a study in Maharashtra examining the nesting structure of stingless bees. They reported that the average dimensions ($\pm$ standard deviation) of various nest components were as follows: brood cell height 1.93 ± 0.08 mm, brood cell width 2.13 ± 0.05 mm, oval-shaped pollen pot height 5.69 ± 0.56 mm, oval-shaped pollen pot width 4.50 ± 0.21 mm, entrance tube length 1.63 mm, entrance tube width 0.93 mm, honey pot height 6.75 ± 0.4 mm, and honey pot width 5.52 ± 0.3 mm.

Nest duplication of stingless bee

Nest duplication in stingless bees involves two main methods: hiving and eduction. The first method is commonly used and involves transferring naturally occurring colonies of stingless bees into artificial bee boxes. While hiving is efficient in quickly acquiring colonies, it can be detrimental to the original colonies as it involves removing them from their natural habitat. This process can disrupt the bees' established environment and potentially harm the original nest structure. In contrast, the eduction method aims to duplicate colonies without damaging the original nest. In this approach, an artificial nesting box is attached to the entrance of the existing colony. Over time, the colony gradually expands into the new box, eventually dividing into two separate colonies. This method is less invasive as it allows the bees to remain in their natural habitat and preserves the integrity of the original nest. However, education can be a slower process, taking anywhere from a few months to over a year for the colony to divide and establish itself in the new box (Virkaret al. 2014).

Nesting site

Stingless bees exhibit a diverse range of nesting behaviours, typically favoring hollow trunks, tree branches, and underground cavities. However, they have also been observed nesting in unconventional locations such as wall cavities, old rubbish bins, water meters, and storage drums. This adaptability allows them to utilize various nesting sites to regulate nest temperature, avoid direct exposure to sunlight, and protect themselves from predators, as noted by Charan et al. (2023). In India, different species of stingless bees demonstrate specific nesting preferences. For example, *T. iridipennis* tends to nest in timber, utilizing the hollow spaces within wooden structures. On the other hand, *T. bengalensis* primarily nests in bamboo, while some species may choose cracks and crevices within stone or mud walls (Newis et al. 2023). These observations were reported by Rahman et al. (2015), highlighting the diverse nesting habits exhibited by different species of stingless bees.

Nesting habits of *Trigona* spp.

The nesting habits of various *Trigona* species demonstrate a remarkable diversity, with each species exhibiting unique behaviours and preferences. *T. denoiti* constructs its nests inside the nests of termites. By utilizing the existing structures created by termites, *T. denoiti* avoids the need to build its own nest from scratch, benefiting from the protection and resources provided by the termite colony. Unlike *T. denoiti*, *T. spinipes* builds exposed nests, often using leaves and other vegetative

parts mixed with resin. These nests are typically visible and constructed in open areas, allowing for easy access and ventilation. *T. oryani* has a unique nesting behaviour, as it builds its nests within ant nests of the *Crematogaster* species. By cohabiting with ants, *T. oryani* may benefit from the protection provided by the ants and the resources available within the ant nest environment. *T. laeviceps* bees prefer nesting in tree cavities, utilizing the hollow spaces within trees for their nest construction. Tree cavities provide a protected and secluded environment, offering shelter from the elements and potential predators. Lastly, *T. iridipennis* constructs its nests inside compound walls, hollow blocks, and similar structures. This species demonstrates a preference for nesting in man-made structures, possibly due to the availability of suitable nesting sites and the protection afforded by these structures. These nesting behaviours, documented by Danaraddi et al. (2009), highlight the diverse strategies employed by different *Trigona* species to establish their nests and ensure the survival of their colonies. Each species has adapted to utilize specific nesting substrates and environments, reflecting their ecological niche and evolutionary history.

Flight range

The differences in flight range observed between stingless bees and honey bees, as well as among different species and subgenera within the stingless bee genus, can be attributed to various factors, including body size and physiological adaptations. Stingless bees generally exhibit a more limited flight range compared to honey bees. This limitation is partly due to their smaller body size and differences in foraging behaviour. Honey bee workers, known for their ability to travel long distances, can forage over 2-3 kilometers, while stingless bee workers typically have a maximum foraging range of around 1 kilometer. The correlation between flight range and body size among stingless bees further illustrates this point. In general, smaller bees, such as those belonging to the subgenus *Plebia* (3-4 mm), have more restricted flight ranges, typically around 300 meters. Medium-sized bees, like those in the subgenus *Trigona* (around 5 mm), can cover slightly longer distances, with flight ranges of about 800 meters. Conversely, very large bees, such as *Melipona fuliginosa* (13-15 mm), exhibit the longest flight ranges among stingless bees, reaching approximately 2000 meters. The relationship between body size and flight range can be explained by physiological constraints and energy requirements. Smaller bees may have less energy reserves and muscle mass, limiting their capacity for sustained flight over longer distances. Additionally, larger bees may have greater wing surface area relative to body size, allowing for more efficient flight and longer endurance. However, it's essential to consider that factors other than body size also influence flight range, including environmental conditions, resource availability, and nesting habits. Moreover, individual variations within species and subgenera can also contribute to differences in flight capabilities. Overall, the correlation between body size and flight range in stingless bees highlights the intricate interplay between morphology, behaviour, and ecology in shaping the foraging strategies and ecological niche of these fascinating pollinators (Amano et al. 2000).

Foraging behaviour

Foraging behavior in pollinators, including stingless bees, is essential to understanding their ecological roles. Free (1993) measured the foraging rate (flowers visited per minute) and foraging speed (time per flower) to evaluate pollinator efficiency. Stingless bees often forage within 0.5 km of their nests, with body size influencing distance (Rakshitha et al., 2022). Temperature significantly affects their activity; bees tolerate heat above 34°C with evaporative cooling from water (Souza-Junior et al. 2019). Research on *T. iridipennis* revealed peak foraging activity in the morning, with seasonal variations affecting patterns (Rakshitha et al. 2022; Gadhiya & Pastagia 2019). Understanding these behaviors is crucial for assessing pollinator roles and responses to environmental changes (Painkra 2019).

Stingless bees are involved in pollinating a variety of crops

Common name	Source	Common name	Source
Medicinal plants		Fruit crops	
Neem	Nectar	Mango	Pollen
Ixora	Nectar + Pollen	Banana	Nectar
Javanese wool plant	Nectar	Papaya	Pollen
Tulsi	Nectar	Guava	Nectar + Pollen
Plantation crops		Field crops	
Coconut	Nectar + Pollen	Bajra	Pollen
Cashew	Nectar + Pollen	Sunflower	Nectar + Pollen
Coffee	Nectar	Red gram	Nectar
Vegetable crops		Condiments and spices	
Sponge gourd	Pollen	Cinnamon	Pollen
Drumstick	Nectar + Pollen	Mustard	Nectar
Bottle gourd	Pollen	Ornamental plants	
Brinjal	Nectar + Pollen	Balsam	Nectar
Sweet gourd	Pollen	Rose	Nectar + Pollen
Herbs, shrubs & bushes		Coral creeper	Nectar + Pollen
<i>Euphorbia</i>	Nectar	<i>Hamelia</i>	Nectar
<i>Jatropha</i>	Nectar	Marigold	Nectar
<i>Cassia</i>	Nectar	Peacock plant	Nectar + Pollen
<i>Zizipus</i>	Nectar	Golden dew drop	Nectar
<i>Crotolaria</i>	Nectar	Sage	Pollen
Wild tapioca	Nectar + Pollen		

Source: Vazhacharickal et al. 2021

Pollination

Putra et al. (2016) conducted observations in Indonesia, revealing that chili pepper plants pollinated by *T. leaviceps* exhibited significantly higher fruit number (82.93), fruit weight (562g), and yield (8186 kg/ha) compared to those pollinated by wind alone, which resulted in a fruit number of 64.13, fruit weight of 337.67 g, and yield of 5306.7 kg/ha. Wahizatul et al. (2017) found that stingless bee (*Heterotrigona itama*) pollination significantly increased greenhouse cucumber (*Cucumis sativus*) yield and quality, suggesting their potential as effective pollinators in agricultural contexts. Wahizatul et al. (2017) from Malaysia found that chili plants pollinated by *H. itama* showed superior characteristics with the highest fruit number (112.54), weight (11.61g), length (13.00 cm), and diameter (12.40 mm) compared to those without stingless bee pollination, which recorded a fruit number of 48.54, fruit weight of 337.67 g, fruit length of 9.02 cm, and fruit diameter of 11.38 mm. Kishan et al. (2017) in

Impact and features of stingless bees on pollination

Stingless bees play a crucial role in pollination, significantly boosting crop yields. Bueno et al. (2023) highlighted their widespread floral visitation in tropical and subtropical regions. According to Kishan et al. (2017), they can increase yields by 50-60% in fruits, 45-50% in crops like sunflower, and up to 150% in cucurbits. They are essential for vanilla pollination in Mexico (*Trigona* and *Melipona*). Key traits like polylecty, floral constancy, adaptability, and food hoarding enhance their efficiency as pollinators (Contrera et al. 2011; Karthick et al. 2018). Norowi et al. (2010) emphasized the importance of conserving stingless bees for sustainable food production. Their broad floral preferences and effective communication further enhance their pollination impact.

Tamilnadu observed that cucumber pollinated by stingless bees exhibited maximum fruit length (19.1 cm), fruit girth (11.4 cm), fruit weight (119 g), number of fruits (20.6 fruits/plant), and fruit yield/plant (3.07 kg/plant) compared to the control group, which showed the lowest fruit length (17.6 cm), fruit girth (10.7 cm), fruit weight (113.7 g), number of fruits (20.1/plant), and fruit yield (2.8 kg/plant). Sen et al. (2021) in Assam investigated the effect of *T. iridipennis* pollination on cucumber yield during summer and winter, reporting the highest fruit characteristics in stingless bee pollination plots, with fruit length ranging from 18.08 cm to 18.31 cm, fruit girth from 10.08 cm to 10.14 cm, fruit weight from 202.62 g to 205.11 g, and fruit set from 79.06% to 83.85%, surpassing the open pollination and pollinator exclusion plots.

Threat to the stingless bee

Stingless bees face numerous threats, including habitat loss, pesticides, climate change, diseases, and competition. Pests such as syrphid and phorid flies, dry

fruit mites, black soldier flies, nitidulid beetles, and honeycomb moths cause colony damage (Karthick et al. 2018; Vazhacharickal et al. 2021; Bachahalli & Sekarappa 2022). Predators like spiders, geckos, lizards, and human activities further endanger these bees (Bachahalli & Sekarappa 2022). Pesticides like thiamethoxam, fipronil, and imidacloprid cause mortality and developmental issues in various stingless bee species (Toledo-Hernandez et al. 2022). Conservation and pest management are crucial to protecting these vital pollinators.

Management of stingless bee colonies

The management of stingless bee colonies involves several practices aimed at ensuring the well-being and productivity of the colonies. Firstly, it is essential to keep the colonies in shaded areas to shield the nest components from the harmful effects of direct sunlight, which can cause damage to the nest structure and affect the bees' behaviour. To prevent rainwater from entering the hives, measures should be taken to ensure proper hive construction and maintenance, such as providing adequate shelter and covering to protect the colonies during inclement weather Kumar et al. (2012). This helps avoid mold growth within the hive, which can lead to undesirable conditions and potentially result in the colony's abandonment. Another important aspect of colony management is the removal of spider webs found within the hive. This practice helps to safeguard the colony against potential predation by spiders, which can pose a threat to both adult bees and developing brood Bachahalli & Sekarappa (2022). Furthermore, it is crucial to seal the inner lid tightly with resin to prevent ants from gaining access to the hive. Ants can disrupt the colony and steal valuable resources, so sealing the lid effectively helps to protect the colony from such intrusions. Lastly, proactive measures such as removing affected pollen pots and brood cells are essential for preventing the spread of storage mites infesting pollen pots. By promptly addressing any signs of infestation, beekeepers can help maintain the health and productivity of the colony. Overall, these management practices contribute to creating a suitable environment for stingless bee colonies, supporting their growth, productivity, and overall well-being. (Chauhan & Singh 2022; Jamir et al. 2022; Kumar et al. 2012).

Conclusion

In conclusion, stingless bees (*Meliponines*) are vital to ecosystems and agriculture due to their efficient pollination and unique honey production. Their complex social structures and ecological roles make them invaluable, but they face significant threats such as habitat loss and pesticide use. Protecting these bees through conservation efforts is crucial for maintaining biodiversity and ensuring the sustainability of natural ecosystems.

Future scope

The future scope of stingless bees lies in their potential to enhance pollination, improve crop yields, and contribute to biodiversity conservation. Research is advancing their use in agriculture, exploring their medicinal properties, and promoting sustainable beekeeping practices.

Conservation efforts aim to protect their habitats and genetic diversity, underscoring their importance for sustainable development and ecosystem health.

Author contributions

The roles of authors were: Research paper gathered by Z. N. Patel, Conceptualization, Writing - original draft done by R. D. Dodiya, Sai Thilak K; Supervision, Writing - review & editing by N. P. Pathan, P. S. Patel.

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Declaration of interests

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