

Comparative nest architecture in open vs. cavity-nesting bees: Structural adaptations in *Apis* and *Tetragonula* species

Devyani S Wardhe¹, Dr. Sharyu V Ghonmode²

¹ Department of Zoology, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, Maharashtra, India

² Department of Zoology, Shri Shivaji Education Society Amravati's Science College, Nagpur, Maharashtra, India

Abstract

This study examines the architectural distinctions between the nesting structures of honey bees gathered from Nagpur, Maharashtra, India, belonging to the *Meliponini* (*Tetragonula* sp.) and Apini (*Apis dorsata*, *Apis florea* and *Apis cerana*) tribes. To study structural variances, nests were obtained from nearby beekeepers, bee hunters, and a sawmill. Brood cells, honey cells, pollen storage, midrib construction, dimensional parameters (length, width, thickness), preferred nesting sites (cavity vs. open), cell density, nest coloration, cell capping properties, and waste management regions were the main subjects of the comparative analysis. The findings showed that there was a considerable structural difference between the tribes; *Meliponini* constructed elliptical or oval cells, whilst Apini constructed hexagonal cells of varying length depending on purpose. Selection of nesting sites showed notable differences, with species-specific preferences for cavity or open-air nesting correlating to the ecological requirements and adaptive foraging tactics. The studied architectural contrasts underscore the important morphological and behavioral distinctions between meliponiculture and apiculture practices, and they offer fundamental insights into how evolutionary constraints have formed these unique nesting techniques. In addition to providing useful applications for conservation initiatives and management strategies of both honey bee tribes in the Indian subcontinent, these findings advance our scientific knowledge of bee nesting biology.

Keywords: Honey bee architecture, stingless bees, nest structure, *apis*, *tetragonula*, comparative morphology, India

Introduction

One of the most economically and ecologically important families of pollinating insects in the world is the *Apidae*, which has a remarkable taxonomic variety in both tropical and temperate climates (Michener, 2007) [14]. In Asian ecosystems, particularly on the Indian subcontinent, the tribes Apini and *Meliponini* hold significant niches (Rasmussen & Cameron, 2010) [21]. The various evolutionary histories and environmental adaptations of these tribes have resulted in radically divergent nesting techniques and architectural patterns, despite their shared heritage and ecological functions (Oldroyd & Wongsiri, 2006) [17].

The honey bee fauna of the central Indian state of Maharashtra comprises members of both tribes: the *Meliponini* genus *Tetragonula*, represented by native stingless bee species, and the Apini genus *Apis*, with species *A. dorsata* (giant honey bee), *A. florea* (dwarf honey bee), and *A. cerana* (eastern honey bee) (Hepburn & Radloff, 2011) [7]. These bees build complex nests that are essential to the survival and reproduction of their colonies because they can be used for a variety of purposes, including the rearing of brood, the storage of food, defense against parasites and predators, and microclimate adjustment (Seeley, 2019) [26].

Nest architecture offers important insights on the ecology, behavior, and evolutionary history of species by serving as a tangible representation of behavioral adaptations that have developed over millions of years (Roubik, 2006) [23]. While a great deal of study has been done on the biology of bee nesting in many parts of the world, there are still few comparative studies that particularly address the architectural distinctions between Apini and *Meliponini* in the Indian setting (Vijayakumar & Jeyaraaj, 2016) [30]. This

information gap is especially noticeable in central India, where the ecosystem of tropical dry deciduous forests places special environmental demands on bee nesting techniques.

Indian honey bee and stingless bee nests have been the subject of scientific study since the middle of the 20th century. Singh's (1962) [29] groundbreaking work documented the native honey bee species' natural nesting habits and conventional beekeeping methods. Although these early studies laid the groundwork for a regional understanding of bee nesting biology, they lacked the comparative methodology required to differentiate between tribe architectural forms.

The groundbreaking research conducted by Lindauer and Martin (1968) [12] and Wille and Michener (1973) [13, 33] demonstrated the extraordinary accuracy of honey bee construction activities and created methods for assessing bee nest design on a global scale. Since these initial studies, our knowledge of nest building has advanced considerably. Seeley (2010) [25] and Roubik (1989) [22] offered thorough examinations of the ecological and evolutionary elements affecting nest construction in *Apis* and stingless bees, respectively.

The formation of parallel, vertical wax combs with hexagonal cells arranged in a double-layer pattern is one of the architectural characteristics that define the genus *Apis* across species (Ruttner, 1988) [24]. According to Koeniger *et al.* (2010) [11], species-specific variants of this basic design, however, indicate adaptations to various ecological niches.

Numerous studies have examined the evolutionary significance of *Apis*' hexagonal cell structure. Pirk *et al.* (2004) [19] suggested that the hexagonal pattern does not arise through explicit behavioral programming, but rather through a self-organizing process based on the physical characteristics of warming bee wax. Honey bee wax's

material composition and its connection to the nest combs' structural integrity was documented by Hepburn (1986) [6]. Oldroyd and Wongsiri (2006) [17] conducted comparative examinations of *A. dorsata*, *A. florea* and *A. cerana*, revealing different architectural adaptations among these sympatric species. For example, *A. florea* creates tiny single-comb nests wrapped around small branches, but *A. dorsata* develops large single-comb nests dangling from the undersides of branches or overhangs. On the other hand, *A. cerana* builds several parallel combs inside protected cavities, a pattern that Phiancharoen *et al.* (2011) [18] attribute to the ecological needs and evolutionary history of the species. Seeley and Morse (1976) [27] examined the adaptive relevance of cavity versus open nesting in *Apis* species, documenting how cavity-nesting species alter their environment to produce ideal nesting conditions. These nesting techniques were further connected by Dyer and Seeley (1991) [2] to species-specific evolutionary adaptations in worker bee behavior and colony management. Studies by Michener (1974) [13] and Roubik (2006) [23] have shown that the architectural patterns of stingless bees (*Meliponini*) differ significantly from those of *Apis*. Only a few studies of *Tetragonula* nest building have been conducted in India; Vijayakumar and Jeyaraaj (2016) [30] documented features of *Tetragonula iridipennis* nesting biology, while Rasmussen (2013) [20] provided taxonomic descriptions. According to these investigations, the genus is known for its unique spiral or clustered brood organization and peculiar storage pot architecture. Wille (1983) [32] have examined the functional arrangement of brood, honey, and pollen storage in *Meliponini*, documenting the effects of separating brood and storage regions on colony dynamics and resource management. In comparison to *Apis* nests, stingless bee nests include a higher percentage of plant resins, which improves their structural qualities and antibacterial protection (Roubik, 2006) [23]. Rasmussen and Cameron (2010) [21] and Michener (2013) [14] have directly compared the architecture of the Apini and *Meliponini*, demonstrating the basic distinctions in cell structure, organization, and building materials between these tribes. A more comprehensive context was given by Hansell (2005) [4], who looked at bee nest layout in relation to animal construction activities in other species. Seeley (2019) [26], who linked nest design to resource management, defense, and thermoregulation tactics, investigated ecological causes of architectural differences. There are still a lot of unanswered questions regarding comparative nest architecture throughout the Indian subcontinent, especially in areas like Maharashtra in the center. These gaps are filled in this work by offering a methodical comparison of *Meliponini* and Apini nest construction from a particular geographic area. The purpose of this study is to record and examine the architectural variations between *Meliponini* (*Tetragonula* sp.) and Apini (*A. dorsata*, *A. florea* and *A. cerana*) nests that were gathered from the Nagpur area of Maharashtra, India. Cell morphology, dimensional characteristics, nesting site preferences, and functional organization are some of the nest parameters that we will be analyzing in order to (1) quantify structural differences among tribes, (2) relate these differences to ecological and evolutionary adaptations, and (3) provide fundamental information to guide conservation and beekeeping practices in the area.

As a result of their disparate evolutionary histories and ecological adaptations, we predicted that the tribes would exhibit basic variations in cell structure, organization, and nest site choice. In particular, we anticipated that cell morphology would correspond with taxonomic classifications, with *Meliponini* displaying unique non-hexagonal cell arrangements in line with observations in other regions and Apini displaying the distinctive hexagonal cell structure (Heard, 1999; Michener, 2013) [5, 15].

Materials and Methods

1. Study Site and Sample Collection

The study was carried out in and around Nagpur, Maharashtra, which is situated in central India (21.1458° N, 79.0882° E). With three distinct seasons—summer (March–June), monsoon (July–September), and winter (October–February)—the area has a tropical climate. The average annual precipitation is around 1,000 mm, and the temperature ranges from 10°C to 45°C.

In cooperation with local bee hunters, beekeepers, and a sawmill in the Nagpur district, bee nest samples were gathered from January 2023 to December 2024. Because different species had diverse nesting tendencies, the collection techniques differed as well:

- ***Apis dorsata*:** Five abandoned nests were gathered from bee hunters who customarily gather honey from these colonies. To reduce the impact on active colonies, only abandoned nests or nest pieces were retrieved, in accordance with Oldroyd and Nanork's (2009) [16] ethical principles.
- ***Apis florea*:** After establishing the absence of colonies, six entirely abandoned nests were carefully removed from branches. The agricultural regions in and around Nagpur were among the collection sites.
- ***Apis cerana*:** From local beekeepers who keep traditional bee boxes, four nest samples were collected.
- ***Tetragonula* sp.:** Three pieces of a natural nest were found in tree cavities that were left open during the local sawmill's timber processing.

In order to protect the structure, all samples were carefully moved to the lab in cushioned containers. Before being removed, every nest was photographed in its original location whenever feasible.

2. Morphometric Analysis

All nest samples were morphometrically measured according to a standard procedure:

- For smaller nests, the overall nest dimensions (length, width, and thickness) were measured with a digital caliper (Mitutoyo, accuracy ± 0.01 mm), and for bigger constructions, a measuring tape.
- Twenty cells chosen at random for each nest were measured for: For hexagonal cells, the diameter is measured between parallel sides; whereas for oval cells, it is measured at the widest point along with: 1. The cell depth and 2. The thickness of the wall
- A clear ruler was used to count the number of cells per linear inch at five different points on each comb in order to calculate the cell density.

- Ten randomly selected spots on each sample were used to quantify the midrib's (the comb's central foundation) thickness.

To avoid wax deformation during handling, all measurements were carried out in a controlled laboratory setting with a temperature of 25°C and a relative humidity of 60%.

3. Structural Analysis

Qualitative assessment of nest structures included:

- Cell shape determination through visual inspection and microscopic examination, with cells categorized as hexagonal, circular, oval, or irregular.
- Classification of functional cell types (brood, honey storage, pollen storage) based on contents, location, and structural characteristics.
- Midrib structure examination to determine construction pattern and attachment mechanisms.
- Assessment of nest entrance structures, defensive adaptations, and special-purpose structures.
- Color assessment using a Munsell color chart for standardized comparison.
- Documentation of involucre layers, batumen sheets, and other protective structures in stingless bee nests and Apini nests.
- Identification and measurement of waste disposal areas when present.

Photographic documentation was completed using both standard digital photography (Canon EOS M50 Mark II) and microscopic imaging.

4. Statistical Analysis

Data was collected in the CSV format and then organized in Microsoft Excel spreadsheets and analysed. Descriptive statistics (mean, standard deviation and average) were calculated for all quantitative measurements.

Results

1. General Nest Architecture

The four-bee species analyzed in this study all had nests with unique architectural designs that matched their tribal categories. The main dimensions traits of each species' nests are compiled in Table 1.

The most striking architectural differences were observed between tribal groups rather than within them. The vertical, parallel honeycombs used in the nests of all three *Apis* species were made up of hexagonal cells organized in a double-sided arrangement around a central midrib. Conversely, the architecture of *Tetragonula* nests was essentially different with storage pots arranged haphazardly around horizontal brood arrangements (Figure 1).

With single huge combs that were noticeably larger than those of other species, *A. dorsata* built the largest nest. These nests had no protective covering and were hung from the undersides of big branches, overhanging rocks, or building eaves. Although *A. florea* nests were also formed outside, they were much smaller and centred on little branches, with worker bees encircling the comb when it was active.

Nests of *A. cerana* were found in tree cavities or artificial hives, and were made composed of several parallel combs (usually 6 - 8 combs per nest). In contrast, *Tetragonula* nests, which are also found in cavities, showed distinct storage pots made of cerumen (a mixture of wax and plant resins) and brood cells arranged in horizontal spiral or clustered patterns.

Table 1: Mean dimensional characteristics of bee nests by species (± standard deviation)

Species	Comb Length (cm)	Comb Width (cm)	Midrib Thickness (mm)
<i>A. dorsata</i>	68.69 ± 8.80	39.05 ± 9.24	0.98 ± 0.1
<i>A. florea</i>	25.64 ± 4.08	22.27 ± 6.95	0.22 ± 0.2
<i>A. cerana</i>	14.32 ± 0.53	16.86 ± 0.69	0.5 ± 0.1
<i>Tetragonula</i> sp.	9.61 ± 11.4	N. A. *	N. A. *

**Meliponini* nest structure does not feature traditional combs with measurable thickness or midrib as found in Apini.



Fig 1: Nests of a) *Apis dorsata*; b) *Apis florea*; c) *Apis cerana*; d) *Tetragonula* sp.

2. Cell Morphology and Organization

The most consistent distinction between Apini and *Meliponini* nests was seen in the form and structure of the cells. While *Tetragonula* created roughly spherical pots for storing food and oval or elliptical cells for rearing brood, all three *Apis* species formed exact hexagonal cells. The size of the cells differed greatly between species (Table 2), with *Tetragonula* having the smallest brood cells overall and *A. dorsata* building the largest cells among the *Apis* species.

With *A. florea* having the highest density among *Apis* species (7.27 ± 0.12 cells per linear inch) and *A. dorsata* having the lowest (4.15 ± 0.7 cells per linear inch), cell density measurements (cells per linear inch) revealed significant variations among species. The arrangement of *Tetragonula* brood cells was roughly 10.26 ± 0.23 cells per linear inch.

One characteristic that set Apini nests apart was the exact placement of cells in regular rows, with cell walls meeting

at 120° angles. This layout was shown to improve space efficiency while limiting material use through mathematical analysis. In contrast, *Meliponini* brood cells were placed in

spiral or horizontal clusters, which made effective use of available space despite having less geometric perfection (Figure 2).

Table 2: Mean cell dimensions by species and function (± standard deviation)

Species	Worker Brood Cell Diameter (mm)	Drone Brood Cell Diameter (mm)	Storage Cell Diameter (mm)	Cell Depth (mm)	Cell per linear inch
<i>A. dorsata</i>	5.21 ± 0.13	6.22 ± 0.14	5.25 ± 0.05*	18.45 ± 0.41*	4.15 ± 0.7
<i>A. florea</i>	3.27 ± 0.18	4.17 ± 0.07	3.23 ± 0.1*	8.44 ± 0.47*	7.27 ± 0.12
<i>A. cerana</i>	4.45 ± 0.24	5.40 ± 0.14	4.46 ± 0.13*	10.16 ± 0.85*	5.42 ± 0.11
<i>Tetragonula</i> sp.	2.41 ± 0.5	N. A. **	3.74 ± 0.71***	5.48 ± 0.5	10.26 ± 0.23

*In *Apis* species, storage cells have the same diameter as worker cells but may be extended in depth when filled with honey. **Stingless bees do not produce distinct drone brood cells. ***Stingless bee storage pots are measured at their widest point.

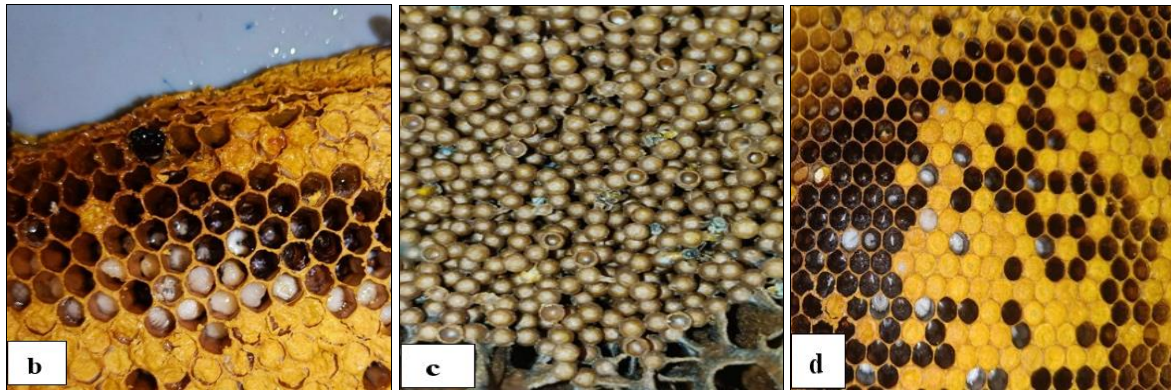


Fig 2: Brood cells of a) *Apis florea*; b) *Apis dorsata*; c) *Tetragonula* sp; d) *Apis cerana*

3. Functional Specialization of Cells

The functional organization of cell types revealed both similarities and differences between tribes. All species constructed specialized cells for different colony functions, but the implementation varied significantly. When utilized to store honey in Apini nests, the depth of the food storage and brood chambers varied, but their diameters were the same. The diameter of worker and drone brood cells varied; in all three *Apis* species. Unlike *Apis* nests, where brood and storage cells coexist on the same comb, the brood and storage compartments were completely separated in space. In *Tetragonula* nests, the distinction between functional cell

types was more pronounced. The eggs were made of pale cerumen and were grouped in spirals or horizontal clusters. They were of the same size. Honey and pollen storage pots, on the other hand, were much bigger, fashioned differently, and made of darker cerumen that contained more resin (Figure 3).

There were also notable differences in pollen storage between groups. Pollen was directly stored by apini in regular hexagonal compartments, which were usually placed next to brood regions. Clearly different in size and shape from honey pots, *Meliponini* built specialist pollen pots with thicker walls and more resin.

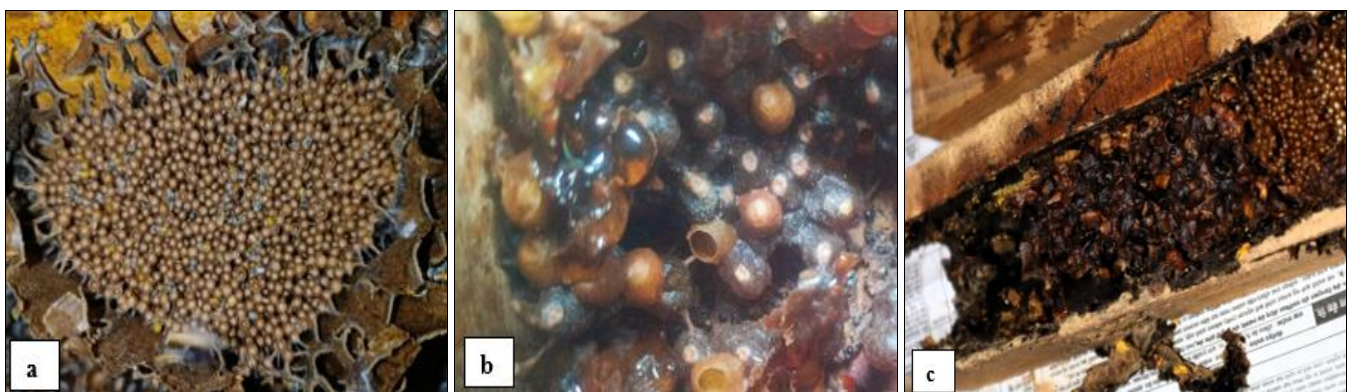


Fig 3: *Tetragonula* sp. a) Brood cells; b) Honey pots; c) Pollen pots

4. Nesting Site Preferences

Clear patterns of nesting site preference were observed, corresponding to species-specific adaptations (Table 3). These preferences represent fundamental ecological adaptations that correlate with other architectural features. The nests built by open-air nesters (*A. dorsata* and *A. florea*) had unique protective features. Whereas *A. florea* encircled

its solitary comb with a protective layer of workers, *A. dorsata* nests had a curtain of worker bees covering the comb surface when active. The absence of physical defenses was made up for by these behavioral adaptations (Figure 4). Species that nest in cavities displayed varying alterations to their nesting habitats. *A. cerana* reduced cavity openings to manageable sizes and sealed fissures with propolis. As a

major defensive adaptation, *Tetragonula* created intricate entry tubes from cerumen that frequently had unique colony-specific designs and narrowed internal diameters that only permitted single-bee passage.

Comb attachment techniques showed the strongest correlation between nest site and other architectural

elements. The "comb curtain" in *A. dorsata* and the "comb crown" in *A. florea* are strong attachment structures that open-nesting *Apis* species built to hold their combs to the substrate. Cavity-nesting species distributed the structural load over the cavity surfaces by using several attachment points.

Table 3: Nesting site characteristics by species

Species	Nesting Site	Nest Exposure	Supporting Structure	Entrance Features
<i>A. dorsata</i>	Open-air	Fully exposed	Single attachment to overhead surface	No constructed entrance
<i>A. florea</i>	Open-air	Branch-wrapped	Small branch encircled by comb	No constructed entrance
<i>A. cerana</i>	Cavity	Protected	Multiple attachment points to cavity walls	Propolis-lined entrance hole
<i>Tetragonula</i> sp.	Cavity	Protected	Attached to cavity surfaces	Elaborate entrance tube of cerumen



Fig 4: Defense/Protective features in bees nesting:

- A. dorsata* nests showing a curtain of worker bees covering the comb surface
- A. florea* encircled its solitary comb with a protective layer of workers
- A. cerana* reduced cavity openings to manageable sizes and sealed fissures with propolis
- Tetragonula* created intricate entry tubes from cerumen

5. Nest Material Composition

The materials used by different tribes to build their nests varied significantly. The main material used to build apini nests was secreted beeswax, which darkens with age as a result of cocoon buildup in brood areas and appears pale yellow to white when new. The cerumen, a blend of wax and plant resins, used to build *Tetragonula* nests, giving them a deeper hue that varied from light brown to almost black, depending on the amount of resin.

There were also notable differences in cell capping architectures between tribes. Honey cells were sealed with non-porous wax, but brood cells were sealed with porous wax capping's that permit gas exchange. *Tetragonula*-capped brood cells with spiral cerumen structures and storage pots that are sealed and have thick, resin-rich cerumen plugs.

Only *Tetragonula* nests were found to have waste management areas, with particular sections of the nest cavity set aside for the accumulation of waste. Without specific internal waste sites, apini colonies usually eliminate waste completely from the nest.

Discussion

1. Evolutionary Significance of Architectural Differences

The fundamental architectural differences observed between Apini and *Meliponini* nests reflect their distant evolutionary divergence, estimated at 80-100 million years ago (Engel, 2001) [3]. The most obvious distinction is between the hexagonal cells of Apini and the oval/elliptical cells of *Meliponini*, which reflect different evolutionary responses to

the problems of effective material economy and space use.

It has long been acknowledged that *Apis* combs' hexagonal cell structure is a mathematically optimal space-efficient design. In contrast to geometrically designed behavior, Pirk *et al.* (2004) [19] showed that this pattern arises as a result of cylindrical cell pressures and wax warming. When building vertical combs with malleable wax, the hexagonal structure appears to be an energetically advantageous arrangement, according to this description of physical processes.

On the other hand, *Tetragonula's* spherical storage pots and oval brood cells might be adaptations to various structural needs. Because horizontal brood arrangements are not as affected by gravity as vertical combs, there may be less selection pressure for the hexagonal layout that minimizes material. As per Hepburn *et al.* (2014) [8], cerumen's increased resin concentration makes it a stiffer building material than pure wax, which could potentially change the physical processes involved in construction.

Meliponini builds specialized structures for each function, while Apini uses the same cell type for many purposes. These starkly different approaches to functional cell specialization point to alternative evolutionary solutions for colony organization. Colony defense tactics, brood growth patterns, and resource allocation are all likely impacted by this differentiation (Roubik, 2006) [23].

2. Ecological Adaptations in Nest Structure

The architectural variations reported in this study are a result of the Nagpur region's adaptations to particular ecological niches and environmental difficulties. Although *A. dorsata* and *A. florea's* open-air nesting technique allows

for site selection flexibility, it necessitates defensive adaptations to guard against environmental stressors and predators. The thermoregulatory behavior of "shimmering," which Kastberger *et al.* (2011) [10] described as a collective defense mechanism against hornets and other threats, is facilitated by the huge, exposed nests of *A. dorsata*. The study showed that *A. dorsata* nest distribution was uneven, clustered, and distributed over the metropolitan region. *A. dorsata* selected nesting sites that include buildings, a metro line, a water tank, and trees. Buildings are the most common followed by metro lines and the trees and water tank least chosen in metropolitan region of Nagpur (Wardhe D., Ghonmode S.; 2024) [31].

Although the enclosed setting naturally protects cavity-nesting species, it also presents difficulties with ventilation, humidity regulation, and space usage. Different architectural solutions to these problems have been developed by *Tetragonula* and *A. cerana*. Through size adjustment and selective attachment locations, *A. cerana* adapts the vertical parallel combs that make up the ancestral *Apis* pattern to the limited space. In order to maximize the use of uneven cavity spaces, *Tetragonula* have developed a fundamentally different design with horizontal brood arrangements and distinct storage structures.

Tribe-to-tribe variations in material composition—pure wax in Apini versus cerumen in *Meliponini*—reflect responses to various environmental stresses. Simone-Finstrom and Spivak (2010) [28] have documented that the addition of plant resins to *Meliponini* nests produces improved antibacterial and structural stability. As pathogen load is considerable in tropical areas, this benefit might be especially significant.

These changes to the architecture are in line with more comprehensive ecological plans. Because of its single-comb, open-nesting architecture, which permits comparatively rapid nest abandonment and repair, certain *A. dorsata* populations exhibit migratory behavior. In contrast, *Tetragonula's* intricate, resin-rich constructions indicate a greater commitment in a permanent nesting location, which is in line with their non-migratory way of life.

3. Functional Organization Implications

Colony operation is significantly impacted by the disparities in functional organization between Apini and *Meliponini* nests. The combination of brood and storage cells in the same comb construction in Apini enables effective temperature control since heat from the brood region can support the maintenance of ideal temperatures for honey ripening. This configuration enables the accurate temperature control necessary for brood development, as Seeley (2019) [26] illustrated.

A distinct strategy for managing resources and organizing colonies is suggested by *Tetragonula's* total separation of brood and storage structures. Although there are benefits to moisture management and pathogen isolation, this division may lessen the effectiveness of heat transfer across regions. Jones and Oldroyd (2006) [9, 17] proposed that, in contrast to *Apis's* vertical brood arrangements, stingless bees' horizontal brood arrangement would allow worker bees to provide more effective brood care.

Variations in cell size within and between species are associated with the morphology and function of bees. *Tetragonula's* smallest cells develop to *A. dorsata's* largest, which reflects the worker bees' body proportions in these species. This association shows how the biology of the nest

builders is closely related to the nest construction, which may have consequences for evolutionary limitations on the evolution of body size.

The distinct ways that these tribes determine caste and reproductive biology are reflected in the different ways that queen cells are constructed, with modified worker cells in *Tetragonula* and specialized royal cells in *Apis* (Michener, 2013) [15]. Both the reproductive tactics of each group are influenced by these architectural distinctions.

4. Applications for Beekeeping Practices

The study's findings about architectural variations have immediate implications for conservation and beekeeping methods in central India. Apiculture can maximize brood production and honey storage by designing suitable foundation wax sheets for managed colonies based on accurate measurements of *A. cerana* cell diameters. By following the known comb orientation and spacing, hives can be designed to resemble natural nest architecture, which may enhance colony productivity and health.

Understanding the natural arrangement of brood and storage structures is crucial for constructing suitable hive systems for emerging meliponiculture practices with *Tetragonula* species. India has traditionally kept stingless bees in log hives or clay pots, but new box hive designs based on natural nest architecture may enhance colony management and honey harvesting methods (Cortopassi-Laurino *et al.*, 2006) [1].

Knowledge of species-specific nesting needs is useful for wild bee population conservation. Secure attachment places (big branches, rock overhangs) must be protected for open-nesting species, whereas large trees with appropriate cavities must be preserved for cavity-nesting species. Requirements for environmental resources are also affected by variations in nest material composition and building behavior. In conservation areas meant to support *Tetragonula* populations, it is crucial to preserve plant diversity, especially resin-producing plants, as evidenced by the high resin dependency of stingless bees.

Conclusion

The structural organization, cell morphology, and nesting strategies of the Apini (*Apis dorsata*, *A. florea* and *A. cerana*) and *Meliponini* (*Tetragonula* sp.) bee tribes from the Nagpur region of Maharashtra have been found to differ consistently and significantly from one another. The hexagonal cell structure that is common to all *Apis* species stands in stark contrast to *Tetragonula's* spherical storage pots and oval brood cells, which are different evolutionary responses to the difficulties of effective nest building.

With *A. dorsata* and *A. florea* building exposed nests and *A. cerana* and *Tetragonula* occupying protected cavities, the observed patterns of nest site selection represent basic ecological adaptations that impact various facets of colony biology. These architectural distinctions reflect integrated adaptations to particular environmental difficulties, foraging techniques, and life history patterns rather than just structural variances.

This study fills a major knowledge gap in the scientific literature by providing detailed measurements and observations that advance our understanding of the biology of bee nesting in central India. Beyond their scholarly significance, these findings have real-world implications for the management of honey bees and stingless bees in the

area, influencing conservation plans, beekeeping techniques, and hive design.

Future studies should broaden this comparative approach to incorporate experimental investigations of construction behavior, in-depth examinations of construction materials, and seasonal fluctuations in nest architecture. Expanding the geographic reach to encompass other ecological regions in India would also yield important insights into the ways in which environmental factors impact architectural adaptations.

Understanding the basic nesting needs and architectural adaptations of these vital pollinators is becoming more and more crucial in an era where bee populations face growing environmental difficulties on a global scale. This study contributes to scientific knowledge and practical conservation efforts for these economically and environmentally vital insects by laying the groundwork for such understanding in the setting of central India.

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Data Availability Statement

All the morphometric measurements, statistical analysis and images will be made available on the request by google drive link.

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