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NESTING PREFERENCES AND THEIR MORPHOMETRIC STINGLESS BEES IN LUWU REGENCY, SOUTH SULAWESI, INDONESIA

Preferensi Bersarang dan Morfometrik Lebah Tanpa Sengat di Kabupaten Luwu, Sulawesi Selatan, Indonesia

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ABSTRACT

Stingless bees (Apidae: Meliponini) are pollinators in tropical ecosystems that show morphological and ecological variations between species. This study aims to identify nesting preferences and their morphometric characters of stingless bees in Luwu Regency, South Sulawesi, Indonesia. Data collection was carried out through field surveys to access nesting preferences of stingless bees by locating their natural nests and documenting them in different habitats, after which bee samples were measured to obtain morphometric data. Data were then analyzed using one-way Analysis of Variance (ANOVA), Pearson correlation, and hierarchical clustering with SPSS 30.1.1.1.. Observations showed that stingless bees preferred *Lansium domesticum* trees as nest locations (42.5%), with variations in nest height, elevation, and entrance size that differed significantly between species ($p < 0.05$). The results showed that *Tetragonula fuscobaltea* had the smallest body size (2.99 ± 0.05), while *T. biroi* was larger (3.97 ± 0.10 mm) and formed a contiguous morphometric cluster, where there were two main groups, with *T. fuscobaltea* separated from the other three species. Strong positive correlations were found between body characters ($r > 0.95$), while environmental variables such as elevation and nest height did not show significant relationships to morphometry. The results of this study are expected to be the basis for the identification of stingless bee species morphometrically, as well as supporting the development of natural habitat-based conservation and the improvement of local bee cultivation in Luwu Regency and the South Sulawesi region in general.

Keywords: Conservation; Host tree; Meliponini; Morphology; Pollinator

ABSTRAK

Lebah tanpa sengat (Apidae: Meliponini) merupakan polinator dalam ekosistem tropis yang menunjukkan variasi morfologis dan ekologis antar spesies. Penelitian ini bertujuan untuk mengidentifikasi karakter morfometrik dan preferensi bersarang lebah tanpa sengat di Kabupaten Luwu, Sulawesi Selatan, Indonesia. Pengumpulan data dilakukan melalui survei lapangan untuk mengakses preferensi sarang lebah tanpa sengat dengan menemukan sarangnya di habitat alami yang berbeda, kemudian sampel lebah diukur untuk memperoleh data morfometrik. Data selanjutnya dianalisis menggunakan analisis varian (ANOVA) satu arah, korelasi Pearson, dan klastering hierarki dengan aplikasi SPSS 30.1.1.1.. Pengamatan menunjukkan preferensi lebah tanpa sengat terhadap pohon *Lansium domesticum* sebagai lokasi sarang (42.5%), dengan variasi ketinggian sarang, elevasi, dan ukuran pintu masuk yang berbeda signifikan antar spesies ($p < 0.05$). Hasil menunjukkan bahwa *Tetragonula fuscobaltea* memiliki ukuran tubuh paling kecil (2.99 ± 0.05), sedangkan *Tetragonula biroi* lebih besar (3.97 ± 0.10 mm), dan membentuk klaster morfometrik yang berdekatan, dimana terdapat dua kelompok utama, dengan *T. fuscobaltea* terpisah dari tiga spesies lainnya. Korelasi positif kuat ditemukan antar parameter tubuh ($r > 0.95$), sedangkan variabel lingkungan seperti elevasi dan ketinggian sarang tidak menunjukkan hubungan signifikan terhadap morfometri. Hasil penelitian ini diharapkan dapat menjadi dasar dalam identifikasi spesies lebah tanpa sengat secara morfometrik, serta mendukung pengembangan konservasi berbasis habitat alami dan peningkatan budidaya lebah lokal di Kabupaten Luwu dan wilayah Sulawesi Selatan secara umum.

Kata kunci: Konservasi; Meliponini; Morfologi; Penyerbuk; Pohon inang

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A. INTRODUCTION

Stingless bees (Meliponini) are pollinating insects in tropical areas, including in Indonesia. This group of bees contributes to the pollination of forest, agricultural, and horticultural plants, thus having an ecological and economic role (Khalifa *et al.* 2021; Harianja *et al.* 2023). In Indonesia, the presence of stingless bees is widespread in various ecosystems, from lowlands to mountains, and from forest areas to cultivated land (Ramadhan *et al.* 2020; Kahono *et al.* 2023). In addition to being pollinators, these bees are also cultivated in honey cultivation and other products such as propolis and bee bread. The main advantage of stingless bees is their non-aggressive nature, making it easier to practice beekeeping safely even in residential areas (Prastiyo *et al.* 2025). However, until now, information on the ecology and morphological characteristics of various stingless bee species in certain areas, such as Luwu Regency, South Sulawesi, is still very limited.

The main problem in managing stingless bees at the local level lies in the lack of knowledge about natural nesting preferences, including the selection of host tree species, nest height, and supportive microhabitat conditions (Hora *et al.* 2023; Pereira *et al.* 2025). This lack of data can complicate in-situ and ex-situ conservation efforts and make it difficult for breeders to determine effective domestication strategies. On the other hand, information on morphometric variation between stingless bee populations is also needed to accurately identify species, understand local adaptation, and design breeding or colony relocation strategies (Prastiyo *et al.* 2024). This knowledge gap is an obstacle to the utilization of stingless bees as a sustainable local biological resource. Luwu Regency as an area with a complex landscape and high biodiversity potential, is a strategic location to fill this data gap.

Several previous studies have explored aspects of nesting preferences of stingless bees, but they have focused on certain areas, such as Java and Kalimantan (Rasmussen 2008; Rachmawati *et al.* 2022; Miharja *et al.* 2024). Sulawesi showed that local topography and vegetation affect nest distribution and species composition (Sayusti *et al.* 2021; Budiaman *et al.* 2025), but specific data in the Luwu region are not yet available. Meanwhile, morphometric studies such as those conducted by Maharani *et al*. (2025) showed that body size can vary significantly between populations depending on local environmental pressures and survival strategies. Thus, studies that combine nesting preferences and morphometrics in one geographic landscape would be very valuable, especially in developing a database for local conservation and cultivation of stingless bees.

Based on this, this study aims to explore the nesting preferences and morphometric characteristics of stingless bees in Luwu Regency, South Sulawesi. This study is expected to provide new information related to host tree species, nest height from the ground, general location altitude (m asl), and nest entrance size and bee body morphology. The hypothesis proposed in this study is that stingless bees in Luwu Regency show specific nesting preferences for certain tree species and show morphometric variations influenced by geographic location and local environmental conditions. These findings will contribute to the formulation of ecological-based conservation strategies and the development of sustainable local beekeeping.

B. METHODS

Site Location

The research was conducted from July 2023 to November 2024 in Luwu Regency, South Sulawesi, Indonesia, focusing specifically on two subdistricts: Suli and Bua Ponrang. These areas were selected based on their diverse topographical and ecological conditions, which include a range of elevations, forest fragments, agricultural landscapes, and semi-urban environments, providing a representative variation of potential nesting habitats for stingless bees. Both subdistricts are known for their mixed vegetation, including native and cultivated plant species that support meliponine foraging and nesting activities. Field observations and sample collections were carried out at various nest locations found on different host tree species and structures. Geographic coordinates of each nest site were recorded using a handheld GPS to ensure precise spatial data for subsequent analyses. The detailed distribution of nest locations across the two subdistricts is illustrated in Figure 1, which maps the spatial arrangement of the sampling sites and highlights the environmental variability encountered during fieldwork.

Data Collection

Field data were collected across multiple stingless bee colonies in Luwu Regency, South Sulawesi, Indonesia. For each bee species was observed, 30 individual worker bees were sampled and measured to ensure representative morphometric data. Additional nest-related variables such as nest height from the ground, elevation above sea level, and the length and width of the entrance tube were documented using a GPS device for elevation and coordinates, a measuring tape for nest height, and a ruler for entrance dimensions. These environmental and structural parameters were systematically recorded to assess their potential influence on bee morphology and nesting behavior.

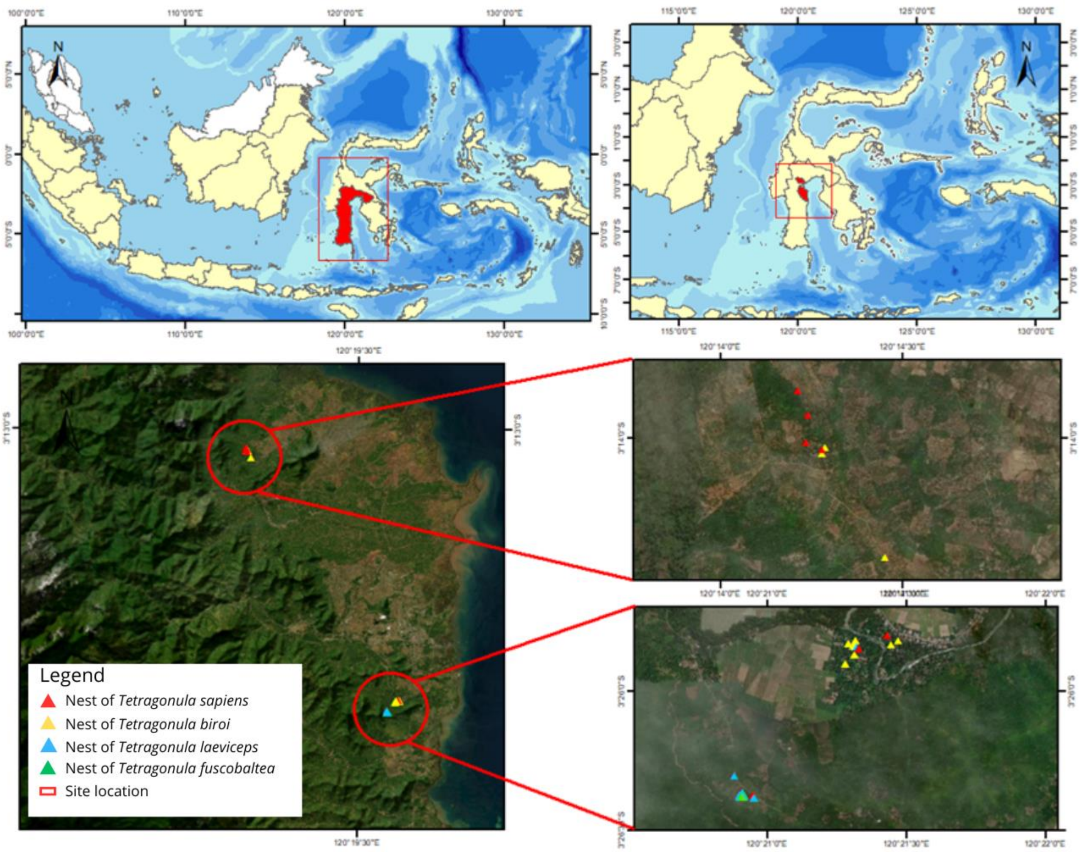

Figure 1. Map of stingless bee nest locations in Luwu Regency, South Sulawesi, Indonesia

Identification and Measurement

Stingless bee species were identified based on external morphological features, and detailed morphometric measurements were conducted using a stereo microscope (STEM 2000) equipped with an ERC 5S phototube camera. Each bee specimen was measured for eleven morphometric traits: total body length, head length, head width, mandible length, mandible width, forewing length, forewing width, hindwing length, hindwing width, proboscis length, tibia length, and tibia width (Prastiyo *et al.* 2024). These traits were selected to capture variations in body size and shape that reflect environmental adaptations. Measurement consistency and accuracy were maintained across samples to support robust statistical analysis, reliable comparisons among species, and correlation with environmental variables.

Data Analysis

The data analysis in this study employed a range of statistical approaches to evaluate the relationships between nest-site environmental characteristics and the morphometric traits of stingless bees in Luwu Regency, South Sulawesi, Indonesia. One-way ANOVA was used to test for significant differences in morphometric parameters of the bees, such as body length, thorax width, and other body part measurements, to assess variation among different stingless bee species. Hierarchical cluster analysis using an agglomerative method (dendrogram) was conducted to group bee colonies based on morphometric similarity, enabling the identification of potential population clusters or geographic variation. Lastly, Pearson correlation analysis was then applied to measure the relationships between environmental variables such as abundance of nest bees, nest height above ground, elevation (m asl), nest entrance bee, and bee body size, aiming to identify which environmental factors influence morphological adaptations. This combination of four analytical methods provides a comprehensive approach to understanding the ecological and statistical relationships among environmental factors, nest substrates, and the morphometric characteristics of stingless bees.

C. RESULTS AND DISCUSSION

Observations of stingless bee nest (Table 1) locations in Luwu Regency showed that the tree species most commonly used as nesting sites was *Lansium domesticum* (42.5%), followed by *Anthocephalus macrophyllus* (20.0%) and *Gmelina arborea* (15.0%). Other tree species that were also used, but with lower frequencies, was *Syzygium aromaticum* (12.5%), *Gigantochloa atter* (5.0%), and *Artocarpus elasticus* and *Cocos nucifera* each at 2.5%. These data indicate variations in tree preferences stored between bee colonies, which are influenced by tree characteristics such as trunk structure and the availability of natural cavities.

Table 1. Tree species preferences for nesting by stingless bees

Order	Family	Species	Percentage (%)
Rosales	Moraceae	*Artocarpus elasticus* Reinw. ex Blume	2.5
Poales	Poaceae	*Gigantochloa atter* (Hassk.) Kurz	5.0
Lamiales	Lamiaceae	*Gmelina arborea* Roxb.	15.0
Gentianales	Rubiaceae	*Anthocephalus macrophyllus* Roxb.	20.0
Sapindales	Meliaceae	*Lansium domesticum* Corr.	42.5
Myrtales	Myrtaceae	*Syzygium aromaticum* (L.) Merrill & Perry	12.5
Arecales	Arecaceae	*Cocos nucifera* L.	2.5

The high preference for *Lansium domesticum* is related to its hard and hollow wood structure, as well as its abundant presence in the local landscape in Luwu. This is in line with the findings of Roubik (2006) and Macedo *et al*. (2020), which stated that stingless bees tend to choose trees with trunk conditions that support the formation of natural nests. In addition, the use of cultivated trees such as *S. aromaticum* shows the adaptability of bees to agroforestry environments in tropical rainforest areas of Southeast Asia. The diversity of nest tree species supports sustainable beekeeping practices (meliponiculture) and ecosystem-based local bee conservation (Macharia *et al.* 2007).

The distribution of stingless bee nest locations based on tree conditions and stem positions showed that the majority of nests were found on the main stem (primary stem), with a percentage reaching more than 70% (Figure 2). In addition, living trees were used more as nest substrates (around 60%) than dead trees (around 45%). In contrast, secondary stems were only used in around 30% of the total nest locations. These data indicate a strong preference for living trees and the position of the main stem as the dominant nesting location.

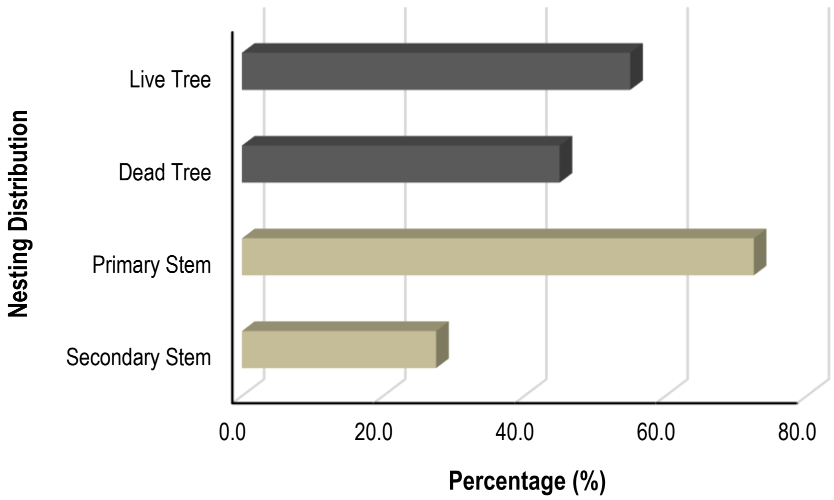

Figure 2. Distribution of stingless bee nest sites based on tree condition (live or dead) and stem position (primary or secondary)

The preference of stingless bees to nest on the main trunk of living trees can be explained by several ecological and structural factors. The main trunk generally has a larger diameter, better structural stability, and a larger natural cavity to build a colony (Smith 2021). Living trees also provide a more stable microenvironment than dead trees, both in terms of internal humidity, trunk temperature, and protection from predators or physical disturbances (Roubik 2006; Prastiyo & Nuraeni 2023). A study by Toledo-Hernandez *et al*. (2022) stated that stingless bees actively choose plant structures that are not only physically safe but also have long-term ecological value for the sustainability of the colony. In addition, according to Layek & Karmakar (2025), a structurally stable nesting substrate in a stable environment is very important in maintaining colony productivity and resilience. Secondary trunks and dead trees are only used to a small extent, indicating that bees have high selectivity for nesting substrates, and this is a consideration in habitat conservation and beekeeping management.

Nest Distribution and Environment Characteristics of Stingless Bee Species

Based on Figure 3, the distribution of stingless bee nests in Luwu Regency is divided into four main species, with the highest proportion of each in *T. leaviceps* and *T. biroi* at 30%. Meanwhile, *T. sapiens* and *T. fuscobaltea* have a lower proportion of nests, which are 20% each. This shows population variation or habitat preferences between species in an area.

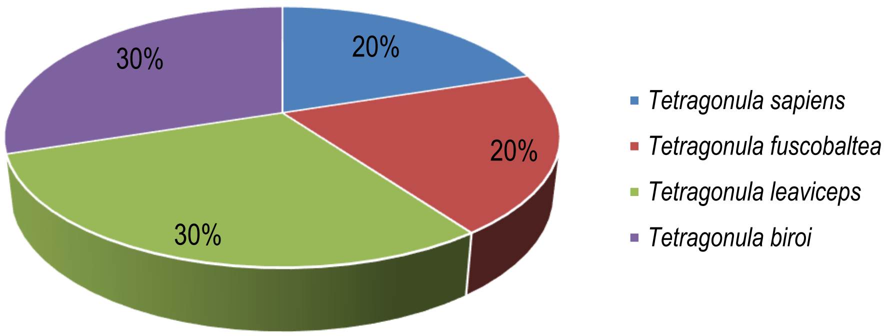

Figure 3. Percentage distribution of nests by stingless bee species

Differences in the proportion of nests between stingless bee species may reflect the availability of suitable habitat and the behavior of each species. *Tetragonula leaviceps* and *T. biroi*, which dominate in terms of nest numbers, are known to have high tolerance to varying habitat conditions and are often found in agroforestry landscapes and residential areas (Bhatta *et al.* 2019; Withaningsih *et al.* 2023). In contrast, species such as *T. sapiens* and *T. fuscobaltea* are more selective in choosing nest sites and have a more limited population range locally (Anaktototy *et al.* 2021). Knowing the most adaptive species is necessary to design sustainable colony enhancement strategies. The distribution of colonies in nature is influenced by inter-colony competition, food resource availability, and landscape structure (Jones & Rader 2022). The distribution of stingless bees, as shown in Figure 3, can be a useful early indicator in understanding the dynamics of local stingless bee populations and their potential for development in tropical areas such as Sulawesi.

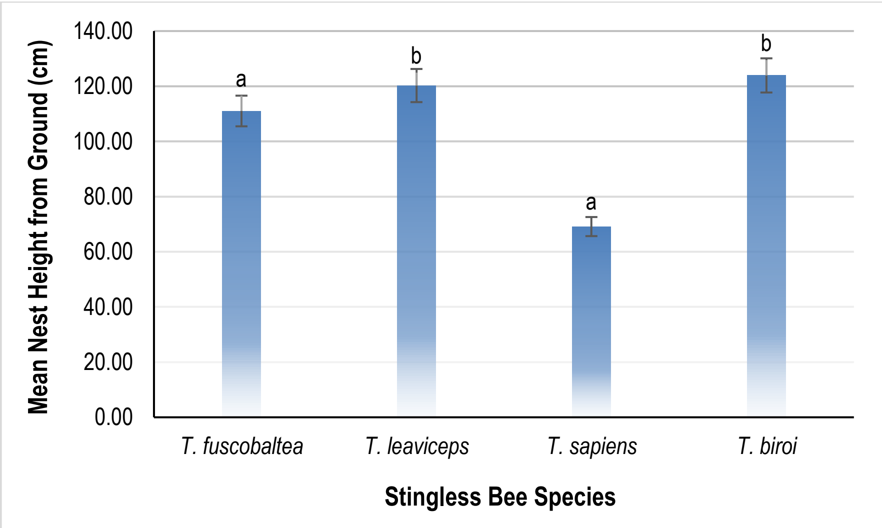

Figure 4. Comparison of mean nest height from the ground among four stingless bee species in Luwu, Indonesia

The results (Figure 4) of one-way ANOVA revealed significant differences in nest height among the four *T. species* ($p < 0.05$). *Tetragonula biroi* had the highest average nest height (132.25 m), followed by *T. laeviceps* (127.75 m), *T. fuscobaltea* (103.50 m), and *T. sapiens* (67.88 m). Species that build nests higher above the ground, such as *T. biroi* and *T. laeviceps*, are associated with reduced exposure to stable microclimatic conditions. Nest height varies by species, depending on their need for protection from predators, soil moisture, and light (Antoine & Forrest 2021). These nest height patterns reflect consistent ecological strategies shaped by physical structure availability and environmental pressures. Nest height variation is influenced by vegetation distribution and the availability of suitable nesting sites (Silva & Ramalho 2016).

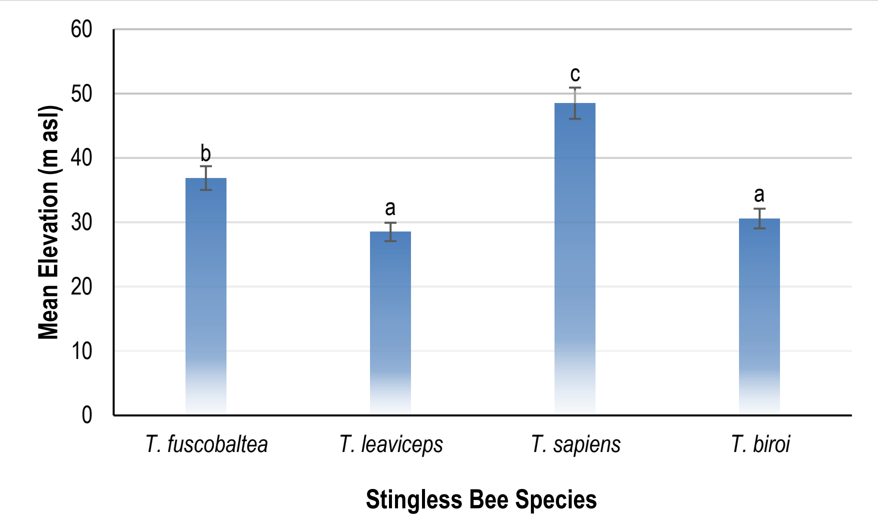

Figure 5. Mean elevation of stingless bee nest sites in Luwu, South Sulawesi, Indonesia

The results (Figure 5) of one-way ANOVA showed clear differences in nest site elevation among the species ($p < 0.05$). *Tetragonula sapiens* nested at the highest elevation (48.63 m asl), while *T. laeviceps* occupied the lowest (28.50 m asl). Elevational variation directly influences ambient temperature, humidity, and vegetation types, affecting nest placement and foraging dynamics (Aleixo *et al.* 2017; Gonzales *et al.* 2022). These results confirm that each species occupies a specific elevational range based on its environmental tolerances and resource utilization.

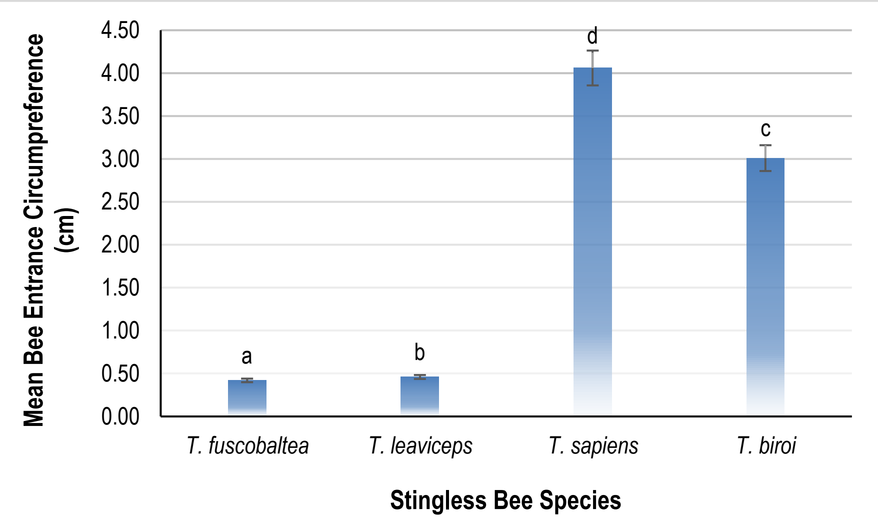

Figure 6. Mean bee nest entrance circumference of four stingless bee species in Luwu, South Sulawesi, Indonesia

One-way ANOVA indicated significant variation in nest entrance circumference ($p < 0.05$). The largest entrances were found in *T. sapiens* (3.69 cm) and *T. biroi* (2.91 cm), while *T. laeviceps* and *T. fuscobaltea* had smaller openings (1.27 cm and 0.72 cm). Entrance size is a functional trait related to ventilation, traffic flow, and nest defense. Smaller entrances limit access by predators and parasitic bees, while larger ones support higher foraging traffic and improve airflow (Nuraeni *et al.* 2022). These measurements reflect species-specific architectural designs aligned with colony structure and ecological adaptation. Bees with small nest entrances, such as *T. fuscobaltea,* rely on a passive defense strategy, considering that small size can prevent predators or foreign bees from entering the nest (Anaktototy *et al.* 2021).

Morphometric Differences Among Species

Morphometric analysis showed significant differences in all body parameters between four stingless bee species, namely *T. fuscobaltea*, *T. laeviceps*, *T. sapiens*, and *T. biroi* (Table 2). In general, *T. fuscobaltea* has the smallest body size (2.99 ± 0.05 mm), while *T. biroi* has the largest body size (3.97 ± 0.10 mm). Head length and width, mandible length, forewing and hindwing length and width, as well as proboscis and tibia length, showed an increase in size from *T. fuscobaltea* to *T. biroi*. The highest hind tibia length (PTB) was found in *T. sapiens* (1.53 ± 0.01 mm), followed by *T. biroi*

(1.51 ± 0.02 mm), *T. laeviceps* (1.44 ± 0.01 mm), and the lowest in *T. fuscobaltea* (1.34 ± 0.01 mm). This is also true for the hind tibia width and proboscis length, which are related to specific adaptations to the microenvironment.

Table 2. Morphometry of four species of stingless bees in Luwu Regency, South Sulawesi, Indonesia

No	Parameters	*T. fuscobaltea*	*T. laeviceps*	*T. sapiens*	*T. biroi*
1	Body Length (PT)*	2.99 ± 0.05a	3.56 ± 0.62b	3.75 ± 0.07c	3.97 ± 0.10d
2	Head Length (PK)*	1.16 ± 0.02a	1.34 ± 0.01b	1.50 ± 0.01d	1.40 ± 0.03c
3	Head Width (LK)*	1.41 ± 0.05a	1.59 ± 0.04b	1.70 ± 0.01c	1.71 ± 0.03c
4	Mandible Length (PM)*	0.41 ± 0.01a	0.52 ± 0.01b	0.59 ± 0.01c	0.59 ± 0.01c
5	Mandible Width (LM)*	0.13 ± 0.01a	0.14 ± 0.01b	0.17 ± 0.01c	0.18 ± 0.01d
6	Fore Wing Length (PSD)*	3.10 ± 0.05a	3.48 ± 0.06b	3.78 ± 0.06c	3.78 ± 0.08c
7	Fore Wing Width (LSD)*	1.00 ± 0.03a	1.16 ± 0.02b	1.27 ± 0.05c	1.25 ± 0.03c
8	Hind Wing Length (PSB)*	1.95 ± 0.03a	2.34 ± 0.04b	2.45 ± 0.03c	2.34 ± 0.03b
9	Hind Wing Width (LSB)*	0.50 ± 0.01a	0.59 ± 0.02b	0.62 ± 0.01d	0.61 ± 0.01c
10	Proboscis Length (PB)*	1.02 ± 0.02a	1.23 ± 0.01b	1.23 ± 0.02b	1.42 ± 0.02c
11	Hind Tibia Width (LTB)*	0.34 ± 0.01a	0.41 ± 0.01b	0.46 ± 0.02c	0.50 ± 0.02d
12	Hind Tibia Length (PTB)*	1.34 ± 0.01a	1.44 ± 0.01b	1.53 ± 0.01d	1.51 ± 0.02c

Notes: Values are presented as mean ± standard deviation. Different letters in the same row indicate statistically significant differences between species based on ANOVA and Tukey's HSD ($p < 0.05$). Parameters marked with an asterisk (*) indicate significant differences between species.

Morphometric differences between stingless bee species in Luwu Regency reflect ecological adaptations to local resources and habitat conditions. The larger body size and tibia length of *T. biroi* and *T. sapiens* indicate a greater ability to explore wider areas and access a wider variety of flowers, particularly those with deep crowns and spikes, which require a long proboscis (Trianto & Purwanto 2020). Conversely, smaller stingless bees with short proboscises and tibiae are likely more limited in their forage choices and are better suited to homogeneous habitats or low vegetation (Prastiyo *et al.* 2024). Differences in wing length also affect flight ability and range, with larger-bodied species such as *T. sapiens* and *T. biroi* tending to have longer ranges and better temperature tolerance in tropical lowlands (Maharani *et al.* 2025). This variation is relevant to the conservation and domestication of local bees, as morphology is closely linked to pollination efficiency, nesting site selection, and adaptability to microclimate changes in South Sulawesi.

The results of hierarchical cluster analysis based on morphometric parameters indicate that the four stingless bee species are divided into two main groups (Figure 7). The first group consists of *T. sapiens*, *T. biroi*, and *T. laeviceps,* which form a cluster with relatively close morphometric distances, indicating similarities in size and body shape among the three. Meanwhile, *T. fuscobaltea* is significantly separated and forms its cluster at a larger rescaled distance (>20), indicating quite striking differences in body morphology compared to the other three species. This dendrogram structure represents the morphometric closeness between species and confirms that *T. fuscobaltea* is the most different species in terms of body size among the four species observed.

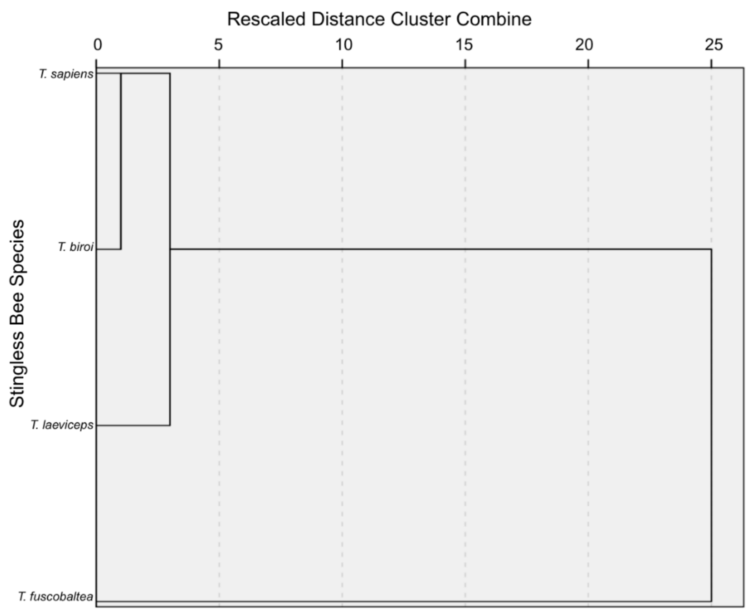

Figure 7. Cluster dendrogram of four stingless bee species based on morphometric data in Luwu Regency, South Sulawesi, Indonesia

Clustering based on morphometric data revealed clear phenotypic variation among stingless bee species, with *T. fuscobaltea* occupying the most morphologically distinct position. This is consistent with previous descriptive analyses showing that *T. fuscobaltea* has the smallest body size and other body parts (Table 2). The clustering of *T. sapiens*, *T. biroi*, and *T. laeviceps* reflects similar size characteristics and ecological strategies, such as home range (Trianto & Purwanto 2020). The separation of *T. fuscobaltea* may also be related to adaptation to different habitats or stronger selection pressures in certain environments (Anaktototy *et al.* 2021). This cluster analysis not only strengthens morphometric evidence but can also be used to support taxonomic approaches and local species conservation based on phenotypic traits.

Correlation Between Morphometrics and Environmental Factors

Pearson correlation analysis showed that most morphometric parameters between stingless bee body parts had a highly significant and positive relationship (Table 3). Body length (PT) was highly correlated with mandible length (PM) (0.98) and head width (LK) (0.98), as well as hind tibia length (PTB) (0.95). Forewing length (PSD) also had a significant correlation with almost all other morphological parameters, such as head length (PK), mandible length (PM), and hind wing length (PSB), each with an r value above 0.95 and high significance. In contrast, environmental variables such as nest height from the ground (AA) and elevation (BB) tended to be insignificantly correlated with the main morphometric parameters, even showing a negative relationship, especially between elevation and hind tibia length (-0.11) and AA with several parameters such as head length (-0.53). A significant negative correlation was also found between nest entrance circumference (CC) and elevation (BB) (-0.97).

Table 3. Correlation between morphometric parameters and environmental factors in four species of stingless bees in Luwu Regency, South Sulawesi, Indonesia

Parameters	PT	PK	LK	PM	LM	PSD	LSD	PSB	LSB	PP	LTB	PTB	AA	BB	CC	DD
PT	1															
PK	0.87	1														
LK	0.98**	0.95*	1													
PM	0.98**	0.96*	1.00**	1												
LM	0.91	0.82	0.92	0.91	1											
PSD	0.97*	0.96*	1.00**	1.00**	0.93	1										
LSD	0.96*	0.98**	1.00**	1.00**	0.90	1.00**	1									
PSB	0.89	0.96*	0.94	0.94	0.73	0.93	0.95	1								
LSB	0.95*	0.96*	0.98**	0.98**	0.82	0.97*	0.98**	0.99**	1							
PP	0.96*	0.71	0.89	0.88	0.86	0.87	0.84	0.75	0.84	1						
LTB	0.99**	0.86	0.97*	0.97*	0.96*	0.97*	0.95*	0.83	0.91	0.95*	1					
PTB	0.95*	0.98**	0.99**	0.99**	0.91	1.00**	1.00**	0.94	0.97*	0.82	0.94	1				
AA	-0.08	-0.53	-0.27	-0.29	-0.25	-0.31	-0.35	-0.36	-0.29	0.19	-0.11	-0.40	1			
BB	-0.03	0.39	0.15	0.17	0.22	0.20	0.22	0.18	0.13	-0.28	0.04	0.28	-0.97*	1		
CC	0.74	0.86	0.82	0.83	0.91	0.86	0.84	0.69	0.74	0.58	0.80	0.88	-0.63	0.61	1	
DD	0.54	0.16	0.39	0.37	0.24	0.34	0.33	0.37	0.42	0.71	0.46	0.27	0.73	-0.84	-0.16	1

Notes: Values indicate Pearson's correlation coefficient. (*) indicates significance at $p < 0.05$, and (**) indicates significance at $p < 0.01$. AA: Nest height from the ground, BB: Elevation, CC: Bee entrance circumference, DD: Number of nests observed (nests recorded).

The high correlation between morphometric parameters such as body length, wing length, and hind tibia length indicates consistent proportional morphological development in stingless bees, where larger body size is generally accompanied by increases in size in other body parts such as the head, tibia, and wings (Li *et al.* 2021). This correlation indicates that species with larger bodies tend to have higher flight capacity and foraging range, supporting previous results on morphometrics (Table 2). On the other hand, the low or even negative correlation between morphometric parameters and environmental variables such as elevation and nest height indicates that the ecological conditions of the nesting site do not always have a direct impact on bee body size, but are more influenced by genetic factors or food availability (Torne-Noguera *et al.* 2014). This finding is reinforced by the significant negative correlation between nest entrance circumference and elevation, which may reflect nest structural adaptations to environmental pressures such as temperature, humidity, and predators at high altitudes (Prastiyo 2022). Variations in environmental parameters influence nest architecture more than individual bee body morphometry.

D. CONCLUSION

This study revealed that stingless bees in Luwu Regency showed clear nesting preferences for living trees, especially on the main trunk, and for certain tree species such as *L. domesticum* and *A. macrophyllus*. In addition, nesting environment characteristics such as nest height, site elevation, and entrance size varied among Tetragonula species, reflecting different ecological adaptations. These findings not only provide insight into the nesting behavior and distribution of bee species but also emphasize the conservation of natural host trees and appropriate habitat planning to support the conservation and sustainable cultivation of stingless bees. This study is useful for the management of agroforestry landscapes and the restoration of pollinator-friendly tropical ecosystems, as well as opening up local biodiversity-based economic opportunities for communities.

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AUTHOR'S DECLARATION

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- No potentially identified images or data are present in the manuscript.

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