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Morphometric characteristics of the endemic stingless bee *Wallacetrigona incisa* at different altitudes in North Luwu, Indonesia

ABD. RAHMAN, SITTI NURAENI♥, ANDI SADAPOTTO, ANDI PRASTIYO
Department of Forestry, Faculty of Forestry, Universitas Hasanuddin. Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, South Sulawesi, Indonesia.
Tel./fax.: +62-411-589592, ♥email: sitti.nureny@unhas.ac.id

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Abstract. *Rahman A, Nuraeni S, Sadapotto A, Prastiyo A. 2026. Morphometric characteristics of the endemic stingless bee* Wallacetrigona incisa *at different altitudes in North Luwu, Indonesia. Asian J For 10 (1): r100105. https://doi.org/10.13057/asianjfor/r100105.* The endemic stingless bee *Wallacetrigona incisa* is one of the important pollinator species in the Wallacea Region, contributing to the pollination of forest and agricultural plants. However, information regarding its morphological variations remains very limited, particularly in South Sulawesi, Indonesia. This study provides a novel approach to examining the morphometric characteristics of *W. incisa* as a basis for understanding its morphology. This research aimed to analyze the differences in morphometric traits of *W. incisa* at three altitudinal levels in North Luwu. Sampling was conducted purposively at lowland, midland, and highland sites with a total of 90 individual bees. Data analysis included One-Way Analysis of Variance (ANOVA), Pearson correlation, and Principal Component Analysis (PCA) to determine relationships and grouping patterns among morphometric traits. ANOVA results showed that altitude had a significant effect ($p<0.05$) on several key morphometric traits, including Body Length (BL), Malar Length (ML), Hind Femur Length (HFL), and Hind Tibia Width (HTW), with the largest mean body size observed in highland populations. Pearson correlation analysis revealed strong positive relationships among several morphometric traits, particularly between body size and hind leg dimensions ($r>0.70$, $p<0.05$). PCA indicated that morphometric traits cluster according to altitudinal groups, suggesting structured variation by altitude and morphological potential. PC1 covers 38.45% of the variation in bee morphometric data, while PC2 covers 12.55%. Average body size increases with height, indicating a morphological response to altitudinal and environmental differences. This study provides a scientific basis for considering elevation variations in North Luwu, thus supporting the determination of key habitats and efforts to maintain endemic stingless populations.

Keywords: Body size, habitat, morphological response, pollinator, *Wallacetrigona incisa*

INTRODUCTION

Wallacetrigona incisa is an endemic bee species distributed along the Wallacea line, particularly in Sulawesi, Indonesia. *Wallacetrigona incisa* colonies utilize various floral resources as food sources (Suhri et al. 2025a). This species is relatively easy to cultivate and has a large body size comparable to the genus *Geniotrigona*. *Wallacetrigona incisa* is recorded in several locations across Sulawesi, including South Sulawesi, specifically in North Luwu District (Budiaman et al. 2021). Bees in high altitude areas show more active nectar seeking activity (Kohl and Steffan-Dewenter 2022). This allows more energy to be devoted to resource collection (Suhri et al. 2023). Compared to other stingless bee species, *W. incisa* larger body size contributes to greater honey production and supports cultivation potential. These bees generally have a higher foraging range and can transport more nectar and pollen, which increases the productivity of bee products for the farmer (Tarekegn and Ayele 2020). Furthermore, this roaming capacity also enhances pollination in forest and agroforestry landscapes, contributing to seed set (Wayo et al. 2020). Colony translocation beyond its native high-elevation habitats has exposed *W. incisa* to new environments, prompting observable phenotypic variability, including differences in wing dimensions, thorax width, and leg proportions that reflect resource availability (Kang et al. 2025). Bee body size can influence foraging and pollination efficiency, thus affecting forest regeneration and understory plant composition in ecosystems (Suhri et al. 2025b). This expansion highlights the need to assess morphometric characteristics across elevations to understand morphological responses to habitat differences, changes in body size and shape that occur during life can affect survival (Nannan et al. 2022).

Similar to other Meliponini, *W. incisa* displays shared body characteristics yet retains distinct morphological traits, which help differentiate it from closely related species and facilitate accurate taxonomic identification (Cabrera et al. 2025). Morphometric-based taxonomic clarity helps identify key native pollinators essential for forest restoration, as certain bee species have specific associations with plant communities (Atmowidi et al. 2024). The presence of hamuli, small, stiff hooks located on the hind wings that differ from fine body hairs and function in wing coupling during flight (Packer 2023). The forewings and hindwings lock together during flight, helping the bee maintain steady movement, especially when carrying nectar or sap back to the hive. This species also has a uniformly black body and emits a characteristic resin-derived odor, particularly those from damar trees

(Salatnaya et al. 2021). The morphological abilities of this species are effective in pollen dispersal among forest plants (Pulungan et al. 2023)

Morphometric traits in bees may vary among populations and can reflect environmental influence, so that body character becomes a functional indicator used to understand their response in nature (Li et al. 2021). Body parts can be examined using morphometric measurements to evaluate how external morphology responds to ecological gradients. Morphometric analysis can reveal how a species adapts in response to different environmental conditions (Prastiyo et al. 2024). Altitudinal differences in temperature, humidity, and food resource availability are impacting the adaptability of bees, In line with research on *Tetragonula* spp. bees in rural areas of Sumedang District (Withaningsih et al. 2023).

Morphometric analysis is also widely applied for species in nature through techniques based on variations in the shape and size of observed insects (Sauer et al. 2020). In North Luwu, elevational gradients provide suitable contrasts for examining such variation. The region's extensive topography and forested habitats support the occurrence and cultivation of *W. incisa* (Sayusti et al. 2021), making it an appropriate location for evaluating altitudinal effects on morphology.

Although *W. incisa* plays an important ecological and economic role, morphometric information relating to elevational differentiation remains scarce in Wallacea, particularly in South Sulawesi. Previous studies on stingless bees have generally focused on general taxonomy and colony productivity (Engel et al. 2018; Budiaman et al. 2025). Integrating morphometric assessment with environmental context will contribute to understanding phenotypic adjustment in tropical mountain ecosystems and support region-specific management planning.

Research on *W. incisa* bees remains limited, with little data available on their morphometrics. As an endemic bee species distributed in the Wallacea Region, *W. incisa* has distinct characteristics compared to other bee species. This study aims to assess structural variation in W. incisa across three elevational ranges (lowland, midland, and highland) in North Luwu District, South Sulawesi. The resulting information is expected to strengthen conservation considerations and sustainable management strategies for this endemic stingless bee.

MATERIALS AND METHODS

Site location

The research was carried out from January to March 2024, precisely in Maipi Village (2°29'33.58"S 120°18'10.45" E), 219 meters above sea level (m asl) (lowland), Kanandede Village (2°33'81"S 120°00'99.5" E) with an altitude of 636 m asl (midland) and Pengkendekan Village (2°34'96'S 119°58'01.3" E) with an altitude of 1254 m asl (highlands). Each location represents the observed sampling altitude of *W. incisa* bees in the North Luwu District, South Sulawesi, Indonesia (Figure 1). Sampling locations were selected based on accessibility, habitat suitability, and active *W. incisa* populations. The lowlands have a temperature of 29-30°C with a humidity of 72-75%, dominated by coconut-based agroecosystems with continuous floral resources and open vegetation structure. The midlands have a temperature of 28-29°C, a humidity of 74-79% including mixed fruit agroforests with *Durio zibethinus* as the main food source, supported by various seasonal flowering species. The highlands have a temperature of 26-28°C, a humidity of 81-86%, and comprise a transitional forest mosaic characterized by denser canopy layers, cooler microclimates, although food sources are more scattered, including *Paraserianthes falcataria*.

Data collection

Sampling was carried out at three different altitudes: lowlands, midlands, and highlands (Figure 2) (Layek and Karmakar 2025). At each cultivation site, 30 *W. incisa* workers were collected sufficient to capture morphometric variation, namely three workers taken from 10 separate colonies. The number of colonies available at each location was determined by observing active nests, which identified 23 colonies in Maipi, 19 in Kanandede, and 30 in Pengekendekan. Bee sampling was carried out in the morning, between 07.00-10.00, using bottle traps, and only a small number of workers per colony were retained to avoid pseudo-replication. A total of three bottle traps were installed around the flowering plants. Several *W. incisa* bees trapped in the bottle were then transferred to the sample bottle. After sampling, morphometric measurements were carried out.

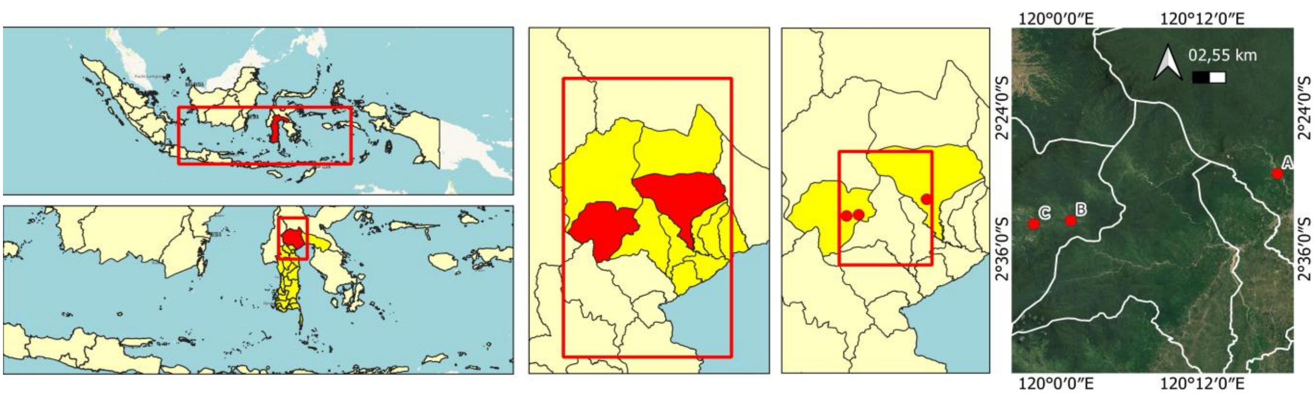

Figure 1. Research locations in North Luwu District, South Sulawesi, Indonesia. A. Lowland, B. Midland, and C. Highland

Figure 2. Locations of *W. incisa* bee cultivation at different sites in North Luwu District, South Sulawesi, Indonesia. A. Maipi Village (lowland), B. Kanandede Village (midland), C. Pengekendekan Village (highland)

Morphometric measurement

Morphometric measurements of *W. incisa* bees were carried out using a stereo microscope (Stem 2000 with phototube camera ERc 5S). Calibration using a stage micrometer allowed the ocular scale to be read with an accuracy of 0.01 mm. The parts measured focused on the external parts of the bee's body. A total of 17 characteristics of bee body parts were selected, including body length, head length, head width, eye length, eye width, gena width, malar length, flagellomere IV width, fore wing length, length of fore wing including tegula, distance between M-Cu bifurcation, hind wing length, hind femur length, hind tibia length, hind tibia width, hind basitarsus length, and hind basitarsus width (Figure 3) (Prastiyo et al. 2024). The above characters reflect functional forms relevant to assessing variation in environmental adaptation (Baltz et al. 2025)

Data analysis

The data analysis employed in this study included a One-Way Analysis of Variance (ANOVA) with Tukey's Honestly Significant Difference (HSD) test to identify significant differences in each height trait at $p<0.05$ (p = the output value of the Tukey test), with all morphometric data first checked for normality to ensure that assumptions were met, and Pearson correlation using the SPSS 6.0 software, as well as Principal Component Analysis (PCA) performed with XLSTAT. The one-way ANOVA test was conducted to evaluate the influence of altitude (samples from three different locations) on the external morphometric characteristics of *W. incisa*. Pearson correlation analysis was then used to determine the strength and direction of relationships among morphometric parameters. Finally, PCA was applied to interpret the overall pattern of morphometric variation of the included bees and to visualize the grouping of populations in response to altitude differences across the three study sites in North Luwu.

RESULTS AND DISCUSSION

Morphometrics of *Wallacetrigona incisa* bees

The morphological characteristics show distinctive features, especially in body size, head morphology, front and rear wings of the stingless bee *W. incisa*, which inhabits the Wallacea Region as an endemic species. The observed morphological traits reinforce its taxonomic identity based on species-level morphological characters (Pardo et al. 2025). Moreover, these features represent adaptive responses to the environmental conditions of the tropical mountain ecosystems of Sulawesi. The morphometric characteristics of *W. incisa* show a dark body coloration with a glossy black appearance (Figure 3). The head is rounded and slightly broad, with 11-segmented antennae. The mandibles function in collecting resin and nesting materials. The thorax is dark and covered with fine yellowish hairs. The forewings appear transparent with distinct venation patterns, while the hindwings are narrower and elongated. The hind legs possess a flat, densely haired corbicula used for carrying pollen. The abdomen consists of six shiny black segments with fine hairs evenly distributed. Variations in the shape and size of body parts such as the wings, tibiae, and thorax serve as references for observing the morphometric characteristics of this bee.

One-way ANOVA of morphometric traits among altitudes

A total of 17 morphometric characters of *W. incisa* bees were measured to describe variations in body size and shape influenced by elevation (Table 1). The results showed that most morphometric characters increased with altitude. Bees from the highland areas exhibited the largest body size, with a mean body length of 6.20±0.24 mm, compared to 5.99±0.23 mm in the midlands and 5.59±0.17 mm in the lowlands. The one-way ANOVA analysis (Tukey test) showed that 12 body parts exhibited significant size differences ($p<0.05$) due to elevation. In addition, other body parts were Eye Length (EL), Malar Length (ML), Flagellomere IV Width (FW), Fore Wing

Length (FWL), distance between M-Cu bifurcation (WL2), Hind Wing Length (HWL), Hind Tibia Length (HTL), Hind Basitarsus Length (HBL), and Hind Basitarsus Width (HBW) (Table 1).

These characters contributed greatly to the variation in body size of *W. incisa* bees across different altitudes. The body length from head to abdomen determines the overall body size of bees (Hrncir et al. 2019). Most morphometric traits, particularly those related to the fore and hind wings, play an important role in the adaptation process. Wing morphology can be used to determine and classify honey bee types as a form of adaptation to their environment (Yancan et al. 2019). These findings are consistent with previous studies indicating that bees inhabiting highland areas tend to have larger body sizes (Gonzalez et al. 2022).

Correlation among morphometric characters

The correlation analysis among 17 morphometric characters of *W. incisa* bees at the three elevations revealed several strong relationships among body traits (Table 2). Body length showed a strong correlation with ML, FW, FWL, HWL, HFL, and HTL, with correlation coefficients ranging from 0.48 to 0.74. The strongest correlation was observed between BL and HFL ($r=0.74$, $p<0.01$), followed by BL and HWL ($r=0.48$, $p<0.01$), and BL and FWL ($r=0.36$, $p<0.05$). These results indicate that increases in overall body size were closely related to the elongation of the hind leg and wing structures.

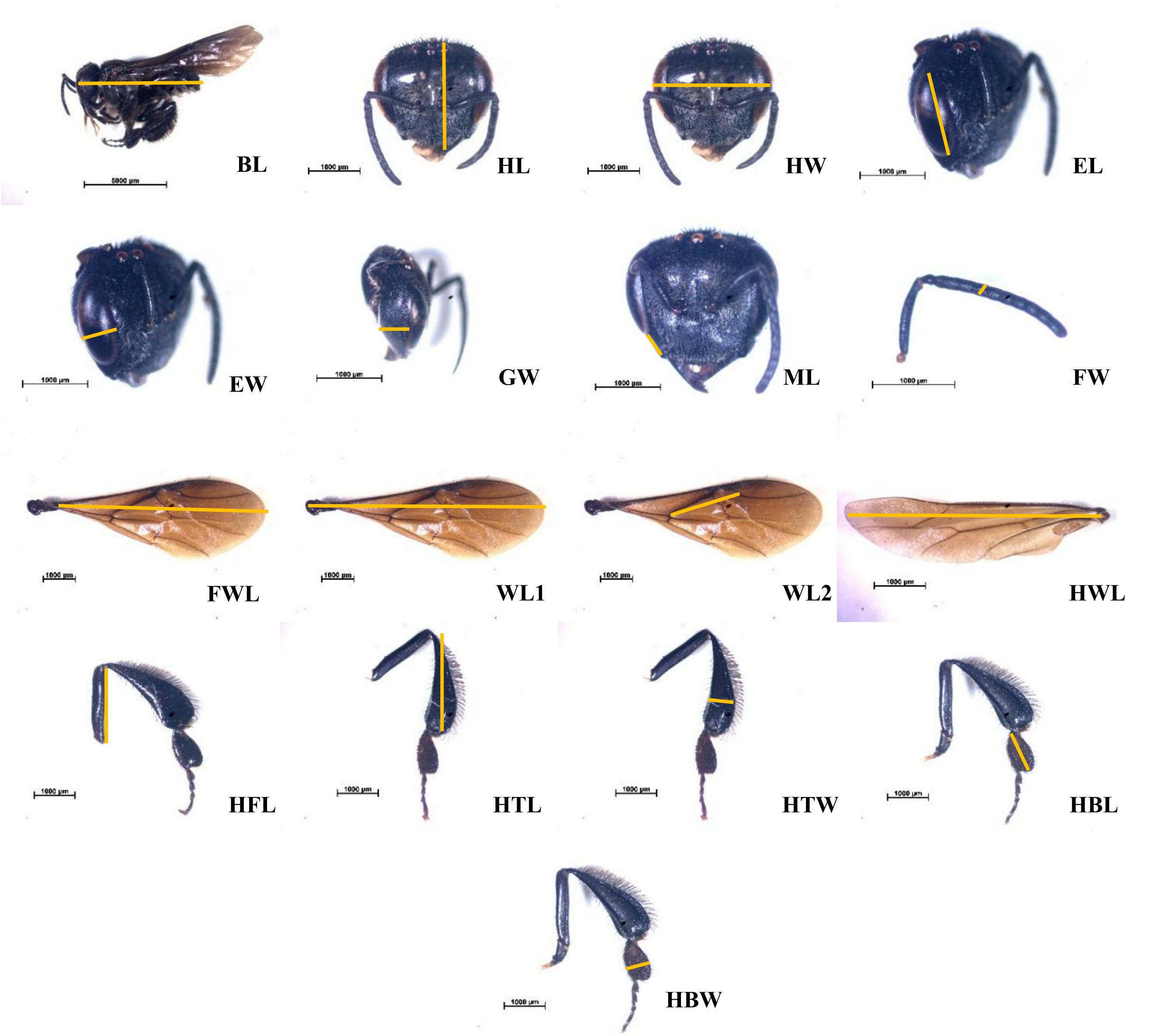

Figure 3. Characteristic body size of the *W. incisa* bee. BL: Body Length, HL: Head Length, HW: Head Width, EL: Eye Length, EW: Eye Width, GW: Gena Width, ML: Malar Length, FW: Flagellomere IV Width, FWL: Fore Wing Length, WL1: Length of fore wing including tegula, WL2: Distance between M-Cu bifurcation, HWL: Hind Wing Length, HFL: Hind Femur Length, HTL: Hind Tibia Length, HTW: Hind Tibia Width, HBL: Hind Basitarsus Length, HBW: Hind Basitarsus Width. Scale bar: 1000 µm

Table 1. Morphometrics of *W. incisa* bees

Characters	Morphometric (mm)					
	Lowland (n=30)		Midland (n=30)		Highland (n=30)	
	Min-Max	Mean±SD	Min-Max	Mean±SD	Min-Max	Mean±SD
Body Length (BL)*	5.33-5.94	5.59±0.17a	5.64-6.38	5.99±0.23b	5.85-6.66	6.20±0.24c
Head Length (HL)	1.92-2.01	1.99±0.03	1.93-2.05	2.00±0.04	1.91-2.03	1.97±0.04
Head Width (HW)	2.30-2.42	2.37±0.04	2.36-2.41	2.38±0.02	2.30-2.45	2.39±0.05
Eye Length (EL)*	1.36-1.45	1.40±0.03a	1.43-1.48	1.45±0.02b	1.39-1.49	1.44±0.03b
Eye Width (EW)	0.51-0.55	0.53±0.02	0.51-0.55	0.53±0.01	0.51-0.55	0.53±0.02
Gena Width (GW)	0.36-0.56	0.44±0.07	0.42-0.49	0.44±0.02	0.42-0.49	0.46±0.02
Malar Length (ML)*	0.21-0.27	0.23±0.02a	0.30-0.32	0.31±0.01b	0.31-0.32	0.32±0.01b
Flagellomere IV Width (FW)*	0.14-0.16	0.15±0.01a	0.15-0.16	0.16±0.03b	0.15-0.16	0.16±0.02b
Fore Wing Length (FWL)*	6.56-6.78	6.69±0.08a	6.72-6.99	6.88±0.09b	6.57-7.10	6.83±0.15b
Length of fore wing including tegula (WL1)	7.10-7.54	7.34±0.13	7.23-7.86	7.48±0.23	7.23-7.92	7.48±0.24
Distance between M-Cu bifurcation (WL2)*	1.96-2.22	2.14±0.09a	2.20-2.33	2.28±0.04b	2.21-2.34	2.27±0.05b
Hind Wing Length (HWL)*	4.63-4.93	4.81±0.10a	4.81-4.98	4.88±0.05b	4.84-5.00	4.91±0.05b
Hind Femur Length (HFL)*	1.70-1.80	1.76±0.04a	1.81-1.84	1.83±0.01b	1.82-1.91	1.87±0.03c
Hind Tibia Length (HTL)*	2.34-2.49	2.39±0.04a	2.38-2.51	2.45±0.04b	2.40-2.57	2.48±0.06b
Hind Tibia Width (HTW)*	0.70-0.76	0.73±0.02a	0.72-0.78	0.74±0.02a	0.76-0.79	0.78±0.01b
Hind Basitarsus Length (HBL)*	1.00-1.07	1.02±0.02a	1.01-1.08	1.03±0.02a	1.02-1.10	1.05±0.03b
Hind Basitarsus Width (HBW)*	0.53-0.60	0.56±0.03a	0.56-0.61	0.59±0.02b	0.56-0.61	0.57±0.01ab

Note: (*) indicates a significant difference at $p<0.05$, Mean ± SD: Mean value ± standard deviation. Tukey's Honestly Significant Difference (HSD)

The strong correlations between BL and several wing and leg dimensions indicate that *W. incisa* exhibits morphological growth as a response to its natural environment, which supports flight mechanics and resource handling. The positive relationship between BL and FWL ($r=0.36$, $p<0.05$) indicates wing expansion as an adaptive response to high-altitude environments characterized by thinner air and lower temperatures. Wing adaptation enhances flight efficiency in such environmental conditions (Hedges et al. 2019). Larger wings provide bees with greater lift and flight stability (Peters et al. 2017), enabling them to maintain aerodynamic performance under reduced air density.

Furthermore, the strong correlations between BL and HFL ($r=0.74$, $p<0.01$) as well as BL and HTL ($r=0.48$, $p<0.01$) indicate that hind leg morphology contributes significantly to functional adaptation. Larger hind legs enhance pollen-gathering capacity and provide greater propulsion during flight (Portman et al. 2019). These structural changes reflect the influence of environmental pressures on morphometric traits. In lowland areas, higher ambient temperatures tend to produce smaller body sizes (Quinlan and Grozinger 2023). While cooler highland conditions promote larger bees with improved thermoregulation and flight performance (Peters et al. 2016). Overall, the correlated variation among morphometric characters of *W. incisa* demonstrates an adaptive response to altitude-driven environmental changes.

Principal component analysis of morphometric variation

The PCA plot (Figure 4) shows the separation of colonies based on morphometric characters across two principal components, with PC1 explaining 38.45% of the variation and PC2 explaining 12.55%. Colonies from the lowland area are positioned in the region with negative PC1 values, while colonies from the midland are distributed across a wider range of both PC1 and PC2 values in the central area of the plot. Colonies from the highland form a cluster at positive PC1 values and predominantly negative PC2 values. PC1 represents the main morphometric variation among colonies, while PC2 represents the distribution variation between elevations. This clustering pattern indicates that the combination of morphometric characters represented by PC1 and PC2 produces distinct groups for each altitude level, with slight overlap between the midland and highland groups. PCA is used to analyze morphometric distribution patterns, not to test for significant differences between elevations. Overall, the contributions of PC1 and PC2 highlight the morphometric differentiation associated with elevation differences.

The PCA analysis visualizes the structure and covariation among morphometric characters, allowing populations from different elevations to be distinguished based on shared trait patterns and confirming the influence of altitude on morphological variation (Bianchi et al. 2021). PCA serves as an effective tool for tracking the relationships among the morphometric traits of bees, identifying changes in bee body characteristics (Henriques et al. 2020). The use of PCA complements the analysis of size variation (Abed et al. 2021). The strong variations observed in bees are often reflected in body length suggesting it is the primary adaptation (Gerard et al. 2018).

Table 2. Correlation of morphometric characters of *W. incisa* at the three locations (n=30/location)

Characters	BL	HL	HW	EL	EW	GW	ML	FW	FWL	WL1	WL2	HWL	HFL	HTL	HTW	HBL	HBW
BL	1																
HL	0.05	1															
HW	0.20	0.06	1														
EL	0.53**	0.20	0.30	1													
EW	0.31	0.13	0.34	0.29	1												
GW	0.10	-0.22	0.01	-0.05	-0.08	1											
ML	0.70**	-0.04	0.08	0.63**	0.19	-0.01	1										
FW	0.62**	-0.12	0.32	0.48**	0.32	0.35	0.59**	1									
FWL	0.36*	0.15	0.11	0.63**	-0.05	0.13	0.52**	0.31	1								
WL1	0.22	0.17	0.16	0.46	-0.11	-0.00	0.29	0.28	0.71**	1							
WL2	0.61**	-0.03	0.35	0.56**	0.06	0.37*	0.60**	0.64**	0.69**	0.48**	1						
HWL	0.35	-0.01	0.11	0.40*	0.28	-0.24	0.59**	0.09	0.37*	0.21	0.30	1					
HFL	0.74**	-0.07	0.24	0.59**	0.33	0.18	0.78**	0.60**	0.56**	0.38*	0.67**	0.61**	1				
HTL	0.49**	-0.12	0.40*	0.52**	0.18	0.21	0.57**	0.49**	0.67**	0.44*	0.64**	0.38*	0.74**	1			
HTW	0.48**	-0.34	0.35	0.17	-0.15	0.21	0.46*	0.40*	0.20	0.23	0.46*	0.22	0.56**	0.47**	1		
HBL	0.25	-0.23	-0.26	0.11	-0.43*	0.29	0.30	0.18	0.40*	0.29	0.42*	0.19	0.43*	0.46**	0.35	1	
HBW	0.31	0.04	0.31	0.18	-0.00	0.01	0.43*	0.37*	0.20	-0.02	0.41*	-0.02	0.25	0.42*	0.32	-0.07	1

Note: Asterisks indicate the level of significance where p<0.05 (*) and p<0.01 (**) based on a two-tailed correlation test. BL: Body Length, HL: Head Length, HW: Head Width, EL: Eye Length, EW: Eye Width, GW: Gena Width, ML: Malar Length, FW: Flagellomere IV Width, FWL: Fore Wing Length, WL1: Length of fore wing including tegula, WL2: Distance between M-Cu bifurcation, HWL: Hind Wing Length, HFL: Hind Femur Length, HTL: Hind Tibia Length, HTW: Hind Tibia Width, HBL: Hind Basitarsus Length, HBW: Hind Basitarsus Width

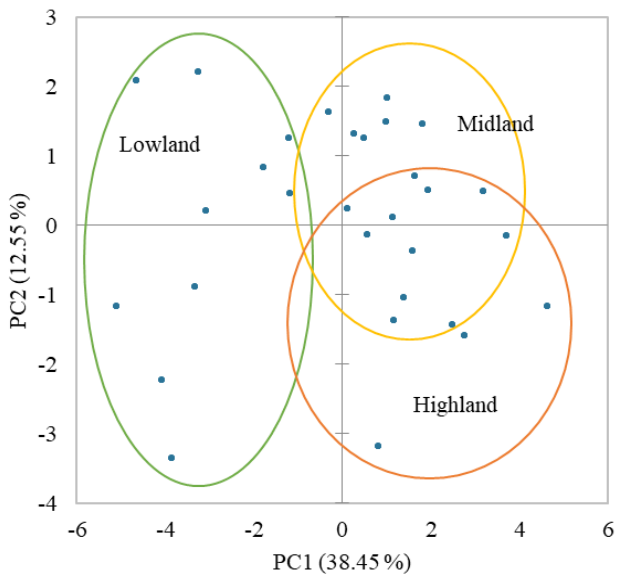

Figure 4. Distribution of morphometric traits of *W. incisa* bees at different elevations (In the PCA plot, each dot represents an individual specimen, with different colors indicating sampling locations (lowland, midland, and highland). The ellipses show the distribution of morphometric traits, where overlapping areas indicate morphological similarity and non-overlapping areas indicate differentiation among locations)

Morphometric diversity among populations is shaped by various environmental conditions. Temperature and humidity play an important role in shaping the body character of bees in tropical regions (Farias-Silva and Freitas 2021). Higher temperatures in lowland areas are often associated with smaller body sizes as an energy-saving strategy to enhance resource-use efficiency (Forrest 2017; Juhasz et al. 2020). Conversely, the cooler climate of highland areas are generally associated with larger body sizes, which improve thermoregulation and flight performance under lower air density conditions (Hailu et al. 2021). These findings indicate that *W. incisa* exhibits a clear altitudinal gradient in body size, consistent with patterns observed in other tropical bee species.

Vegetation also plays a role in providing food sources for bees for colony development (Mramba 2025). The type and diversity of plants, especially flowering plants in the forest at each altitude determines the availability of pollen and nectar. Food sources directly affect body growth and development (Clarke et al. 2017; Wu et al. 2018). The highland ecosystems have a lot of vegetation, with the dominant plant at the research location being *P. falcataria*. Ecological interactions in forests highlight the important role of habitat composition in driving morphological plasticity within bee populations (Ogilvie and Forrest 2017).

As a pollinator, *W. incisa* plays an important role in maintaining biodiversity and ecosystem sustainability, particularly in supporting forest plant regeneration. Morphometric studies provide valuable insights into how a species responds to environmental changes (Ayers and Rehan 2021). Understanding adaptation patterns contribute to the development of effective and sustainable pollinator conservation strategies, especially amidst climate change and habitat degradation (Leroy et al. 2023). The observed correlations among morphometric variations deepen our understanding of the symbiotic relationships between organisms and their ecosystems (Ulyshen et al. 2023).

The conclusion of this study states that the body size of *W. incisa* varies consistently with altitude. PCA population separation is driven by variation across multiple morphometric traits, with environmental influences supported by ecological evidence outside the PCA. This condition reflects the ecological capacity of this endemic stingless bee to adjust to various habitats along elevation gradients. The results highlight the importance of environmental diversity in maintaining population stability and morphometric variation in *W. incisa*. From a conservation perspective, protecting both highland and lowland habitats is essential to preserve genetic and phenotypic diversity. Morphometric traits can serve as effective indicators of environmental change, supporting conservation measures that monitor trait shifts and maintain habitat connectivity to safeguard *W. incisa* as a key tropical pollinator.

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