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Morphology and morphometric of *Tetragonula biroi* bees at three different altitudes in South Sulawesi, Indonesia

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Abstract. *Prastiyo A, Nuraeni S, Budiaman. 2024. Morphology and morphometric of* Tetragonula biroi *bees at three different altitudes in South Sulawesi, Indonesia. Biodiversitas 25: 1993-2002. Tetragonula biroi* Friese 1898 is a stingless bee species that plays an essential role in pollination and environmental conservation. This research is important because bees play a crucial role as pollinators for the sustainability of plants, and morphometric measurements can reveal patterns of adaptation and the potential production of products generated by these bees. This research aims to analyze the morphological and morphometric variations of *T. biroi* at three different altitudes in South Sulawesi. The study was conducted from November 2023 to January 2024, with sampling points in lowland (158 meters above sea level or masl), midland (417 masl), and highland (709 masl), using Principal Component Analysis (PCA) test using XLSTAT and one-way analysis of variance (ANOVA) test using program SPSS. Observations of *T. biroi* morphology at the three locations were generally similar, with a black body color tinged with brown and characteristic hamuli numbering five. The morphometric analysis involved measuring body dimensions of *T. biroi* across 35 characters/sections of the external body, and the one-way ANOVA test results showed that the dominant characters significantly influencing were body length (BL) and length of fore wing, including tegula (WL1). *T. biroi* bees at lowlands tend to have smaller bodies, measuring 3.73±0.09 mm, while those at higher altitudes tend to have larger bodies, measuring 4.09±0.14 mm. This indicates adaptation to environmental conditions such as temperature (26.75°C), humidity (81%), and dominant vegetation (*Cocos nucifera* L.) in lowland, which influence bee adaptation, as well as in midland and highland areas. This research provides a better understanding of morphological and morphometric variations in *T. biroi* bees at various altitudes in South Sulawesi. The morphology and morphometrics description of bees is crucial in determining the growth and production of a species.

Keywords: Body characters, meliponiary, stingless bee, *Tetragonula biroi*

INTRODUCTION

Tetragonula biroi Friese 1898 bees are a widespread stingless bee species in South Sulawesi, Indonesia (Purwanto et al. 2022). These bees play a crucial role in ecosystems as pollinators and honey producers, serving as a livelihood for many communities around forests. Studies on the morphology and morphometrics of stingless bees are critical because they can provide a deeper understanding of the adaptations and changes in this species in various environments, including differences in altitude. The altitude of a location affects the morphology and adaptation of bees (Irshad et al. 2022).

The morphology of *T. biroi* bees can vary depending on the environmental conditions where they live. Stingless bees are widely distributed in tropical and subtropical regions such as Asia, Africa, America, and Australia (Gruter 2020). Altitude can influence these bees' body size, color, and physical characteristics (Novita et al. 2013). Therefore, studying the morphology and morphometrics of *T. biroi* bees at different altitudes can provide insights into their adaptation to different environments. Changes in body size of *T. biroi* bees in colder regions include larger and longer wings compared to those living at lower altitudes (Hines et al. 2022). Ecologically, stingless bees excel primarily in mutualistic relationships with their surroundings and thrive without competition from honey bees (Roubik 2023).

The morphological structure of the body of bees is similar to other insects, consisting of three main parts: head (caput), thorax, and abdomen (Tarigan et al. 2021). The body of bees is partially covered by fine hair, which functions as a receptor for stimuli or touch sensors. Fine hair on bees also serves as a tool for storing pollen, often called pollen baskets, which are located on the hind legs (Fadiah 2023). Honeybees have segmented bodies, where each segment is interconnected. Their mouth is an elongated cylindrical shape used to suck up nectar stored in the honey sac which can expand (Nurdin et al. 2021). Characteristics of external parts or dominant morphological characteristics are intended to consider broader adaptations. Morphological characteristics or sizes can determine the bees' production (Prastiyo et al. 2023).

This research is also relevant to conservation and natural resource management. A better understanding of the morphology of *T. biroi* bees at various altitudes can lead to developing more effective strategies to conserve their populations and habitats. *T. biroi* bee species are mostly found nesting at low altitudes, consistent with their habitat and contribution to their survival (Gascon et al. 2023). This is important considering the crucial role of *T.*

biroi bees in maintaining ecosystem balance and supporting ecological sustainability in South Sulawesi.

Morphometric studies of *T. biroi* bees can also provide information about population health and conditions. Populations of the same species in different locations may face different ecological and climatic conditions, thus affecting population development (Hamid 2023). Changes in morphometric parameters such as body size and proportions of particular body parts may reflect adaptations or environmental stress experienced by *T. biroi* bees at different altitudes. Bees contribute to stable evolution and adaptation in dry tropical areas (Engel et al. 2021). Therefore, regularly monitoring *T. biroi* bee morphometrics can provide early indications of environmental changes that must be considered in conservation efforts.

Morphometric research can also assist in identifying subspecies or genetic variations within stingless bee populations in South Sulawesi. Using morphometric techniques, physical characteristics can be distinguished among individuals from different altitudes, and a better understanding of the existing genetic diversity within the population can be obtained. Using morphometric techniques, stingless bees' diversity and population structure can explain greater genetic diversity from these markers among populations and other factors such as rainfall, flower types, and altitude (Oliveira et al. 2023). This is important for developing appropriate conservation strategies that consider the genetic diversity of stingless bees, especially *T. biroi.*

Research on the morphology and morphometrics of *T. biroi* bees can also contribute to a general understanding of bee evolution and behavior biology. Analyzing morphological changes at the population and individual levels at different altitudes, we can identify adaptation patterns that may have occurred and the environmental factors influencing these changes. The research aims to analyze morphology and morphometrics to varying altitudes in South Sulawesi. This can provide further insights into the evolutionary processes and adaptations of *T. biroi* bee species and provide a basis for further research on their behavior and ecology. The morphology and morphometrics description of bees is crucial in determining the growth and production of a species, especially in collecting nectar, pollen, and resin.

MATERIALS AND METHODS

Research site

This research was conducted from October 2023 to January 2024, where bee sampling points were taken at three locations in South Sulawesi, specifically in Bulukumba at an altitude of 158 meters above sea level (masl), North Luwu at an altitude of 417 masl and Bone at an altitude of 709 masl. The research locations can be seen in more detail in Figure 1. South Sulawesi is a special zone as it falls within the Wallacea zone, with abundant biodiversity in this area (Brambach et al. 2017). The three research locations are located in Bulukumba District (5°27'39"S 120°9'44"E), North Luwu District (2°36'9"S 120°3'14"E), and Bone District (5°3'27"S 120°4'21"E). These three areas are classified as Bulukumba, which is lowland; North Luwu, which is midland; and Bone, which is highland. The selection of locations is based on the distribution of *T. biroi* bees in South Sulawesi, where the species *T. biroi* is widely cultivated. Due to suitable environmental conditions and abundant bee food sources, *T. biroi* bees are widely distributed in South Sulawesi. Environmental data such as temperature and humidity are measured using an analog thermometer at each location with three repetitions (Table 1). The temperature at the sampling points in Bukit Harapan Village, Gantarang Sub-district, Bulukumba District, averaged 26.75°C, with an average humidity of 81%. The temperature at the sampling points in Tandung Village, Sabbang Sub-district, North Luwu District, 26.10°C, with an average humidity of 83%. The temperature at the sampling points in Pammusureng Village, Kahu Sub-district, Bone District, averaged 25.30°C, with an average humidity of 84%. The rainy season usually occurs from November to April, peaking in January. The dry season lasts from May to October, peaking in September. The three data collection locations have diverse potential food sources and their dominant vegetation.

Collection of bee

The bee samples were taken at each observed meliponary height. The sampling of *T. biroi* focuses on the worker bees that are highly active in the hive. Procedure for the sponge trap method for bee sampling: the sponge was prepared by soaking it in a sugar solution to attract bees; the sugar-soaked sponge was placed in a suitable location where bee activity was observed or suspected, waited for some time, typically around 20 minutes, allowing the bees to discover and consume the food source from the sponge trap, once many bees were attracted to and feeding from the sponge trap, we proceeded to close the trap using netting or another suitable cover to prevent the bees from escaping, after closing the trap, the trapped bees were carefully collected for further analysis or measurement, the trapped bees were handled gently to avoid harming them during the sampling process. To avoid sample damage during measurement and other reasons, the bee samples that have been collected, at a minimum of more than ten individuals per location, are then further analyzed with morphological observations and morphometric measurements.

Characteristics of *T. biroi*

Tetragonula biroi, also known as the dwarf honey bee or stingless bee, is easily recognizable by its small size and lack of a sting. These bees are typically black or dark brown and have a distinctive behavior of flying in large groups around their hive entrances. Unlike the bee species of apinae (stinging bees), *T. biroi* does not possess a sting, making them safe to handle for those unfamiliar with beekeeping. They are commonly found in tropical regions, particularly in Southeast Asia, where they play a crucial role in pollination and are often kept by local communities for their honey production.

Table 1. Research site conditions

Location	Altitude (masl)	Temperature (°C)	Humidity (%)	Dominant vegetation	Area
Lowland (BK)	158	26.75	81	*Cocos nucifera* L.	Meliponiary
Midland (LU)	417	26.10	83	*Durio zibethinus* Murray	Meliponiary
Highland (BN)	709	25.30	84	*Mangifera indica* L.	Meliponiary

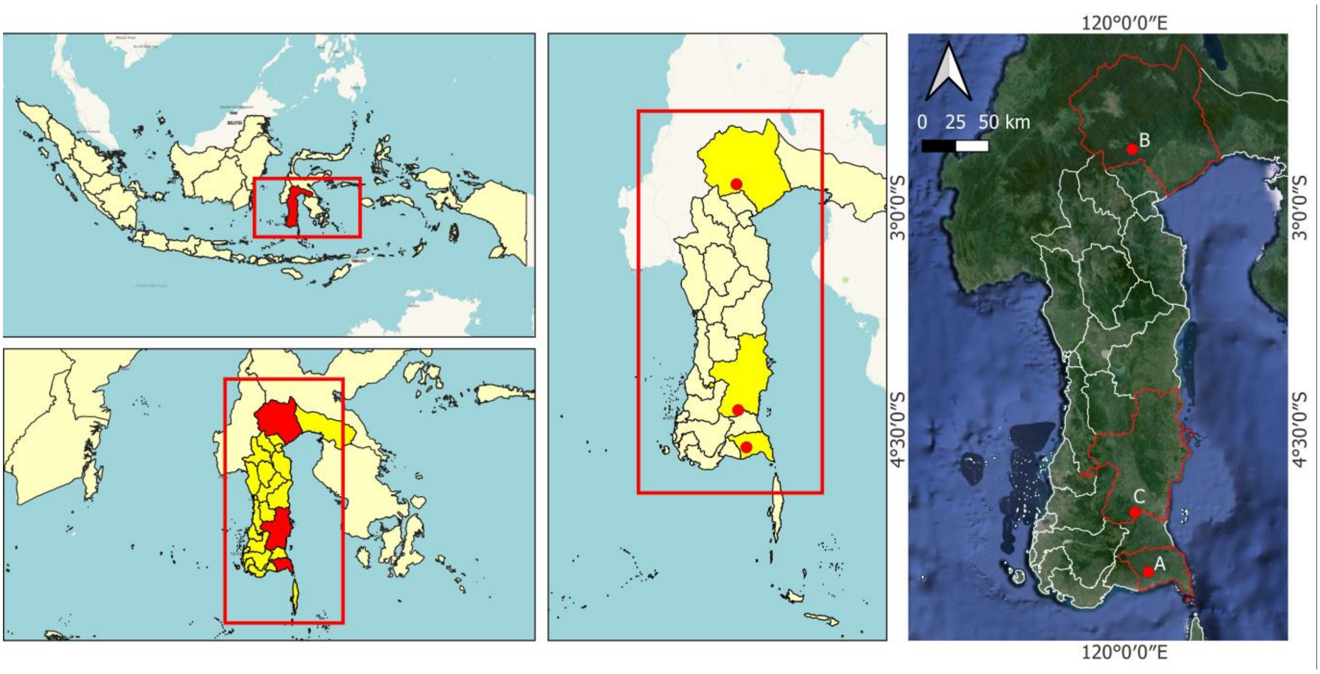


Figure 1. Research samples in South Sulawesi, Indonesia. A. Lowland (Bulukumba); B. Midland (North Luwu); and C. Highland (Bone)

Morphometric measurement of bees

The morphometric measurements of *T. biroi* were conducted on ten individuals per location. Morphometric measurements of *T. biroi* were made by observing several dimensions of the external parts of the bees. Measurements were conducted using a stereo microscope (stem 2000 with phototube camera ERc 5S) at various magnifications. Parts of the bee measured include body length, head length, head width, mandible length, mandible width, clypeus length, lower interocular distance, upper interocular distance, eye width, eye length, maximum interorbital distance, lower interorbital distance, interantennal distance, interocellar distance, ocellocular distance, antennocellar distance, antennocular distance, gena width, flagellomer iv length, flagellomer iv width, malar length, mesoscutum length, mesoscutum width, length of fore wing including tegula, the distance between M-Cu bifurcation, fore wing length, fore wing width, hind wing length, hind wing width, proboscis length, hind femur length, hind tibia width, hind tibia length, hind basitarsus width, and hind basitarsus length.

Data analysis

The morphometric data of *T. biroi* bees were analyzed using the Principal Component Analysis (PCA) method with XLSTAT to observe variables that explained most of the variability by simplifying the data of various parts of *T. biroi* bees into the principal components. The second analysis is a one-way analysis of variance (ANOVA) test using the program SPSS 6.0 to test whether the morphometric characteristics of T. biroi bees differ at three altitudes. A normality test was conducted to ensure the data met the assumptions of ANOVA. The results of the one-way ANOVA analysis can be seen in Table 2.

RESULTS AND DISCUSSION

Morphology of *T. biroi* bees

Based on the morphological observations of *T. biroi* at the three locations, the body color of *T. biroi* bees at three altitudes is black with a slight brownish tint (Figure 2). This is consistent with findings by Purba et al. (2023), indicating that the body color of *T. biroi* bees is predominantly black with a slight brownish. The characteristics of *T. biroi* in terms of the number of hamuli are also consistent. Differences are found in the structural size of characters/parts, as seen in Table 1. The body color is relatively similar, ranging from blackish-brown between Luwu Utara and Bone but less blackish in Bulukumba. The elevation of the location, influenced by the climate, may affect the morphology as an adaptation form of *T. biroi* bees.

Table 2. Morphometric characters of *Tetragonula biroi*

Characters	Morphometric (mm)					
	Lowland (BK)		Midland (LU)		Highland (BN)	
	Min-Max	Mean±SD	Min-Max	Mean±SD	Min-Max	Mean±SD
Body Length (BL)*	3.62-3.87	3.73±0.09a	3.81-3.98	3.90±0.05b	3.84-4.23	4.09±0.14c
Head Length (HL)	1.35-1.46	1.41±0.03	1.36-1.47	1.41±0.03	1.37-1.46	1.42±0.03
Head Width (HW)*	1.62-1.73	1.67±0.03ab	1.59-1.69	1.66±0.03a	1.66-1.74	1.69±0.03b
Mandible Length (ML)*	0.58-0.62	0.61±0.01a	0.58-0.64	0.62±0.02a	0.61-0.68	0.65±0.02b
Mandible Width (MW)*	0.14-0.20	0.17±0.02a	0.20-0.25	0.22±0.02b	0.18-0.24	0.21±0.02b
Clypeus Length (CL)*	0.37-0.50	0.44±0.04a	0.41-0.47	0.43±0.02a	0.43-0.50	0.48±0.02b
Lower Interocular Distance (LID)*	0.86-0.95	0.91±0.03a	0.88-0.96	0.92±0.03ab	0.92-0.97	0.94±0.02b
Upper Interocular Distance (UID)*	1.05-1.17	1.11±0.04a	1.08-1.15	1.11±0.03a	1.10-1.23	1.16±0.04b
Eye Width (EW)*	0.40-0.46	0.43±0.02a	0.42-0.48	0.46±0.02b	0.40-0.48	0.46±0.02b
Eye Length (EL)*	1.04-1.13	1.10±0.03a	1.11-1.16	1.14±0.02b	1.12-1.20	1.15±0.02b
Maximum Interorbital Distance (MOD)*	1.17-1.26	1.20±0.03b	1.14-1.22	1.18±0.02a	1.14-1.22	1.17±0.02a
Lower Interorbital Distance (LOD)	0.92-1.01	0.96±0.03	0.95-1.04	0.98±0.02	0.95-0.99	0.97±0.01
Interantennal Distance (IAD)*	0.17-0.21	0.19±0.01b	0.17-0.20	0.18±0.01a	0.20-0.25	0.21±0.01c
Interocellar Distance (IOD)	0.29-0.41	0.36±0.03	0.34-0.41	0.37±0.03	0.34-0.41	0.37±0.02
Ocellocular Distance (OOD)*	0.21-0.29	0.26±0.03a	0.27-0.31	0.29±0.01b	0.30-0.37	0.32±0.02c
Antennocellar Distance (AD)*	0.75-0.80	0.77±0.02a	0.74-0.80	0.78±0.02a	0.82-0.89	0.84±0.02b
Antennocular Distance (AOD)*	0.28-0.36	0.32±0.03a	0.29-0.32	0.31±0.01a	0.33-0.45	0.39±0.04b
Gena Width (GW)*	0.16-0.32	0.25±0.05a	0.22-0.39	0.31±0.05b	0.30-0.37	0.34±0.02b
Length of Flagellomere IV (FL)*	0.10-0.12	0.11±0.01a	0.10-0.12	0.11±0.01a	0.12-0.14	0.13±0.01b
Width of Flagellomere IV (FW)*	0.13-0.14	0.13±0.00ab	0.13-0.26	0.15±0.04b	0.12-0.14	0.13±0.01a
Malar Length (ML)	0.06-0.07	0.07±0.00	0.07-0.07	0.07±0.00	0.07-0.07	0.07±0.00
Mesoscutum Length (MCL)	0.88-1.08	0.98±0.07	0.82-0.99	0.96±0.06	0.93-0.96	0.95±0.01
Mesoscutum Width (MCW)*	1.05-1.11	1.08±0.02a	1.02-1.13	1.07±0.03a	1.10-1.17	1.12±0.02b
Length of Fore Wing Including Tegula (WL1)*	3.53-3.83	3.77±0.10b	3.54-3.77	3.69±0.07a	3.80-3.95	3.86±0.05c
Distance Between M-Cu Bifurcation (WL2)*	1.00-1.14	1.09±0.04a	1.11-1.14	1.12±0.01b	1.12-1.23	1.16±0.03c
Fore Wing Length (FWL)*	3.20-3.55	3.47±0.10a	3.40-3.53	3.48±0.04a	3.52-3.89	3.68±0.10b
Fore Wing Width (FWW)*	1.11-1.23	1.13±0.04a	1.21-1.29	1.24±0.03b	1.20-1.47	1.37±0.10c
Hind Wing Length (HWL)*	2.23-2.60	2.42±0.09a	2.25-2.56	2.45±0.10a	2.50-2.70	2.64±0.06b
Hind Wing Width (HWW)	0.60-0.69	0.63±0.03	0.59-0.69	0.63±0.03	0.58-0.71	0.66±0.04
Proboscis Length (PL)*	1.40-1.44	1.42±0.01a	1.40-1.48	1.44±0.02b	1.42-1.53	1.46±0.04b
Hind Femur Length (HFL)*	1.06-1.09	1.08±0.01a	1.05-1.12	1.07±0.02a	1.08-1.12	1.11±0.01b
Hind Tibia Width (HTW)*	0.46-0.52	0.49±0.02a	0.47-0.52	0.50±0.02a	0.50-0.56	0.54±0.02b
Hind Tibia Length (HTL)*	1.44-1.52	1.47±0.03a	1.41-1.53	1.47±0.03a	1.47-1.59	1.52±0.04b
Hind Basitarsus Width (HBW)*	0.24-0.30	0.28±0.02a	0.25-0.33	0.29±0.02a	0.31-0.42	0.36±0.03b
Hind Basitarsus Length (HBL)	0.52-0.61	0.57±0.03	0.52-0.62	0.58±0.03	0.55-0.62	0.58±0.03

Note: The (*) indicates a significant influence with a P value <0.05

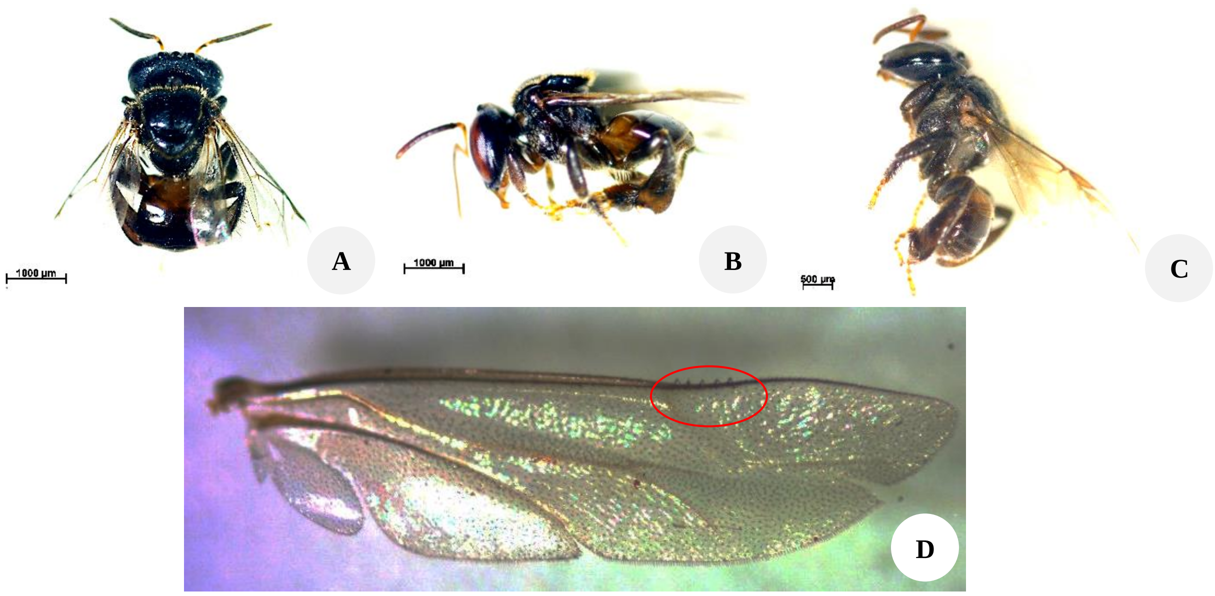


Figure 2. Morphology of *Tetragonula biroi*. A. *T. biroi* from Lowland; B. *T. biroi* from Midland; C. *T. biroi* from Highland; D. Hamuli of *T. biroi*

Tetragonula biroi has a blackish-brown body color with the characteristic of having five hamuli. It has dark brownish-black eyes, with compound eyes being brown and simple eyes being brownish-yellow with a hint of black. The color of the antennae is dark brownish-black, with 11 flagellomeres, where the first scape is brownish-yellow, the second to the ninth scapes are blackish-brown, and the tenth to eleventh scapes are slightly yellowish-brown. It has a pair of mandibles that are somewhat dark brown. The clypeus is covered with fine hairs (setae).

Thorax is in the area, and there is a shiny black propodeum without hairs. It has transparent front and back wings, dark brownish-black wing veins, bright black tegula, and a round shape. It has three pairs of legs, with the hind legs having different sizes. The legs have blackish-brown femurs, bright brownish tibia with slight darkening, and bright yellowish-brown basitarsus covered with branched setae.

Abdomen in the area, there are six tergites or segments that are dark brownish-black in color. Tergites one to two are brownish, while three to six are blackish-brown. The sternite is covered with fine setae. *T. biroi*'s abdomen does not have a sting; thus, this bee is called a stingless bee. As known, *T. biroi* bees belong to the group of stingless bees because they do not have a sting and are smaller in size than *Apis* honey bees (Mohammad et al. 2021).

Morphometric measurement of *T. biroi*

Based on morphometric measurements of *T. biroi* bees, it was found that three locations have different body part size characteristics. The differences in morphometric sizes at the three locations can be seen in Table 2. Significant differences exist, especially in the body length of *T. biroi* bees (Table 2). The influence of altitude at the three locations causes the structure of the bee's body parts to adapt. Adapting the bee's body parts indicates that *T. biroi* bees can live at certain altitudes and thrive in different conditions (Rachmawati et al. 2022). *T. biroi* is highly adaptive to environmental changes, which has led to its widespread distribution in many regions of Indonesia, especially in South Sulawesi.

Morphometric research on *T. biroi* bees is an important endeavor to understand the variations in the physical characteristics of these bees across various geographical locations. The analysis results indicate clustering in body size characteristics. The PC1 and PC2 values in the morphometric analysis are 99.99%, with the highest eigenvalue of PC1 being 5.056 for body length (BL) and PC2 being 0.091 for the length of the forewing including tegula (WL1). The formation of influential characteristics towards group formation is BL, followed by WL1, FWL, FWW, and HWL.

The distribution from Figure 3 shows the contribution of each morphometric variable to data variation. The relationship pattern between morphometric variables and data distribution also provides statistical insights into the morphometric variability of bees at different altitudes, as depicted in Figure 4. The relationship between bee body part sizes in a PCA biplot is generated to observe the relationship between variables and patterns along the graph (Tercel et al. 2018). Biplot aids in understanding the relationship patterns between variables and observation units.

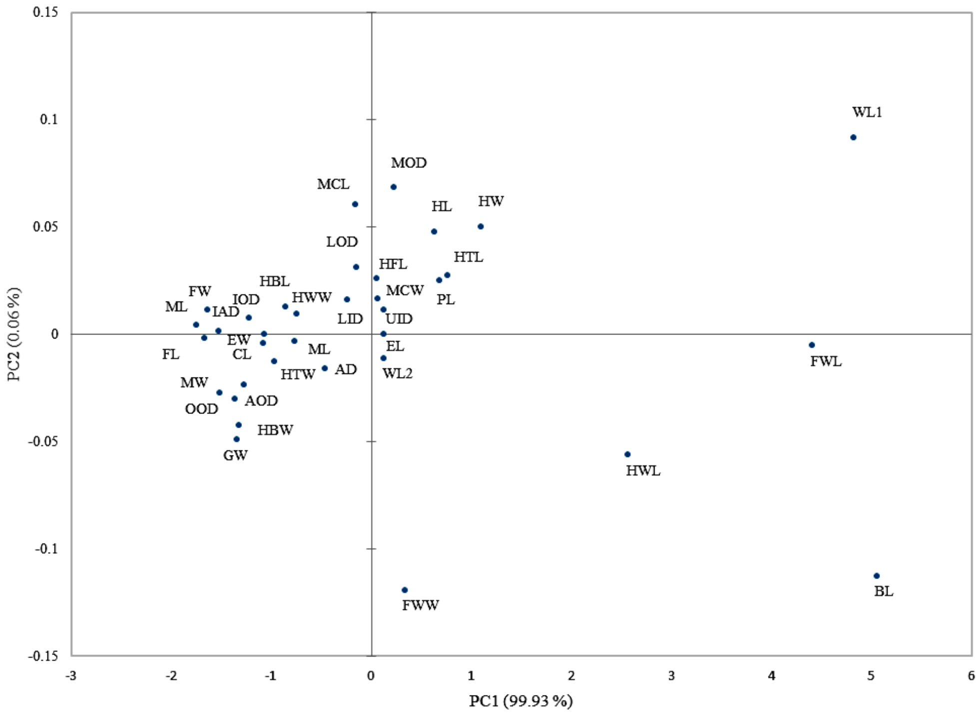


Figure 3. PCA results of *Tetragonula biroi* bees. The three groups' separate characters are BL, followed by WL1, FWL, FWW, and HWL. This can be observed from the distribution of the formed data. The more separate, the higher the role of characters in group formation. PC1 is the principal vector capturing the maximum variability in the data, followed by PC2, which captures the most significant remaining variability after PC1

PCA analysis can observe whether there are significant morphometric differences among bees living at different altitudes (Dukku et al. 2022). The results suggest that body length is highly substantial in response to environmental changes. These results also aid in understanding how *T. biroi* bees adapt to altitude changes. Morphological changes facilitate adaptation to varying ecological conditions (Maebe et al. 2021).

The research results indicate the angles between vectors of correlated characteristics among *T. biroi* bees at three elevations, which can be seen in Figure 5. The same species of bees have a very close and tight relationship (Carrie et al. 2017). The difference lies in the characteristics of body parts sizes, which is caused by the altitude of the habitat location. The location's altitude affects the availability of food sources and different climates (Nuraeni et al. 2021). Although they are in different altitudes, factors such as topography and dominant plant species contribute to the differences in physical dimensions between the two bee populations.

This study provides valuable insights into the local adaptation of *T. biroi* bees in South Sulawesi. These results could serve as a basis for further research to deepen our understanding of environmental factors influencing bee morphology and the potential implications for the ecosystem and the survival of these bees, which can be seen in Table 1 and Table 2. Morphometrics is crucial for understanding phenotypic variation within this bee population (Ostwald et al. 2023). This is important for understanding bee adaptation to environmental changes.

These findings have important ecological implications, especially in climate change and biodiversity (Table 2). Morphometrics aids in understanding how organisms can adapt to changing environments (Klingenberg 2014). It is important to remember that other factors, such as genetic variation or other environmental factors, may influence these results. This research provides a better understanding of morphometric changes in *T. biroi* bees at different altitudes, which could open the door to further study in morphometrics and bee ecology.

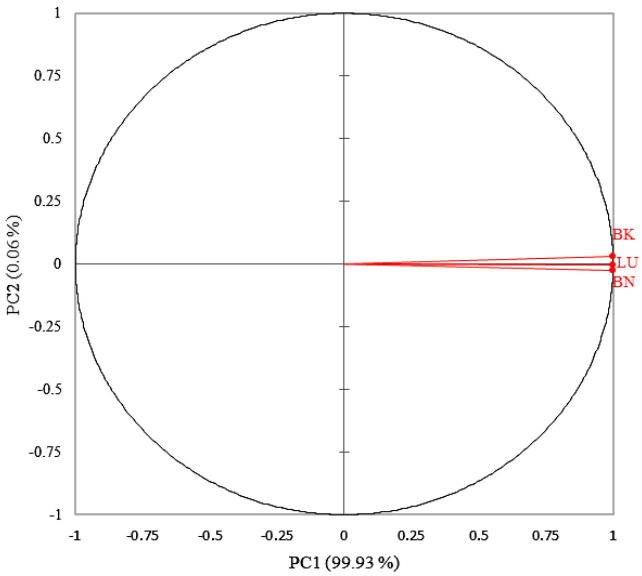


Figure 5. Dendrogram of variable clustering

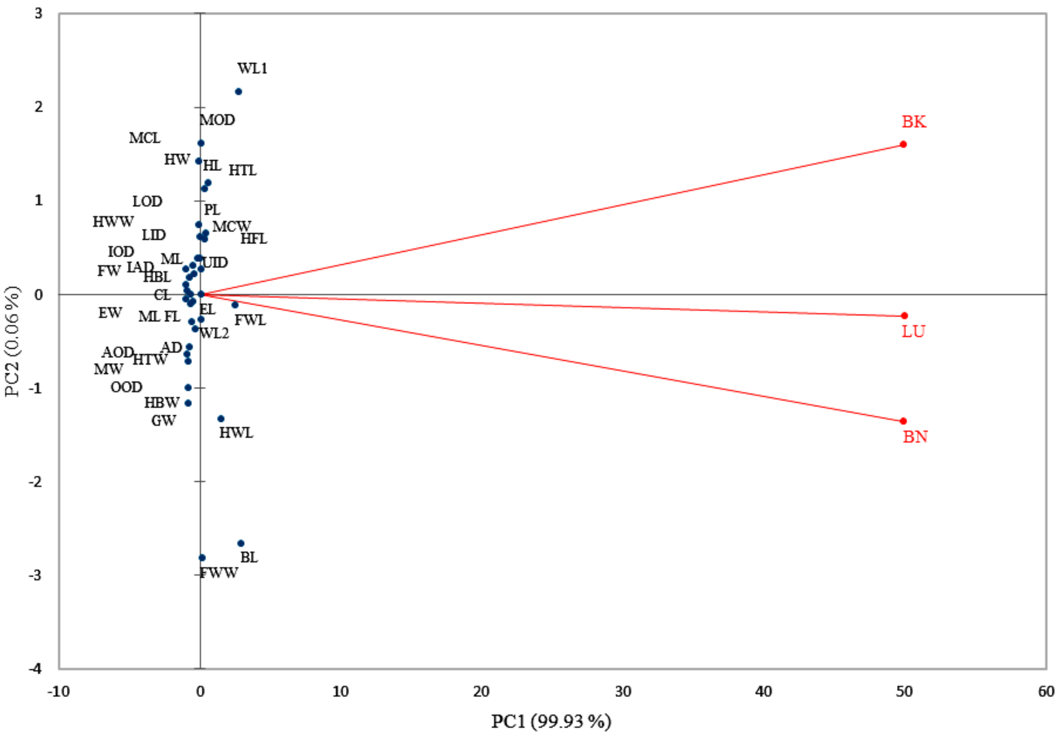


Figure 4. PCA biplot of *Tetragonula biroi* at three different altitudes, lowland (BK), midland (LU), highland (BN)

Discussion

The *T. biroi* bee, commonly known as the stingless bee, is a species of social bee found in the Southeast Asian region, including Indonesia. *T. biroi* bees are widely cultivated for products such as honey, propolis, and bee bread (Nuraeni et al. 2021). Generally, *T. biroi* bees are small, with an average length of 3.73 mm in lowland areas, 3.90 mm in midland areas, and 4.09 mm in highland areas. They have a few fine hairs on some parts of their bodies. This slightly differs from the findings of Suriawanto et al. (2017), who reported the body length of *T. biroi* bees to be between 4.0 and 4.17 mm. The body size of *T. biroi* bees is influenced by environmental factors in their habitat (Prastiyo et al. 2023). They have a predominantly blackish-brown body color with yellow markings on certain parts, such as the abdomen and antennae.

Tetragonula biroi bees are characterized by having five hamuli and a few fine hairs on some parts of their bodies. Hamuli are hardened hairs on the rear wings (Purwanto et al. 2022). One morphological characteristic distinguishing *T. biroi* bees is their long and slender proboscis structure. This proboscis aids them in collecting nectar and consuming other liquid food. These bees also have relatively small wings, making them less efficient in long-distance flight than other bee species.

Morphological and morphometric studies on *T. biroi* bees living at different altitudes in South Sulawesi are essential contributions to understanding fauna adaptation to the environment (Figure 6). The morphology of *T. biroi* bees can encompass various aspects, including body size, wing length, antenna proportions, and other characteristics that may change in response to different environmental conditions (Jezierski et al. 2023). This research is significant because South Sulawesi has a diverse topography, ranging from lowlands to high mountains, allowing for studying bee adaptations at different altitudes.

The results of morphometric studies on *T. biroi* bees in South Sulawesi show significant differences in several morphological parameters between populations living at different altitudes (Table 2). Morphological and morphometric characteristics at different altitudes can lead to bee adaptations (Pratama et al. 2023). Bees at low altitudes have smaller bodies with shorter wings than those in highlands. This indicates the morphological adaptations of bees according to different environmental conditions (Engel et al. 2023).

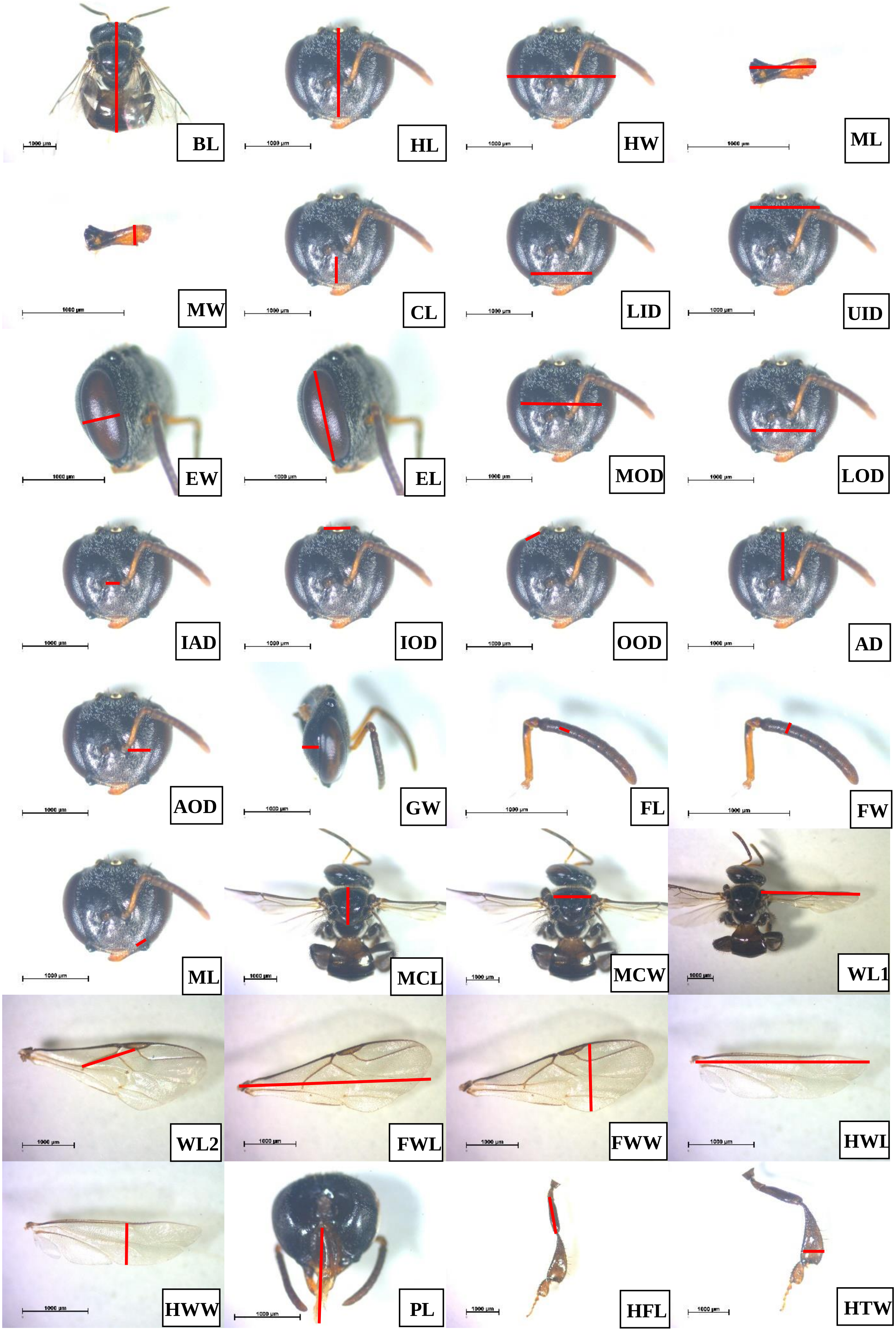
This research concludes that *T. biroi* bees exhibit morphological adaptation patterns corresponding to their altitude of residence in South Sulawesi (Table 2). The observed morphometric changes illustrate the bees' ability to adapt to environmental changes. Morphometric measurements on bees can depict adaptation patterns to specific regional conditions (Ribeiro et al. 2019). This study provides important insights into the ecology and evolution of bees and the importance of protecting genetic diversity and species in various habitats.

In the context of conservation, further understanding of the morphological adaptation of *T. biroi* bees can aid in designing more effective preservation strategies (Crone et al. 2022). Efforts to protect different habitats in South Sulawesi can help maintain genetic diversity within bee populations, supporting ecosystem sustainability and the ecosystem services bees provide (Chantawannakul 2018). Therefore, further research is essential to support conservation efforts and better understand fauna adaptation to environmental changes. Studies on bee’s physical structure and morphometrics at different altitudes provide valuable insights into how these insects adapt to the environmental (Ji et al. 2023).

This research includes an analysis of the physical body structure of bees, including body size, color, and proportions that may change in response to environmental changes. One interesting finding is that *T. biroi* bees living at lower altitudes tend to have smaller body sizes than those living at higher altitudes (Table 2). The warmer environmental conditions in lowland areas may drive the evolution of smaller bee bodies to be more efficient in utilizing available resources (Herrera et al. 2023).

This study notes that altitude factors significantly influence various size proportions in *T. biroi* bees. This could be an adaptation to enhance flying ability at higher altitudes, where the air is thinner or winds are more robust. Morphometric analysis can also provide insights into changes in specific body part proportions, such as the head, thorax, and abdomen. Such adaptations may have important implications for the biological functions of *T. biroi* bees, such as foraging ability, maintaining body temperature, or interacting with their surrounding environment. The results of this research can also provide a better understanding of the ecological dynamics of *T. biroi* bees at different altitudes. They understand how their morphology changes can predict how bee populations will respond to climate change or increased human activity in higher regions (Montero-Mendieta et al. 2019). Changes in body size of *T. biroi* bees in colder regions include larger and longer wings compared to those living at lower altitudes (Hines et al. 2022).

This research provides insights into the potential changes in interspecies interactions in the ecosystem where *T. biroi* bees live. Changes in their morphology can affect symbiotic relationships with the plants they pollinate or competition with other insect species sharing the same habitat. Morphological and morphometric studies of *T. biroi* bees at different altitudes provide insights into their specific adaptations to changing environments and contribute to a broader understanding of the ecology and ecosystem dynamics in which they live.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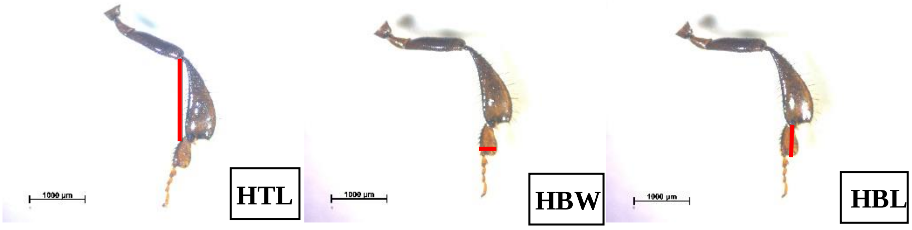

Figure 6. Morphometric of *Trigona biroi*; BL: Body length; HL: Head length; HW: Head width; ML: Mandible length; MW: Mandible width; CL: Clypeus length; LID: Lower interocular distance; UID: Upper interocular distance; EW: Eye width; EL: Eye length; MOD: Maximum interorbital distance; LOD: Lower interorbital distance; IAD: Interantennal distance; IOD: Interocellar distance; OOD: Ocellocular distance; AD: Antennocellar distance; AOD: Antennocular distance; GW: Gena width; FL: Flagellomer IV length; FW: Flagellomer IV width; ML: Malar length; MCL: Mesoscutum length; MCW: Mesoscutum width; WL1: Length of fore wing including tegula; WL2: Distance between M-Cu bifurcation; FWL: Fore wing length; FWW: Fore wing width; HWL: Hind wing length; HWW: Hind wing width; PL: Proboscis length; HFL: Hind femur length; HTW: Hind tibia width; HTL: Hind tibia length; HBW: Hind basitarsus width; HBL: Hind basitarsus length

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