BIODIVERSITAS
Volume 25, Number 5, May 2024
Pages: 2290-2306

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250547

Taxonomic study on selected species of stingless bees (Hymenoptera: Apidae: Meliponini) in Sulawesi Island, Indonesia

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Manuscript received: 22 March 2024. Revision accepted: 29 May 2024.

Abstract. *Trianto M, Arisuryanti T, Purwanto H, Ubaidillah R. 2024. Taxonomic study on selected species of stingless bees (Hymenoptera: Apidae: Meliponini) in Sulawesi Island, Indonesia. Biodiversitas 25: 2290-2306.* Stingless bees are strong candidates as alternative crop pollinators. They are found throughout the tropics, with the exception of the Pacific islands. There are three tropical regions in the world, namely the tropical Americas (Neotropic), Sub-Saharan Africa (Afrotropic), and Indoaustralian (Austroasiatic) region. In this research, we explored the morphological and morphometric characteristics of stingless bees in Sulawesi Island, Indonesia. The genera and species identification of stingless bees were based on morphological characters and coloration, such as the structure and color of the antenna, head, thorax, wing, leg and abdomen. Morphological and morphometric identification of 10 species of stingless bees consisting of five genera, namely the genera *Heterotrigona*, *Homotrigona*, *Lepidotrigona*, *Tetragonula*, and *Wallacetrigona*. The genus *Tetragonula* consists of six small species (<4 mm), namely *T. biroi*, *T. clypearis*, *T. fuscobalteata*, *T. laeviceps*, *T. pagdeni*, and *T. sapiens*. The genera *Heterotrigona*, *Homotrigona*, *Lepidotrigona*, and *Wallacetrigona* are a group of large stingless bees (>4 mm), each consisting of one species, namely *H. itama*, *H. canifrons*, *L. terminata*, and *W. incisa*. *H. itama* and *H. canifrons* are new records on Sulawesi Island. These species are found in Lore Lindu National Park (TNLL). Until 2023, these species were only found in Java, Kalimantan and Sumatra. This research can be used as a guide in the identification and validation of stingless bee species on Sulawesi Island.

Keywords: Conservation, *klanceng*, morphological, morphometric

INTRODUCTION

Stingless bees belong to the family Apidae, tribe Meliponini and are a cosmopolitan group of bees in tropical and sub-tropical areas (Toledo-Hernández et al. 2022). The regional distribution of stingless bees includes the Neotropical region (Southern Mexico to Central America and South America), the Paleotropical or Afrotropical region (most of Africa except North Africa, the Sahara Desert and islands in the Western Indian Ocean), and the Australasian region (Indo-Malayan, Wallacea, and Indo-Austalia) (Rahman et al. 2018; Ali and Heaney 2021) and these bees have the highest species diversity among other eusocial bee species, with approximately 600 species recorded (Engel et al. 2023). Generally, stingless bees are small to medium-sized with vestigial (non-functional) stingers, living in colonies (social) and collecting pollen (Vollet-Neto et al. 2017). Some species use biting and swarming to defend against danger. Nests can be found below ground, in hollow tree hollows, in wood cavities, in hollow bamboo trees, and cracks in the walls of houses. Each stingless bee species has a preference for certain cavities depending on the species and type of environment (Dollin et al. 1997; Engel et al. 2019; Taye 2020).

The structure of a stingless bee nest starts from the outer entrance, the inner entrance, the brood cells, the honey pots and the pollen (bee bread) (Mohammad et al. 2021). Together with the morphology of other nest parts, such as the cerumen and bitumen layers, they form an important nest character that can be used to identify stingless bee species. Stingless bee nest entrances vary in shape, texture, length, ornamentation, and color (Kelly et al. 2014; Suriawanto et al. 2017); variations in color, shape, and size of the pollen pots and honey pots, as well as the arrangement pattern of the brood cells (Sayusti et al. 2021). Stingless bees have high prospects as pollinators of agricultural crops due to their small body size, high foraging activity, and high adaptation to environmental stress (Hrncir et al. 2019). Stingless bees play an important role in pollinating various types of plants (Michener 2007), including *Trigona* sp. on mustard greens (Mishra et al. 2022), *Tetragonula laeviceps* on strawberries (*Fragaria* x *annanassa*) and *Heterotrigona itama* on melons (*Cucumis melo*) in greenhouses (Atmowidi et al. 2022).

From a taxonomic aspect, there are different numbers of species in each member classified as a single species due to their morphological similarity within the tribe Meliponini. This is due to the large number of taxonomic revisions and cryptic species. There are 400 species and at least 250

species of stingless bees have been described in South and Central America. About 50 species live in South Asia and Malaysia; 20 live in Australia, Papua New Guinea, and the Philippines; and 40 species are endemic to Africa (Grüter 2020). Michener (2007) reported that more than 374 species of stingless bees are divided into 26 genera. Another source states that there are more than 397 species of stingless bees from 33 genera that are members of the tribe Meliponini (Moure et al. 2007). Indonesia has 52 species of stingless bees distributed in Sumatra (27 species), Java (13 species), Borneo (34 species), Bali (1 species), Nusa Tenggara (1 species), Maluku (4 species), Irian Jaya (Papua) (12 species), and Sulawesi (8 species). Six small stingless bee species have been reported in Sulawesi from the genus *Tetragonula: Tetragonula biroi, Tetragonula clypearis, Tetragonula fuscobalteata, Tetragonula laeviceps, Tetragonula pagdeni,* and *Tetragonula sapiens*. In addition, two larger stingless bees have been reported in Sulawesi: *Lepidotrigona terminata*; and the endemic species *Geniotrigona incisa*, which was renamed *Wallacetrigona incisa* and has a restricted distribution in mountainous areas in Sulawesi (Trianto et al. 2023). In this research, we explored the morphological and morphometric characteristics of stingless bees in Sulawesi Island, Indonesia.

MATERIALS AND METHODS

Study area

This research was conducted from November 2022 to April 2023 in six provinces located on Sulawesi Island, namely West Sulawesi, South Sulawesi, Central Sulawesi, Southeast Sulawesi, North Sulawesi, and Gorontalo (Table 1, Figure 1).

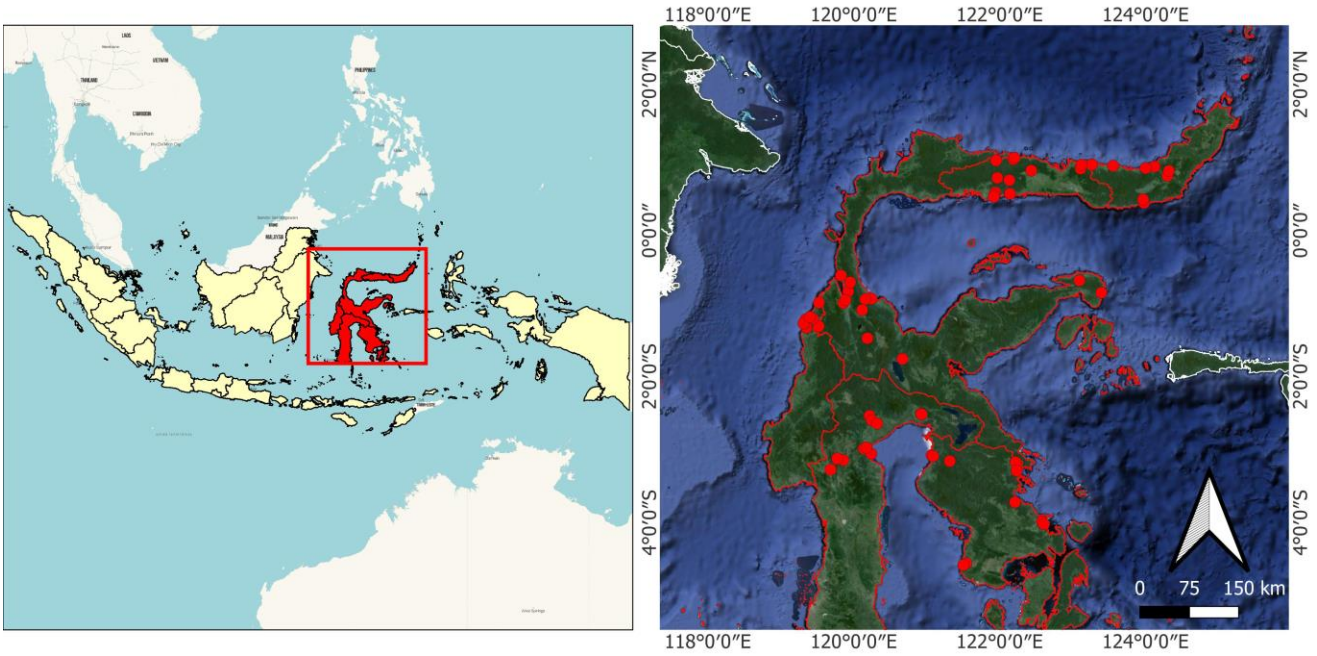

Figure 1. Location study of research in Sulawesi Island, Indonesia

Table 1. Sites of collection of stingless bees in Sulawesi Island, Indonesia

Sites	Districts	GPS	Species
Central Sulawesi Province			
Lore Lindu National Park	Sigi	1°28’29”S, 120°11’20’’E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Heterotrigona itama* *Homotrigona canifrons* *Lepidotrigona terminata* *Wallacetrigona incisa*
Ranjuri Forest	Sigi	0°59’30”S, 119°51’33”E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Lepidotrigona terminata*
Kalukubula	Sigi	0°57’13”S, 119°53’14”E	*Tetragonula fuscobalteata*
Berdikari	Sigi	1°05’17”S, 120°07’04”E	*Wallacetrigona incisa*
Lero	Donggala	0°36’57”S, 119°49’38”E	*Tetragonula laeviceps* *Tetragonula fuscobalteata* *Lepidotrigona terminata*

Nupabomba	Donggala	0°42’31”S, 119°57’17”E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Tetragonula laeviceps*
Nambaru	Parigi Moutong	0°56’20”S, 120°140’08”E	*Tetragonula sapiens* *Tetragonula laeviceps*
Dolago	Parigi Moutong	0°56’20”S, 120°09’43”E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Tetragonula laeviceps* *Tetragonula sapiens* *Lepidotrigona terminata*
Tondo	Palu	0°50’00”S, 119°55’36”E	*Tetragonula fuscobalteata*
Bungkutnyo Tompotika	Banggai	0°41’05”S, 123°05’44”E	*Tetragonula fuscobalteata* *Tetragonula sapiens*
Luok	Banggai	0°51’03”S, 123°23’51”E	*Tetragonula clypearis* *Lepidotrigona terminata*
Batu Rata	Buol	0°58’09”S, 121°57’45”E	*Tetragonula pagdeni* *Tetragonula fuscobalteata* *Tetragonula laeviceps*
Tentena	Poso	1°45’31”S, 120°40’13”E	*Tetragonula fuscobalteata* *Tetragonula sapiens* *Tetragonula clypearis* *Lepidotrigona terminata* *Wallacetrigona incisa*
West Sulawesi Province			
Karya Bersama	Pasangkayu	1°13’07”S, 119°20’28”E	*Tetragonula clypearis* *Tetragonula fuscobalteata*
Ako	Pasangkayu	1°11’10”S, 119°24’02”E	*Tetragonula clypearis* *Tetragonula sapiens* *Tetragonula clypearis*
Pasangkayu	Pasangkayu	1°12’14”S, 119°26’33”E	*Lepidotrigona terminata*
Tikke	Pasangkayu	1°19’38”S, 119°21’09”E	*Tetragonula clypearis* *Tetragonula fuscobalteata*
Pedanda	Pedongga	1°15’29”S, 119°21’20”E	*Tetragonula fuscobalteata* *Tetragonula sapiens* *Tetragonula clypearis* *Lepidotrigona terminata*
Batu Oge	Tikke Raya	1°16’16”S, 119°18’49”E	*Tetragonula sapiens* *Tetragonula clypearis*
Bambaira	Bambaira	0°59’11”S, 119°31’30”E	*Tetragonula clypearis* *Tetragonula fuscobalteata*
Tobadak	Mamuju Tengah	1°18’38”S, 119°31’17”E	*Tetragonula clypearis* *Tetragonula laeviceps* *Tetragonula sapiens* *Lepidotrigona terminata*
South Sulawesi Province			
Bumi Harapan	Luwu Utara	2°38’32”S, 120°19’17”E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Tetragonula sapiens* *Lepidotrigona terminata*
Sassa Tarobok	Luwu Utara	2°32’12”S, 120°13’09”E	*Tetragonula clypearis* *Tetragonula fuscobalteata*
Salassa	Luwu Utara	2°35’53”S, 120°14’56”E	*Tetragonula fuscobalteata* *Tetragonula sapiens* *Lepidotrigona terminata*
Balirejo	Luwu Timur	2°30’55”S, 120°55’59”E	*Tetragonula sapiens*
Wanasari	Luwu Timur	2°30’30”S, 120°55’23”E	*Tetragonula sapiens* *Lepidotrigona terminata*
Lembang Batu Sura	Tana Toraja	3°07’12”S, 119°46’33”E	*Tetragonula biroi* *Tetragonula fuscobalteata* *Tetragonula laeviceps* *Tetragonula sapiens*
Lembang To’ Pao	Tana Toraja	3°07’56”S, 119°46’38”E	*Wallacetrigona incisa*
Lembang Bau	Tana Toraja	3°16’23”S, 119°41’01”E	*Tetragonula fuscobalteata* *Wallacetrigona incisa*
Lembang Randanan	Tana Toraja	3°08’34”S, 119°51’33”E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Tetragonula laeviceps* *Tetragonula sapiens*

Barowa	Luwu	3°03’24”S, 120°14’32”E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Tetragonula sapiens* *Lepidotrigona terminata*
Balandai	Palopo	2°58’13”S, 120°10’30”E	*Tetragonula sapiens* *Tetragonula clypearis* *Tetragonula fuscobalteata* *Tetragonula laeviceps*
Buntu Datu	Palopo	2°59’12”S, 120°08’25”E	*Tetragonula sapiens* *Tetragonula laeviceps*
North Sulawesi Province			
Batu Bantayo	Minahasa Utara	1°38’55”S, 125°00’34”E	*Tetragonula clypearis* *Tetragonula sapiens*
Batulintik	Kepulauan Sangihe	3°39’02”S, 125°33’02”E	*Tetragonula clypearis* *Tetragonula fuscobalteata* *Tetragonula sapiens*
Bigo	Bolaang Mongondow Utara	0°54’08”S, 123°16’00”E	*Tetragonula fuscobalteata* *Tetragonula sapiens*
Ampeng Sembeka	Bolaang Mongondow Utara	2°55’44”S, 125°08’46”E	*Tetragonula clypearis* *Tetragonula fuscobalteata*
Apado	Bolaang Mongondow	0°48’57”S, 124°19’25”E	*Tetragonula sapiens*
Langagon	Bolaang Mongondow	0°51’59”S, 121°05’22”E	*Tetragonula sapiens*
Molibagu	Bolaang Mongondow Selatan	0°25’17”S, 123°58’17”E	*Tetragonula fuscobalteata* *Tetragonula sapiens*
Toluaya	Bolaang Mongondow Selatan	0°22’42”S, 123°58’51”E	*Tetragonula sapiens*
Gogagoman	Kotamobagu	0°44’46”S, 124°18’09”E	*Tetragonula laeviceps*
Southeast Sulawesi Province			
Batu Api	Kolaka Utara	3°05’17”S, 121°05’22”E	*Tetragonula fuscobalteata* *Tetragonula laeviceps*
Bukit Baru	Kolaka Utara	3°08’50”S, 121°16’15”E	*Tetragonula laeviceps* *Tetragonula sapiens*
Latowu	Kolaka Utara	3°04’34”S, 121°04’12”E	*Tetragonula fuscobalteata*
Abola	Konawe Utara	3°43’06”S, 122°12’45”E	*Tetragonula fuscobalteata*
Alenggo	Konawe Utara	3°17’15”S, 122°14’03”E	*Tetragonula fuscobalteata* *Tetragonula laeviceps* *Tetragonula sapiens*
Culambatu	Konawe Utara	3°10’14”S, 122°13’18”E	*Tetragonula sapiens* *Tetragonula fuscobalteata*
Toari	Kolaka	4°33’19”S, 121°32’42”E	*Tetragonula laeviceps* *Tetragonula sapiens*
Lakito	Kolaka	4°34’42”S, 121°30’20”E	*Tetragonula laeviceps*
Abeli	Kendari	4°01’09”S, 122°36’35”E	*Tetragonula fuscobalteata*
Lapulu	Kendari	3°59’02”S, 122°34’55”E	*Tetragonula fuscobalteata*
Gorontalo Province			
Buntulia Tengah	Pohuwato	0°29’17”S, 121°56’12”E	*Tetragonula fuscobalteata* *Tetragonula laeviceps* *Lepidotrigona terminata*
Hulawa	Pohuwato	0°35’24”S, 123°03’03”E	*Tetragonula fuscobalteata* *Tetragonula sapiens*
Karya Indah	Pohuwato	0°48’35”S, 122°27’27”E	*Tetragonula laeviceps* *Tetragonula sapiens* *Lepidotrigona terminata*
Mananggu	Boalemo	0°39’59”S, 122°08’16”E	*Tetragonula fuscobalteata*
Buti	Boalemo	0°30’19”S, 122°08’21”E	*Tetragonula fuscobalteata*
Tabulo	Boalemo	0°30’17”S, 122°08’21”E	*Tetragonula fuscobalteata* *Lepidotrigona terminata*
Bulili	Gorontalo	0°27’26”S, 121°55’21”E	*Tetragonula clypearis* *Tetragonula sapiens*
Mohiyolo	Gorontalo	0°49’18”S, 122°25’39”E	*Tetragonula clypearis* *Tetragonula sapiens* *Lepidotrigona terminata*
Biau	Gorontalo Utara	0°58’56”S, 119°21’09”E	*Tetragonula clypearis*
Bintana	Gorontalo Utara	0°50’18”S, 123°06’51”E	*Tetragonula clypearis*
Bohulo	Gorontalo Utara	0°41’40”S, 123°03’08”E	*Tetragonula clypearis*

Procedures

Observation, collection, and preservation of stingless bees at sampling sites

Observation of sampling sites was carried out using the purposive sampling method. Collection of stingless bees from several research areas was carried out in two ways, namely collection in natural habitats and farming/cultivation areas with the aim of obtaining comprehensive data, both data related to stingless bee species native to Sulawesi or invasive alien species. The collection of the stingless bees was conducted on two consecutive days. At seven o'clock on the first day, a sugar solution was sprayed on one square meter of shrubs at the determined observation points. On the second day, the stingless bees visiting the plot were captured using a sweep net. The catching activities were conducted three times per day at 07.00 am, 13.00 pm, and 16.00 pm. The collection of the stingless bees is done on the second day in order to provide more chances for stingless bees without stings coming to the study area. Furthermore, the stingless bee individuals obtained were put into a bottle containing 95% ethanol for morphological identification. Before morphological identification, stingless bee specimens are mounted so that important characters on the bee body are easily observed (Trianto and Purwanto 2020a, 2020b; Purwanto and Trianto 2021).

Identification of stingless bees

The stingless bee samples were deposited and identified at the Laboratory of Entomology, Faculty of Biology, Universitas Gadjah Mada, Indonesia. The identification of stingless bees based on morphological characters follows Sakagami (1978), Sakagami and Inoue (1987), Sakagami et al. (1990), Dollin et al. (1997), and Smith (2012). Furthermore, as many as 34 morphological characters of stingless bee were selected as parameters for morphometric measurement, namely Body Length (PT), Head Length (PK), Head Width (LK), Mandible Length (PM), Mandible Widht (LM), Clypeus Length (PC), Lower Interocular Distance (JIB), Upper Interocular Distance (JIA), Eye Width (LM), Eye Length (PM), Maximum Interorbital Distance (JMI), Lower Interorbital Distance (LOD), Interantennal Distance (JI), Interocellar Distance (IOD), Ocellocular Distance (JO), Antennocellar Distance (JA), Antennocullar Distance (JAO), Gena Width (LG), Length of Flagellomere IV (PF), Width of Flagellomere IV (LF), Malar Length (PML), Mesoscutum Length (PMS), Mesoscutum Width (LMS), Length of Forewing Including Tegula (WL1), Distance Between M-Cu Bifurcation (WL2), Fore Wing Length (PSD), Fore Wing Width (LSD), Hind Wing Length (PSB), Hind Wing Width (LSB), Hind Femur Length (PJB), Hind Tibia Width (LTB), Hind Tibia Length (PTB), Hind Basitarsus Width (LBB), and Hind Basitarsus Length (PBB) (Table 2; Table 3). Furthermore, the observed characters were made into the Sulawesi stingless bee identification key. Morphological identification was performed under a microscope OLYMPUS SZ61 with OptiLab software.

Data analysis

Principal Component Analysis (PCA) was performed using the PAST4 program based on the measurements of 34 morphological characteristics of stingless bees. The cumulative Eigenvalue of the first two Principal Components (PC) (>70%) was tested in the interpretation of the PCA output. The resulting character loadings on PC1 and PC2 were used to determine the most influential characters in species separation. PC1 and PC2 values were then plotted for visualization of the analysis results (Yudha et al. 2019).

RESULTS AND DISCUSSION

The stingless bees' morphology

Morphological identification of 10 species of stingless bees consisting of five genera, namely the genera *Heterotrigona*, *Homotrigona, Lepidotrigona, Tetragonula*, and *Wallacetrigona*. The genus *Tetragonula* consists of six small species (<4 mm), namely *T. biroi, T. clypearis, T. fuscobalteata, T. laeviceps, T. pagdeni*, and *T. sapiens*. The genera *Heterotrigona, Homotrigona, Lepidotrigona,* and *Wallacetrigona* are a group of large stingless bees (>4 mm), each consisting of one species, namely *H. itama, H. canifrons, L. terminata*, and *W. incisa* (Figure 2).

Description of genera

Heterotrigona (Schwarz, 1939*)*

The tegument is shiny, smooth and sharp. The mandible consists of one tooth, the malar distance being longer than the flagellomer diameter. Gena's eyes widened. Short scutellum, propodeum rather short; smooth and hairless in the basal area. Hamuli consists of seven. Rear tibia with hair on the posterior edge of the tibia is short and plumose (branched). The rear basitarsus is wider than 1/2 the length of the rear basitarsus. The abdomen is narrower than the thorax and elongated.

Homotrigona (Moure, 1961)

Smooth tegument. The mandible consists of two large teeth; the malars are moderately spaced, almost along the diameter of the flagellomer. Gena is round, wider than the eyes. Long Scutellum, propodeum medium-sized smooth, and smooth basal area. Hamuli consists of seven. Rear tibia with hair from the posterior edge is plumose (branched) and quite long. The posterior basitarsus is narrower than half the width of the tibia. The abdomen is narrower than the thorax and rather short.

Lepidotrigona (Schwarz, 1939)

The tegument looks like layers. The mandible consists of two small teeth; the malar distance is medium, equal to the diameter of the flagellomer. Gena is round, narrower than compound eyes. Scutellum is very short, propodeum is curve, and basal area is reticulate. Hamuli consists of six. Rear tibia with very large corbicula; thick posterior edge hair, short, and simple (not branched). The hind basitarsus is wider than half the length of the basitarsus behind. The abdomen is narrower than the thorax and elongated.

Table 2. 34 morphological feature measurements of stingless bee small body sized (<4 mm) (mm)

Body characters	Morphometric of stingless bees (mm)											
	T. biroi **(n = 20)**		***T. clypearis*** **(n = 130)**		***T. fuscobalteata*** **(n = 190)**		***T. laeviceps*** **(n = 85)**		***T. pagdeni*** **(n = 20)**		***T. sapiens*** **(n = 160)**	
	Min-Max	**Mean±SD**	**Min-Max**	**Mean±SD**	**Min-Max**	**Mean±SD**	**Min-Max**	**Mean±SD**	**Min-Max**	**Mean±SD**	**Min-Max**	**Mean±SD**
Body Lenght (PT)	3.89-3.92	3.90±0.03	3.74-3.78	3.75±0.03	3.55-3.58	3.56±0.03	3.44-3.46	3.45±0.02	3.95-3.98	3.96±0.02	3.80-3.82	3.82±0.03
Head Length (PK)	1.47-1.50	1.48±0.02	1.26-1.30	1.27±0.02	1.14-1.16	1.16±0.02	1.36-1.38	1.37±0.01	1.50-1.53	1.51±0.03	1.48-1.53	1.50±0.03
Head Width (LK)	1.83-1.86	1.84±0.02	1.64-1.68	1.65±0.02	1.54-1.56	1.56±0.02	1.63-1.65	1.64±0.01	1.95-1.98	1.96±0.03	1.84-1.89	1.86±0.03
Mandible Length (PM)	0.59-0.62	0.60±0.02	0.58-0.62	0.59±0.02	0.56-0.58	0.58±0.02	0.64-0.66	0.65±0.01	0.72-0.75	0.73±0.02	0.68-0.73	0.70±0.03
Mandible Widht (LM)	0.25-0.28	0.26±0.02	0.23-0.27	0.24±0.03	0.18-0.20	0.20±0.02	0.23-0.25	0.24±0.02	0.27-0.30	0.28±0.02	0.25-0.30	0.27±0.03
Clypeus Length (PC)	0.49-0.52	0.50±0.01	0.47-0.51	0.48±0.04	0.43-0.45	0.45±0.03	0.46-0.48	0.47±0.03	0.50-0.53	0.51±0.01	0.50-0.55	0.52±0.01
Lower Interocular Distance (JIB)	0.93-0.96	0.94±0.02	0.85-0.89	0.86±0.02	0.75-0.79	0.77±0.01	0.90-0.92	0.91±0.01	0.94-0.97	0.95±0.03	1.05-1.10	1.07±0.03
Upper Interocular Distance (JIA)	1.07-1.10	1.08±0.02	0.97-1.01	0.98±0.03	0.92-0.96	0.94±0.04	1.02-1.04	1.03±0.02	1.09-1.12	1.10±0.03	1.09-1.14	1.11±0.04
Eye Width (LM)	0.49-0.52	0.50±0.04	0.48-0.52	0.49±0.03	0.43-0.47	0.45±0.03	0.42-0.44	0.43±0.02	0.49-0.52	0.50±0.03	0.54-0.59	0.56±0.03
Eye Length (PM)	1.27-1.30	1.28±0.03	1.15-1.19	1.16±0.04	1.04-1.08	1.06±0.03	1.04-1.06	1.05±0.03	1.29-1.32	1.30±0.02	1.28-1.33	1.30±0.02
Maximum Interorbital Distance (JMI)	1.23-1.26	1.24±0.01	1.14-1.18	1.15±0.03	1.04-1.08	1.06±0.02	1.15-1.17	1.16±0.04	1.25-1.28	1.26±0.01	1.29-1.34	1.31±0.02
Lower Interorbital Distance (LOD)	0.94-0.97	0.95±0.02	0.81-0.85	0.82±0.03	0.75-0.79	0.77±0.03	0.92-0.94	0.93±0.02	0.96-0.99	0.97±0.02	1.02-1.07	1.04±0.02
Interantennal Distance (JI)	0.18-0.21	0.19±0.01	0.18-0.22	0.19±0.04	0.18-0.22	0.20±0.01	0.20-0.22	0.21±0.03	0.20-0.23	0.21±0.01	0.19-0.24	0.21±0.03
Interocellar Distance (IOD)	0.20-0.23	0.21±0.02	0.20-0.24	0.21±0.21	0.20-0.24	0.22±0.01	0.25-0.27	0.26±0.01	0.22-0.25	0.23±0.02	0.22-0.27	0.24±0.03
Ocellocular Distance (JO)	0.23-0.26	0.24±0.02	0.22-0.26	0.23±0.03	0.21-0.25	0.23±0.01	0.24-0.26	0.25±0.02	0.25-0.28	0.26±0.02	0.27-0.32	0.29±0.02
Antennocellar Distance (JA)	0.68-0.71	0.69±0.01	0.65-0.69	0.66±0.03	0.62-0.66	0.64±0.02	0.68-0.70	0.69±0.02	0.70-0.73	0.71±0.01	0.75-0.80	0.77±0.02
Antennocullar Distance (JAO)	0.29-0.32	0.30±0.01	0.3-0.34	0.31±0.03	0.32-0.36	0.34±0.03	0.31-0.33	0.32±0.02	0.31-0.34	0.32±0.01	0.30-0.35	0.32±0.01
Gena Width (LG)	0.24-0.27	0.25±0.01	0.25-0.29	0.26±0.04	0.28-0.32	0.30±0.02	0.26-0.28	0.27±0.03	0.26-0.29	0.27±0.01	0.26-0.31	0.28±0.01
Length of Flagellomere IV (PF)	0.13-0.16	0.14±0.01	0.13-0.17	0.14±0.02	0.12-0.16	0.14±0.02	0.13-0.15	0.14±0.01	0.15-0.18	0.16±0.01	0.15-0.20	0.17±0.02
Width of Flagellomere IV (LF)	0.14-0.17	0.15±0.03	0.14-0.18	0.15±0.03	0.13-0.17	0.15±0.02	0.14-0.16	0.15±0.02	0.15-0.18	0.16±0.03	0.14-0.19	0.16±0.01
Malar Length (PML)	0.05-0.08	0.06±0.03	0.05-0.09	0.06±0.04	0.05-0.09	0.07±0.01	0.08-0.10	0.09±0.02	0.04-0.07	0.05±0.03	0.06-0.11	0.08±0.01
Mesoscutum Length (PMS)	0.88-0.91	0.89±0.04	0.75-0.79	0.76±0.04	0.66- 0.70	0.68±0.04	0.91-0.93	0.92±0.02	0.90-0.93	0.91±0.04	0.97-1.02	0.99±0.01
Mesoscutum Width (LMS)	1.18-1.21	1.19±0.03	1.00-1.04	1.01±0.03	0.97-1.01	0.99±0.01	1.08-1.10	1.09±0.02	1.19-1.22	1.20±0.02	1.32-1.37	1.34±0.01
Length of Forewing Including Tegula (WL1)	4.13-4.16	4.14±0.02	3.74-3.78	3.75±0.03	3.54-3.58	3.56±0.01	3.77-3.79	3.78±0.04	4.15-4.18	4.16±0.03	4.19-4.24	4.21±0.02
Distance Between M-Cu Bifurcation (WL2)	1.08-1.11	1.09±0.03	1.05-1.09	1.06±0.03	1.00-1.04	1.02±0.02	1.17-1.19	1.18±0.03	1.09-1.12	1.10±0.02	1.19-1.24	1.21±0.02
Fore Wing Length (PSD)	3.76-3.79	3.77±0.04	3.58-3.62	3.59±0.03	3.36-3.40	3.38±0.01	3.63-3.65	3.64±0.03	3.78-3.81	3.79±0.03	3.94-3.99	3.96±0.02
Fore Wing Width (LSD)	1.17-1.20	1.18±0.02	1.16-1.20	1.17±0.03	1.17-1.21	1.19±0.02	1.32-1.34	1.33±0.02	1.19-1.22	1.20±0.03	1.39-1.44	1.41±0.03
Hind Wing Length (PSB)	2.56-2.59	2.57±0.02	2.35-2.39	2.36±0.03	2.16-2.20	2.18±0.02	2.47-2.49	2.48±0.03	2.57-2.60	2.58±0.02	2.79-2.84	2.81±0.03
Hind Wing Width (LSB)	0.59-0.62	0.60±0.03	0.50-0.54	0.51±0.03	0.46-0.50	0.48±0.03	0.63-0.65	0.64±0.04	0.60-0.63	0.61±0.02	0.68-0.73	0.70±0.04
Hind Femur Length (PJB)	1.12-1.15	1.13±0.04	1.09-1.13	1.10±0.04	1.05-1.09	1.07±0.03	1.01-1.03	1.02±0.02	1.13-1.16	1.14±0.03	1.18-1.23	1.20±0.02
Hind Tibia Width (LTB)	0.52-0.55	0.53±0.02	0.52-0.56	0.53±0.02	0.52-0.56	0.54±0.03	0.49-0.51	0.50±0.03	0.53-0.56	0.54±0.01	0.54-0.59	0.56±0.04
Hind Tibia Length (PTB)	1.57-1.60	1.58±0.04	1.58-1.62	1.59±0.04	1.58-1.62	1.60±0.03	1.42-1.44	1.43±0.03	1.59-1.62	1.60±0.02	1.74-1.79	1.76±0.03
Hind Basitarsus Width (LBB)	0.30-0.33	0.31±0.04	0.29-0.33	0.30±0.02	0.26-0.30	0.28±0.04	0.32-0.34	0.33±0.03	0.31-0.34	0.32±0.02	0.33-0.38	0.35±0.01
Hind Basitarsus Length (PBB)	0.55-0.58	0.56±0.04	0.56-0.60	0.57±0.03	0.57-0.61	0.59±0.04	0.62-0.64	0.63±0.02	0.57-0.60	0.58±0.03	0.72-0.77	0.74±0.04

Table 3. 34 morphological feature measurements of stingless bee large body-sized (>4 mm) (mm)

Body characters	Morphometric of stingless bees (mm)							
	H. itama **(n = 20)**		***H. canifrons*** **(n = 20)**		***L. terminata*** **(n = 85)**		***W. incisa*** **(n = 25)**	
	Min-Max	**Mean±SD**	**Min-Max**	**Mean±SD**	**Min-Max**	**Mean±SD**	**Min-Max**	**Mean±SD**
Body Lenght (PT)	4.26-4.28	4.27±0.03	5.53-5.57	5.54±0.02	4.92-4.96	4.94±0.02	5.22-5.28	5.24±0.01
Head Length (PK)	1.95-1.97	1.96±0.03	3.00-3.04	3.01±0.02	2.29-2.33	2.31±0.03	2.64-2.70	2.66±0.02
Head Width (LK)	2.22-2.24	2.23±0.02	3.45-3.49	3.46±0.01	2.62-2.66	2.64±0.02	3.03-3.09	3.05±0.03
Mandible Length (PM)	1.17-1.19	1.18±0.03	1.98-2.02	1.99±0.02	1.43-1.47	1.45±0.02	1.70-1.76	1.72±0.03
Mandible Widht (LM)	0.41-0.43	0.42±0.02	1.34-1.38	1.35±0.01	0.71-0.75	0.73±0.02	1.02-1.08	1.04±0.03
Clypeus Length (PC)	0.59-0.61	0.60±0.02	0.95-0.99	0.96±0.01	0.70-0.74	0.72±0.04	0.82-0.88	0.84±0.02
Lower Interocular Distance (JIB)	1.24-1.26	1.25±0.03	1.69-1.73	1.70±0.01	1.38-1.42	1.40±0.02	1.53-1.59	1.55±0.03
Upper Interocular Distance (JIA)	1.26-1.28	1.27±0.01	2.10-2.14	2.11±0.02	1.53-1.57	1.55±0.02	1.81-1.87	1.83±0.03
Eye Width (LM)	0.64-0.66	0.65±0.03	1.54-1.58	1.55±0.02	0.93-0.97	0.95±0.04	1.23-1.29	1.25±0.03
Eye Length (PM)	1.51-1.53	1.52±0.02	2.20-2.24	2.21±0.01	1.73-1.77	1.75±0.03	1.96-2.02	1.98±0.02
Maximum Interorbital Distance (JMI)	1.56-1.58	1.57±0.02	1.98-2.02	1.99±0.01	1.69-1.73	1.71±0.03	1.83-1.89	1.85±0.02
Lower Interorbital Distance (LOD)	1.21-1.23	1.22±0.03	1.81-1.85	1.82±0.02	1.40-1.44	1,42±0.02	1.60-1.66	1.62±0.03
Interantennal Distance (JI)	0.45-0.47	0.46±0.02	1.05-1.09	1.06±0.03	0.64-0.68	0.66±0.04	0.84-0.90	0.86±0.03
Interocellar Distance (IOD)	0.57-0.59	0.58±0.03	0.87-0.91	0.88±0.04	0.66-0.70	0.68±0.02	0.76-0.82	0.78±0.01
Ocellocular Distance (JO)	0.46-0.48	0.47±0.03	0.88-0.92	0.89±0.02	0.59-0.63	0.61±0.02	0.73-0.79	0.75±0.01
Antennocellar Distance (JA)	1.03-1.05	1.04±0.02	1.39-1.43	1.40±0.03	1.14-1.18	1.16±0.02	1.26-1.32	1.28±0.03
Antennocullar Distance (JAO)	0.55-0.57	0.56±0.02	0.88-0.92	0.89±0.02	0.65-0.69	0.67±0.01	0.76-0.82	0.78±0.01
Gena Width (LG)	0.41-0.43	0.42±0.01	1.28-1.32	1.29±0.02	0.69-0.73	0.71±0.02	0.98-1.04	1.00±0.01
Length of Flagellomere IV (PF)	0.38-0.40	0.39±0.02	1.04-1.08	1.05±0.01	0.59-0.63	0.61±0.03	0.81-0.87	0.83±0.03
Width of Flagellomere IV (LF)	0.39-0.41	0.40±0.03	1.02-1.06	1.03±0.02	0.59-0.63	0.61±0.02	0.80-0.86	0.82±0.02
Malar Length (PML)	0.31-0.33	0.32±0.04	0.85-0.89	0.86±0.04	0.48-0.52	0.50±0.01	0.66-0.72	0.68±0.01
Mesoscutum Length (PMS)	1.22-1.24	1.23±0.03	1.61-1.65	1.62±0.03	1.34-1.38	1.36±0.01	1.47-1.53	1.49±0.01
Mesoscutum Width (LMS)	1.54-1.56	1.55±0.02	1.84-1.90	1.85±0.02	1.63-1.67	1.65±0.01	1.73-1.79	1.75±0.01
Length of Forewing Including Tegula (WL1)	4.46-4.48	4.47±0.03	4.88-4.92	4.89±0.03	4.59-4.63	4.61±0.02	4.73-4.79	4.75±0.02
Distance Between M-Cu Bifurcation (WL2)	1.38-1.40	1.39±0.02	1.86-1.90	1.87±0.02	1.53-1.57	1.55±0.03	1.69-1.75	1.71±0.03
Fore Wing Length (PSD)	4.18-4.20	4.19±0.03	4.33-4.37	4.34±0.03	4.22-4.26	4.24±0.02	4.27-4.33	4.29±0.02
Fore Wing Width (LSD)	1.52-1.54	1.53±0.02	1.88-1.92	1.89±0.01	1.63-1.67	1.65±0.03	1.75-1.81	1.77±0.03
Hind Wing Length (PSB)	3.02-3.04	3.03±0.02	3.26-3.30	3.27±0.02	3.09-3.13	3.11±0.04	3.17-3.23	3.19±0.04
Hind Wing Width (LSB)	1.01-1.03	1.02±0.02	1.13-1.17	1.14±0.02	1.04-1.08	1.06±0.03	1.08-1.14	1.10±0.03
Hind Femur Length (PJB)	1.36-1.38	1.37±0.02	2.02-2.06	2.03±0.04	1.57-1.61	1.59±0.03	1.79-1.85	1.81±0.02
Hind Tibia Width (LTB)	0.73-0.75	0.74±0.02	1.48-1.52	1.49±0.04	0.97-1.01	0.99±0.02	1.22-1.28	1.24±0.03
Hind Tibia Length (PTB)	1.94-1.96	1.95±0.01	2.24-2.28	2.25±0.03	2.03-2.07	2.05±0.03	2.13-2.19	2.15±0.04
Hind Basitarsus Width (LBB)	0.58-0.60	0.59±0.01	1.12-1.16	1.13±0.02	0.75-0.79	0.77±0.02	0.93-0.99	0.95±0.02
Hind Basitarsus Length (PBB)	0.97-0.99	0.98±0..02	1.12-1.16	1.13±0.01	1.01-1.05	1.03±0.03	1.06-1.12	1.08±0.01

Figure 2. Ten stingless bee species from Sulawesi Island, Indonesia. A. *Tetragonula biroi*; B. *T. clypearis*; C. *T. fuscobalteata*; D. *T. laeviceps*; E. *T. pagdeni*; F. *T. sapiens*; G. *Lepidotrigona terminata*; H. *Heterotrigona itama*; I. *Homotrigona canifrons*; J. *Wallacetrigona incisa*. Scale bar = 1 mm

Key to genera

1. a. The hair on the posterior part of the hind tibia is simple (not branched) ……..…. ***Lepidotrigona***
   b. The hair on the hind tibia is plumose (branched)….. **2**
2. a. Mandibula with one tooth ……...…..... ***Heterotrigona***
   b. Mandibula with two teeth……..…… **3**
3. a. The mesoscutellum is short, only reaching the metanotum……...***Wallacetrigona***
   b. The mesoscutellum extends beyond the propodeum.. **4**
4. a. Hamuli consists of 5 …..…….. ***Tetragonula***
   b. Hamuli consists of 7 …..…… ***Homotrigona***

Tetragonula (Moure, 1961)

Smooth tegument. The mandible consists of two small teeth, the malar distance of which is shorter than the diameter of the flagellomer. Gena is round and shorter than compound eyes. Long scutellum, propodeum medium sized, and smooth and shiny basal area. Hamuli consists of five. Rear tibia with hair on the posterior edge of the tibia is rather short, mostly in the tibial area, and it is hairy and plumose (branched). The posterior basitarsus is narrower than the width of the tibia. Abdomen is narrower than the thorax, somewhat flattened.

Wallacetrigona (Engel and Rasmussen, 2017)

Smooth tegument. The mandible consists of two teeth; the malar distance is very long. Gena is as wide as the eye and round. Scutellum is short, propodeum is short, and basal area is smooth and shiny. Hamuli consists of seven. Hind tibia is almost hairless and plumose (branched). The posterior basitarsus is two-thirds of the width of the tibia. Narrow abdomen, shaped like a triangle.

Description of species

Tetragonula (Moure 1961)

Tetragonula biroi (Friese, 1898)

Head: Nearly twice as wide as long, covered with short hairs. The clypeus and frons are separated by epistomal sulcus. Compound eyes are large. Antenna type is Geniculate. The flagellum is covered with short erect hairs. The length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is almost the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex and has two teeth.

Thorax: Mesoscutum is rough, extends to the propodeum, has no longitudinal hairbands, and has short hairs, almost the same length covering anterior part and width. The anterior part is slightly wider than the posterior part. Scutellum is rough, slightly sharp, almost twice as wide as long, and covered with long hairs posteriorly.

Wings: Tegula is round and scaly. The length of the forewings is almost three times the width, covered with short hairs. Opaque pterostigma on costal margin of the forewing. Number of hamuli is five.

Legs: There is an elliptical disc on the inside of the hind basitarsus, rarely covered with long hair on the apical part and short hair on the basal part. Hind basitarsus is short and the length of the hind tibia is almost twice that of the hind basitarsus, covered by short hair. The hairs on the hind tibia are plumose (branched).

Abdomen: First to third tergite is smooth; and fourth to sixth is rough, covered with short hair. The sternite is completely covered by hairs.

Coloration: Pale brown body color. The head is black; the front is completely covered with fine white hair. Clypeus is brown and completely covered with fine white hairs. The compound eyes and ocelli are blackish. Antennal socket is blackish gray, scape brown, and pedicel, where first flagellum is brown, and second to tenth flagellum is brown. The mandibles are blackish brown and black at the basal part. The mesoscutum is black and has no longitudinal hairbands, surrounded by blackish brown hairs. The scutellum is blackish brown, covered by blackish brown hairs. Tegulae are brown, with uniform color of the fore and hind wings and semi-transparent, and the wing venation is brown. Hind tibia and hind basitarsus are black. The tergite is completely black (Figure 3).

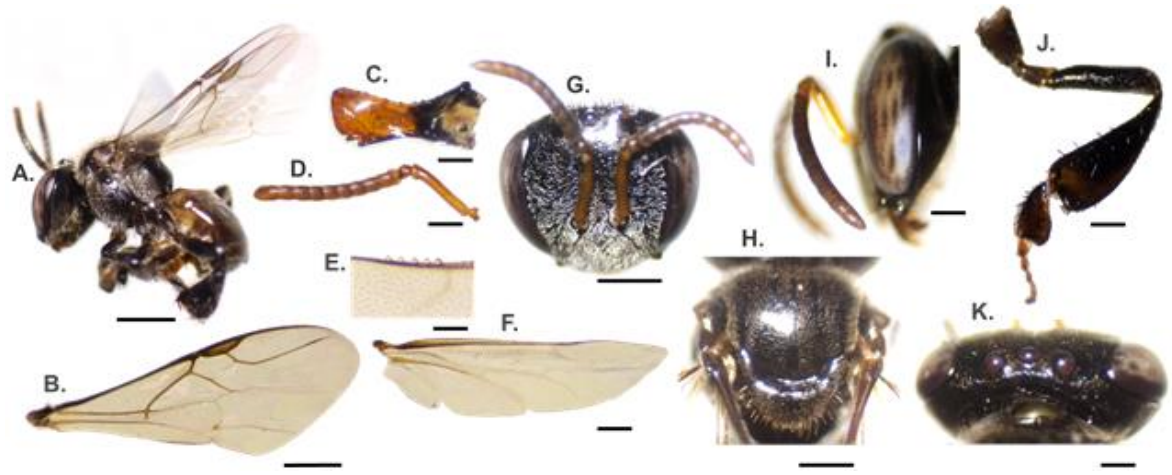

Figure 3. *Tetragonula biroi* (Friese, 1898). A. Habitus, lateral view; B. Forewing; C. Mandibles; D. Antenna; E. Hamulli; F. Hindwing; G. Head; H. Mesoscutum; I. Compound Eye; J. Hind Leg; and K. Ocelli. Scale bar = 1 mm

Tetragonula clypearis (Friese, 1909)

Head: Nearly double the width of the head, covered with short hairs apically. The clypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Antenna type is Geniculate and the flagellum is covered with short erect hairs. The length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth.

Thorax: Rough mesoscutum, extending to the propodeum and having longitudinal hairbands. The anterior part is covered with hair that length and width are almost the same, and the anterior part is wider than the posterior part. Scutellum is rough, sharp, almost twice as wide as long, and covered with short hairs.

Wings: Tegula is round and scaly. The forewings are almost twice as long as their are wide, covered with short and fine hairs. Opaque pterostigma on costal margin of the forewing. Number of hamuli is five.

Legs: There is an elliptical disc on the inside of the hind basitarsus, rarely covered with short hair on the apical and basal parts. Hind basitarsus is short; the length of the hind tibia is almost three times that of the hind basitarsus, covered by short hair. The hairs on the hind tibia are plumose (branched).

Abdomen: The first to fourth tergite abdomen is smooth, and the fifth to sixth is slightly rough. Sternite is covered with fine hairs.

Coloration: Brown body color. The head is black, and the front is covered with fine, yellowish-white hair. Clypeus is black and completely covered with fine, yellowish-brown hairs. The compound eyes and ocelli are blackish brown. Antennal socket is gray, scape brown, and slightly yellow at the apical part. Pedicel and first flagellum are dark brown, and second to tenth flagellum are blackish brown. The mandibles are brown and black at the basal part. Mesoscutum is black with 5 longitudinal hairbands, covered by blackish brown hair, and the scutellum is black. Tegulae are brown, with uniform and semi-transparent color of the fore and hind wings, and the wing venation is dark brown. Hind tibia and hind basitarsus are black. Tergite is light brown (Figure 4).

Tetragonula fuscobalteata (Cameron, 1908)

Head: Nearly double the width of the head, covered with short hair apically. The clypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Antenna type is Geniculate, and the flagellum is covered with short erect hairs. The length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth.

Thorax: Having rough mesoscutum, extending to the propodeum, and having longitudinal hairbands, almost the same length and width. The anterior part is wider than the posterior part. Scutellum is rough, slightly sharp at the posterior edge, almost twice as wide as long, and covered with long hairs.

Wings: Tegula is round and scaly. The forewings are nearly three times as long as their wide, uniformly covered with short, fine hairs. Opaque pterostigma on costal margin of the forewing. Number of hamuli is five.

Legs: There is an elliptical disc on the inside of the hind basitarsus, rarely covered with long hair apically and covered with short hair basally. Hind basitarsus is short, and the length of the hind tibia is almost three times that of the hind basitarsus, covered by short hair. The hairs on the hind tibia are plumose (branched).

Abdomen: First to fourth tergite is smooth; and fifth to sixth slightly is rough. The sternite is completely covered by numerous and long hairs.

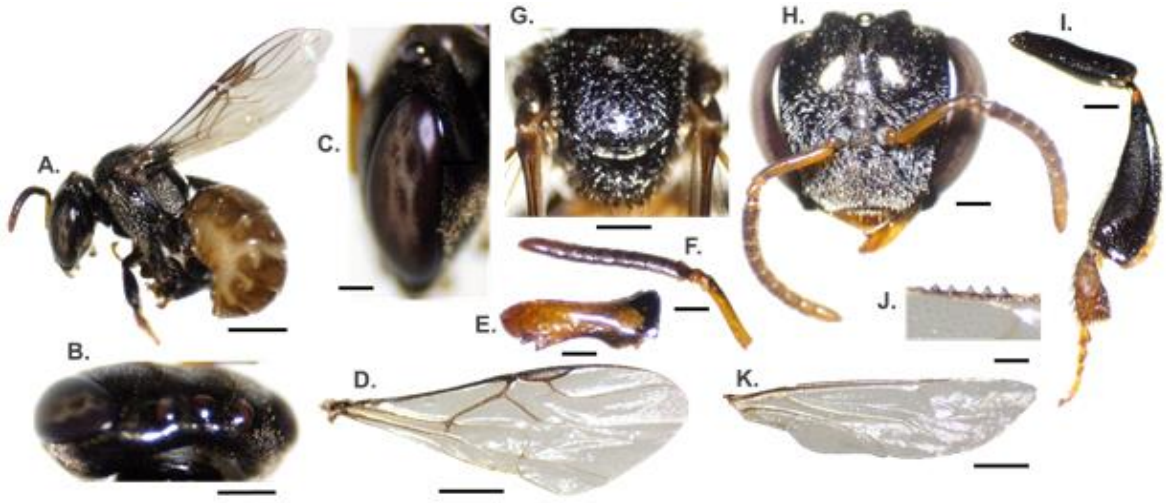

Figure 4. *Tetragonula clypearis* (Friese, 1909). A. Habitus, lateral view; B. Ocelli; C. Compound eye; D. Forewing; E. Mandibles; F. Antenna; G. Mesoscutum; H. Head; I. Hind leg; J. Hamulli; and K. Hindwing. Scale bar = 1 mm

Coloration: Body color is brownish. The head is black and the front is completely covered with fine white hair; the white hair thickens close to the antennal socket and clypeus. Clypeus is black and completely covered with fine white hairs. The compound eyes and ocelli are black. Antennal socket is gray, scape brown and slightly yellow at the apical part. Pedicel and first flagellum are dark brown, and second to tenth flagellum are blackish brown. The mandibles are brown and black at the basal part. Mesoscutum is black with 5 longitudinal hairbands, covered by pale yellow hairs and black scutellum. Tegulae are brown, with uniform and semi-transparent color of the fore and hind wings, and the wing venation is light brown. Hind tibia and hind basitarsus are dark brown. Tergite is brown, with some dark brown on the dorsal side (Figure 5).

Tetragonula laeviceps (Smith, 1857)

Head: Nearly twice as wide as long, covered with long hair. The clypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Antenna type is geniculate, and the flagellum is covered with short erect hair. The length of the pedicel and the entire flagellum are twice that of the scape, while the length of the first and second segments of the flagellum is almost the same, and the length of the second and third segments of the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth.

Thorax: Rough mesoscutum, it extends to the propodeum, and has fine, long, vertical longitudinal hairbands in the middle, almost the same length and width. The anterior part is wider than the posterior part. Scutellum is rough and convex, almost three times as wide as long, covered with long hairs.

Wings: Tegula is round and scaly. The forewings are nearly three times as long as their wide, uniformly covered with short, fine hairs. Prerostigma is blurry on costal margin of the forewing. Number of hamuli is five.

Legs: There is an elliptical disc on the inside of the hind basitarsus, rarely covered with long hair on the apical part and covered with short hair on the basal part. The hind basitarsus is short, and the length of the hind tibia is almost three times that of the hind basitarsus, covered with short hair. The hair on the hind tibia is plumose (branched).

Abdomen: The First to third tergite is smooth, and the fourth to sixth is covered with short hair. The sternite is completely covered by numerous and long hair.

Coloration: Dominant body color is black. The head is black, and the front is completely covered with fine white hair, the white hair thickens close to the antennal socket and clypeus. Clypeus is brown and completely covered with fine white hair. The compound eyes are reddish, and the ocelli are black. Antennal socket is gray, brown scape, and slightly yellow at the apical part. Pedicel and first flagellum are brown, while the second to tenth flagellum is blackish brown. The mandibles are blackish brown and partly black at the basal level. The mesoscutum is black, surrounded by pale yellow hair. The scutellum is black, covered by pale yellow hair. The tegulae are brown, and the color of the fore and hind wings is uniform, semi-transparent, and dark brown wing venation. Hind tibia is black. Hind basitarsus is dark brown. Tergite is dark brown (Figure 6).

Tetragonula pagdeni (Schwarz, 1939)

Head: Nearly twice as wide as long, covered with short hairs. The clypeus and frons are separated by epistomal sulcus. Compound eyes are large. Geniculate antenna type. The flagellum is covered with short erect hairs. The length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is almost the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth.

Thorax: Having rough mesoscutum, extending to the propodeum, and having fine, long, and vertical longitudinal hairbands in the middle. The anterior part is covered with hair, almost the same length and width, and the anterior part is wider than the posterior part. Scutellum is rough, somewhat sharp, almost twice as wide as long, and covered with long hairs.

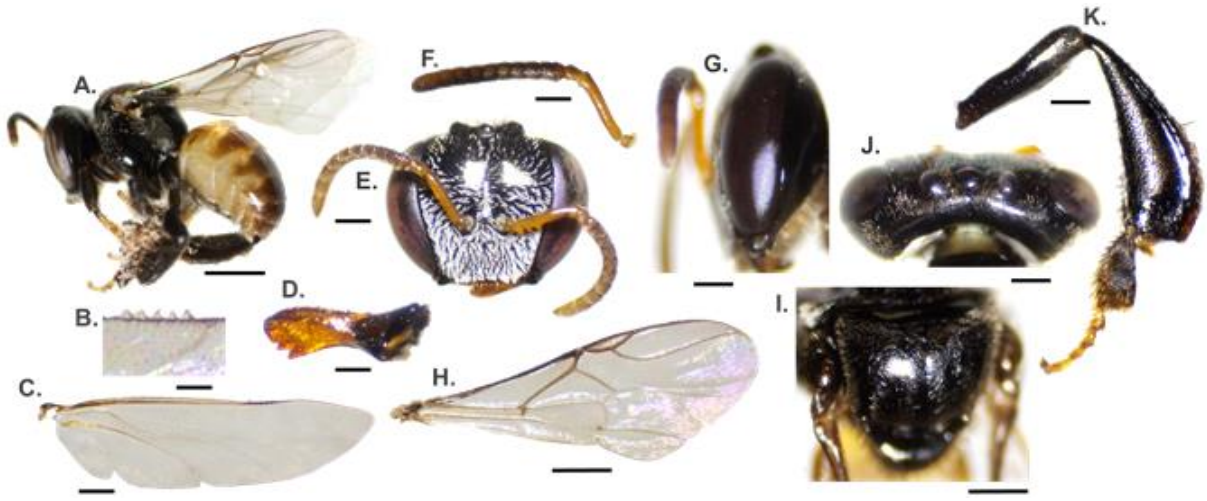

Figure 5. *Tetragonula fuscobalteata* (Cameron, 1908). A. Habitus, lateral view; B. Hamulli; C. Hindwing; D. Mandibles; E. Head; F. Antenna; G. Compound eye; H. Forewing; I. Mesoscutum; J. Ocelli; and K. Hind leg. Scale bar = 1 mm

Wings: Tegula is round and scaly. The length of the forewings is almost three times the width, covered with short hairs. Opaque pterostigma on costal margin of the forewing. Number of hamuli is five.

Legs: There is an elliptical disc on the inside of the hind basitarsus, covered with short hair on the apical and basal parts. Hind basitarsus is short, and the length of the hind tibia is almost three times that of the hind basitarsus, covered by short hair. The hairs on the hind tibia are plumose (branched).

Abdomen: First to third tergite is smooth, and fourth to sixth covered with short hair. The sternite is completely covered by numerous and long hairs.

Coloration: Brown body color. The head is black; the front completely covered with fine white hair, the white hair thickens close to the antennal socket and clypeus. Clypeus is black and completely covered with fine white hairs. The compound eyes and ocelli are blackish. The antennal socket is blackish gray, and the scape is brown and slightly yellow at the apical part. The pedicel and first flagellum are brown. The second to eighth flagellum are dark brown, and the ninth to tenth flagellum are blackish brown. Mandibles are brown. The mesoscutum is black, surrounded by blackish brown hairs, and the scutellum is black, covered by blackish brown hairs. Tegulae are brown, with uniform and semi-transparent color of the fore and hind wings. The wing venation is brown. Hind tibia and hind basitarsus are black. The tergite is completely brown (Figure 7).

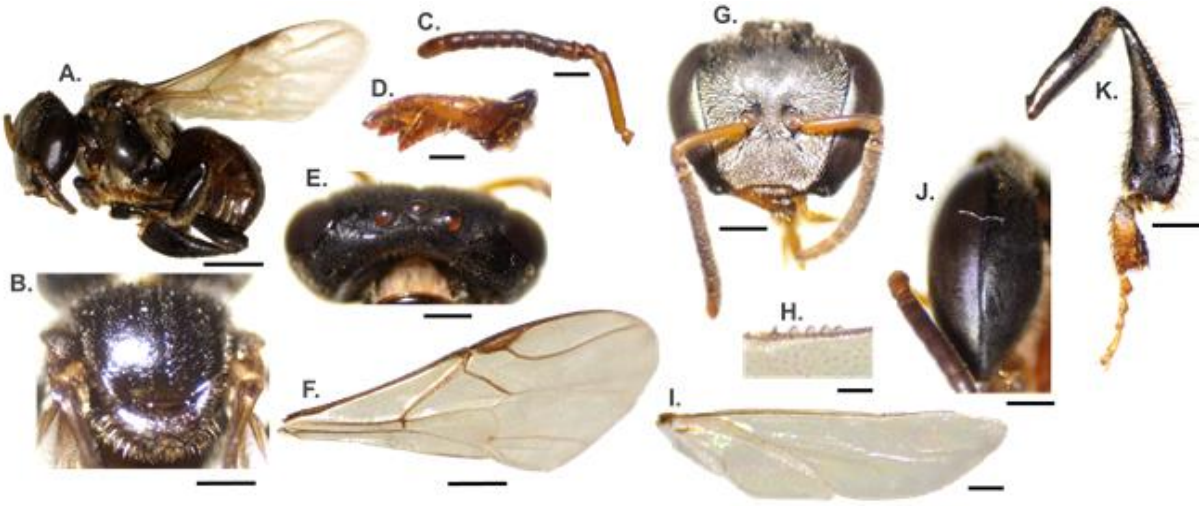

Figure 6. *Tetragonula laeviceps* (Smith, 1857). A. Habitus, lateral view; B. Mesoscutum; C. Antenna; D. Mandibles; E. Ocelli; F. Forewing; G. Head; H. Hamulli; I. Hindwing; J. Compound eye; and K. Hind leg. Scale bar = 1 mm

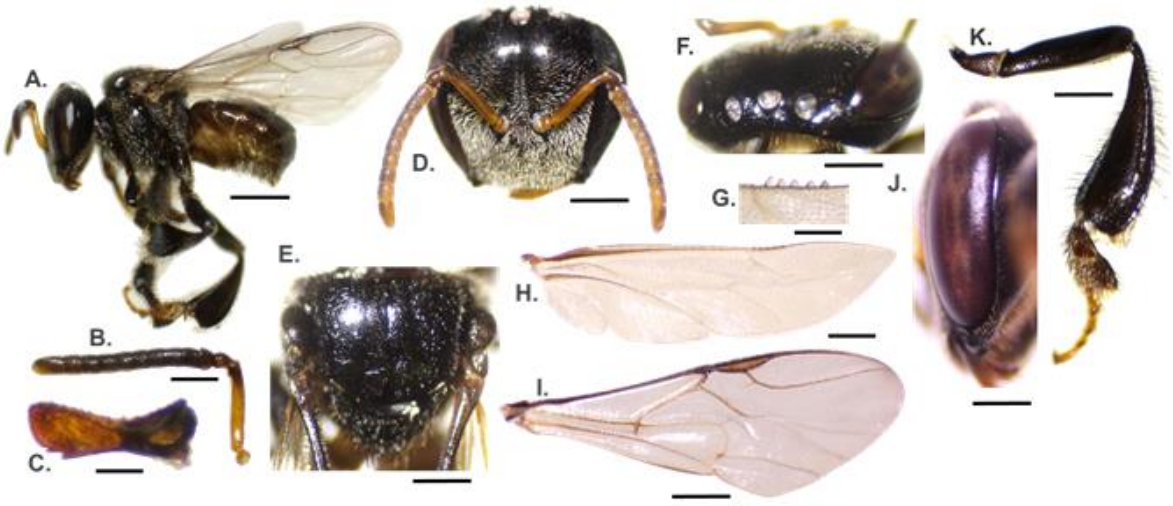

Figure 7. *Tetragonula pagdeni* (Schwarz, 1939). A. Habitus, lateral view; B. Antenna; C. Mandibles; D. Head; E. Mesoscutum; F. Ocelli; G. Hamulli; H. Hindwing; I. Forewing; J. Compound eye; and K. Hind leg. Scale bar = 1 mm

Tetragonula sapiens (Cockerell, 1911)

Head: Nearly twice as wide as long, covered with short hair. The clypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Geniculate antenna type, flagellum is covered with short erect hairs. Long pedicel and the entire flagellum are twice the length of the scape. The length of the first segment and the two on the flagellum are almost the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth.

Thorax: Mesoscutum is rough, extends to the propodeum, and does not have longitudinal hairbands. Anterior part is rarely covered by short hair, where length and width are almost the same, and the anterior part is wider than the posterior part. Scutellum is large, convex, almost three times as wide as long, sparsely covered by long hair posteriorly.

Wings: Tegula is round and scaly. The length of the forewings is almost three times the width, covered with short hairs. Opaque pterostigma on costal margin of the forewing. Number of hamuli is 5.

Legs: There is an elliptical disc on the inside of the hind basitarsus, rarely covered with long hair apically and short hair basally. Hind basitarsus is short, and the length of the hind tibia is almost three times that of the hind basitarsus, covered by short hair. The hairs on the hind tibia are plumose (branched).

Abdomen: First to fourth tergite is smooth; and fifth to sixth is covered with short hair. The sternite completely covered by long hairs.

Coloration: Dominant body color is black. The head is black, the front is completely covered with fine, yellowish-white hair. Clypeus is black and completely covered with fine, yellowish-brown hairs. The compound eyes are reddish and the ocelli are black. Antennal socket is gray, and the scape is yellowish brown. Pedicel and first flagellum are brown, and second to tenth flagellum are blackish. The mandibles are brown and black at the basal part. The mesoscutum is black, has no longitudinal hairbands, and is completely covered by yellowish hairs posteriorly. The scutellum is black, covered by blackish brown hairs. Tegulae are brown, with uniform and semi-transparent color of the fore and hind wings. The wing venation is brown. Hind tibia and hind basitarsus are black. Tergite is dark brown (Figure 8).

Heterotrigona (Schwarz, 1939)

Heterotrigona itama (Cockerell, 1918)

Head: Nearly twice as wide as the head, covered with short hair. The clypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Antenna type is Geniculate, and the flagellum is covered with short erect hairs. The length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is almost the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has one tooth.

Thorax: Mesoscutum is rough, and has longitudinal hairbands. Anterior part is covered with long hair, almost having the same length and width, and it is wider than posterior part. Scutellum is rough, convex, almost three times as wide as long, and covered with long hairs.

Wings: Tegula is round and scaly. The forewings are about three times as long as their wide, covered with short, fine hairs. Opaque pterostigma on costal margin of the forewing. Number of hamuli is seven.

Legs: There is an elliptical disc on the inside of the hind basitarsus, rarely covered with long hair apically and short hair basally. Hind basitarsus is long, and the length of the hind tibia is almost twice that of the hind basitarsus, covered by short hair.

Abdomen: First to third tergite is smooth, fourth tergite is rougher, and fifth to sixth tergite is rougher covered with fine hair. The sternite is completely covered by fine hairs.

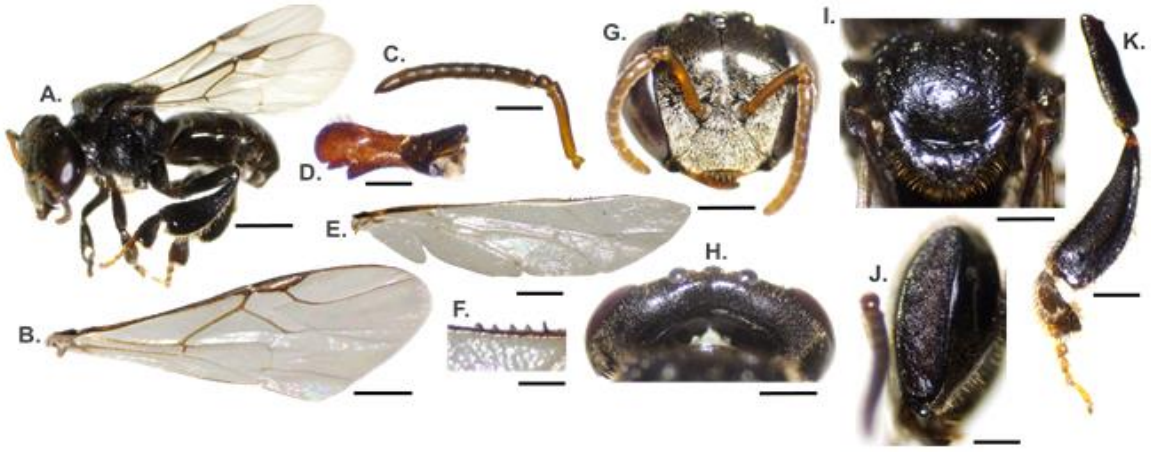

Figure 8. *Tetragonula sapiens* (Cockerell, 1911). A. Habitus, lateral view; B. Forewing; C. Antenna; D. Mandibles; E. Hindwing; F. Hamulli; G. Head; H. Ocelli; I. Mesoscutum; J. Compound eye; and K. Hind leg. Scale bar = 1 mm

Coloration: Black body color. The head is black, rarely covered with fine white hairs. Clypeus is black and completely covered with fine white hairs. Reddish compound eyes and blackish ocelli. The antennal socket is gray, and the scape is yellowish brown. The pedicel and the first segment of the flagellum are brown, and the second to tenth segments are blackish brown. The mandibles are brown and black at the basal part. The mesoscutum is black, covered with yellowish hairs, and the scutellum is black, covered with yellowish hairs at the posterior. Tegulae are brown, with uniform and semi-transparent color of the fore and hind wings. The wing venation is dark brown. Hind tibia and hind basitarsus are black. Tergite is blackish brown (Figure 9).

Homotrigona (Moure, 1961)
Homotrigona canifrons (Smith, 1857)

Head: The head is almost twice as wide as its wide, covered with long hair. The clypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Geniculate antenna type, the flagellum is covered with short erect hairs. The length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth.

Thorax: Mesoscutum is rough, extends to the propodeum, and does not have longitudinal hairbands. The anterior part is surrounded by long hair, almost having the same length and width, and the anterior part is wider than the posterior part. Scutellum is rough, convex, almost twice as wide as long, and covered with long hairs.

Wings: Tegula is round and scaly. The forewings are very long and broad, the forewings being about three times as long as their wide, covered with short, fine hairs. Pterostigma slightly opaque on costal margin of the forewing. Number of hamuli is seven.

Legs: There is an elliptical disc on the inside of the hind basitarsus, covered with long hair. Hind basitarsus is short, and the length of the hind tibia is almost three times that of the hind basitarsus, covered by short hair.

Abdomen: First to third tergite is smooth, the fourth to fifth tergite is covered with short hair, and the sixth tergite is sparsely covered with long hair. The sternite is completely covered by fine hairs.

Coloration: Black body color. The head is black. Clypeus is black and completely covered with white hairs. Compound eyes and ocelli blackish. Antennal socket is gray, and scape is ferruginous and pedicel. The first to ninth segments of flagellum are brown and the tenth segment is ferruginous. Mandibles are dark brown. The mesoscutum and scutellum are black, and covered with blackish brown hairs. Tegulae ferruginous, the color of the forewings is uneven and slightly brownish at the basal part, semi-transparent at the apex. The rear wings are semi-transparent like the front wings. Hind tibia and hind basitarsus are black. Tergite is black (Figure 10).

Lepidotrigona (Schwarz, 1939)
Lepidotrigona terminata (Smith, 1878)

Head: Head is as twice long as wide, covered with hair at the apical part. The alypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Antenna type is geniculate, and the flagellum is covered with short erect hair where the length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth.

Thorax: Mesoscutum is rough and short only reaching metanotum, and has longitudinal hairbands, which the anterior part is covered with long hair, the length and width are almost the same, and the anterior part is wider than the posterior part. Scutellum is rough, convex, almost twice as long as wide, and covered with long hair.

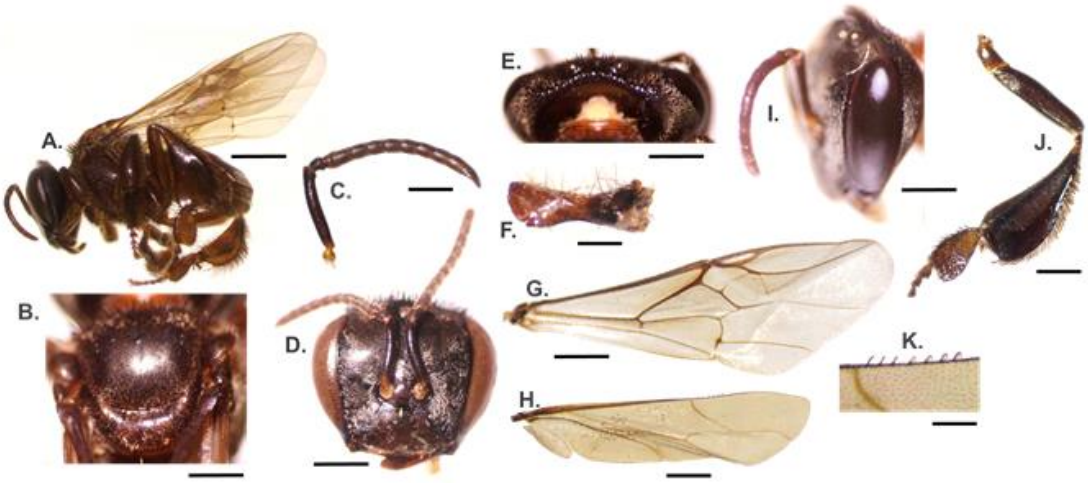

Figure 9. *Heterotrigona itama* (Cockerell, 1918). A. Habitus, lateral view; B. Mesoscutum; C. Antenna; D. Head; E. Ocelli; F. Mandibles; G. Forewing; H. Hindwing; I. Compound eye; J. Hind leg; and K. Hamulli. Scale bar = 1 mm

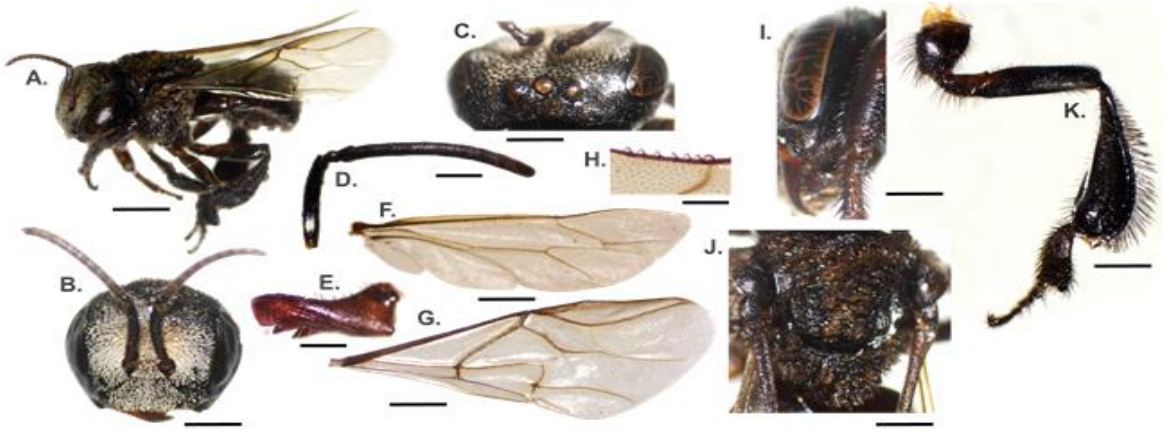

Figure 10. *Homotrigona canifrons* (Smith, 1857). A. Habitus, lateral view; B. Head; C. Ocelli; D. Antenna; E. Mandibles; F. Hindwing; G. Forewing; H. Hamulli; I. Compound eye; J. Mesoscutum; and K. Hind leg. Scale bar = 1 mm

Wings: Tegula is round and scaly. The forewings are three times as long as their wide, covered with short, fine hair. The prerostigma is opaque at the costal margin front wings. Number of hamuli is six.

Legs: There is no elliptical disc on the inside of the hind basitarsus. Hind basitarsus is long, and the length of the hind tibia is almost twice that of the hind basitarsus, covered by short hair. The hair on the posterior part of the hind tibia is simple (not branched).

Abdomen: First to sixth tergite is shiny. The sternite is completely shiny like a tergite.

Coloration: The colour of the body is brownish, and the basal tergite is ivory white. The head is black, where in the front section, it is completely covered with fine white hair, and the white hair thickens close to the antennal socket and clypeus. Clypeus is black and completely covered with fine white hair. The eyes are compound and ocelli blackish. Antennal socket is gray and scape black, but basal part is brown, which pedicel and flagellum are dark brown. The mandibles are black on the basal half and brown on the other half. The mesoscutum is black, surrounded by short, thick hair-like golden yellow scales, and the scutellum is black, covered by brown hair. Tegulae is brown, and the color of the fore and hind wings is uniform, semi-transparent, and dark brown wing venation. Hind tibia and hind basitarsus are black. Tergite is brownish yellow (Figure 11).

Wallacetrigona (Engel and Rasmussen, 2017)
Wallacetrigona incisa (Sakagami & Inoue, 1989)

Head: Nearly twice as wide as the head, covered with short hair. The clypeus and frons are separated by the epistomal sulcus. Compound eyes are large. Geniculate antenna type. The flagellum is covered with short erect hairs. The length of the pedicel and the entire flagellum is twice that of the scape, the length of the first and second segments on the flagellum is almost the same, and the length of the second and third segments on the flagellum is the same. The mandible is wider than basal, narrower at the apex, and has two teeth. It has a "V" shape at the posterior vertex edge.

Thorax: Mesoscutum is rough, short and only reaching metanotum, having no longitudinal hairbands. Anterior part is covered with long hair that length and width are almost the same, and anterior part is wider than posterior part. Scutellum is rough, convex, almost three times as wide as long, and covered with short hairs.

Wings: Tegula is round and scaly. The forewings are about three times as long as its wide, covered with short, fine hairs. Opaque pterostigma on costal margin of the forewing. Number of hamuli is seven.

Legs: There is no elliptical disc on the inside of the hind basitarsus, covered with long hair apically and short hair basally. Hind basitarsus is long, and the length of the hind tibia is almost twice that of the hind basitarsus, covered with long hair. The hairs on the hind tibia are plumose (branched).

Abdomen: First to third tergite is smooth, fourth tergite is rougher, and fifth to sixth tergite is rougher and covered with fine hair. The sternite is completely covered by fine hairs.

Colouration: Body color blackish. The head is black, rarely covered with fine white hairs. Clypeus is black and completely covered with fine white hairs. Compound eyes and black ocelli. The antennal socket is gray, scape, and pedicel. The first to tenth segments of the flagellum is black. Mandibles are black. The mesoscutum is black, covered with yellowish hairs. The scutellum is black, covered with black hairs. Tegulae are dark brown. The color of the fore and hind wings is uniform, and the wing venation is dark brown. Hind tibia and hind basitarsus are black. Tergite is black (Figure 12).

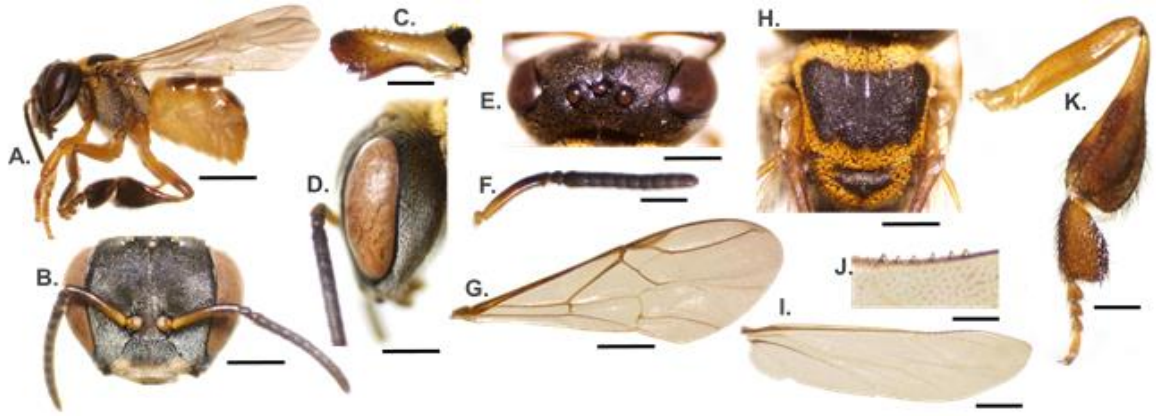

Figure 11. *Lepidotrigona terminata* (Smith, 1878). A. Habitus, lateral view; B. Head; C. Mandibles; D. Compound eye; E. Ocelli; F. Antenna; G. Forewing; H. Mesoscutum; I. Hindwing; J. Hamulli; and K. Hind leg. Scale bar = 1 mm

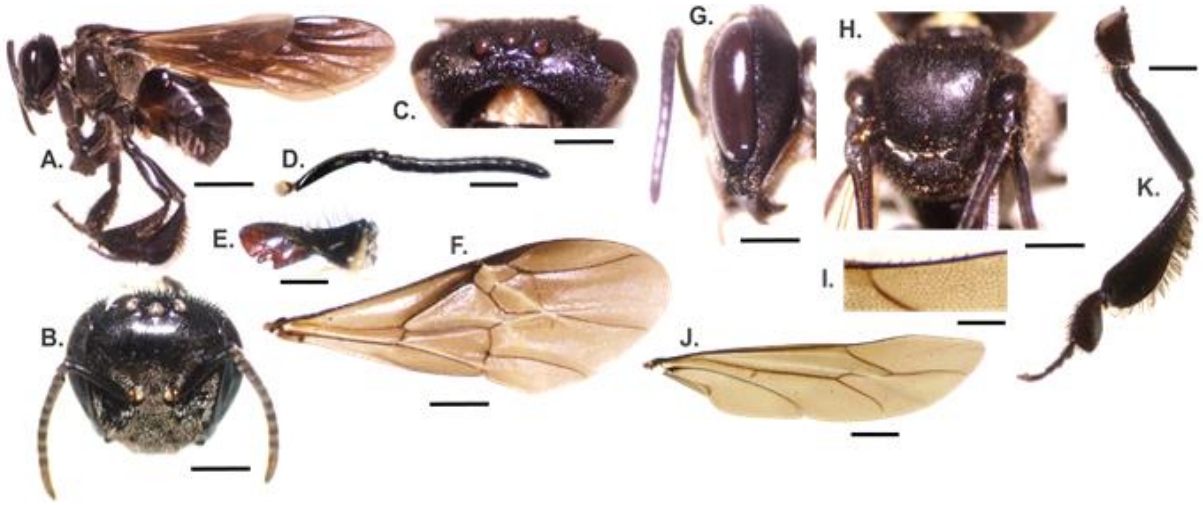

Figure 12. *Wallacetrigona incisa* (Sakagami & Inoue, 1989). A. Habitus, lateral view; B. Head; C. Ocelli; D. Antenna; E. Mandibles; F. Forewing; G. Compound eye; H. Mesoscutum; I. Hamulli; J. Hindwing; and K. Hind leg. Scale bar = 1 mm

Key to species

1. a. The hair on the posterior part of the hind tibia is simple (not branched). The mesoscutum is black, surrounded by short, thick hair like golden yellow scales. The dominant black limbs of …… ……...***Lepidotrigona terminata***
   b. The hair on the hind tibia are plumose (branched) **2**
2. a. Mandible with one tooth. Clypeus is black and covered with fine white hair. Tergite is blackish brown ….…...……..***Heterotrigona itama***
   b. Mandible with two teeth ...……**3**
3. a. The mesoscutellum is short, reaching only to the metanotum. The wings are dark brown overall. There is no protrusion at the vertex, the posterior vertex is shaped like the letter "V", the interdental incision part between the two the mandibular teeth is narrower and the keirotichiate zone on the hind tibia is wider…… ……...……... ***Wallacetrigona incisa***
   b. The mesoscutellum projects beyond the propodeum...**4**
4. a. Hamuli numbered seven. Having uniform body color including head, mesoscutum, scutellum, and tergite… ……...***Homotrigona canifrons***
   b. Hamuli numbered five ……...…**5**
5. a. Mesoscutum with longitudinal hairbands……**6**
   b. Mesoscutum without longitudinal hairbands ……....**9**
6. a. Mesoscutum with three fine, long, vertical longitudinal hairbands in the middle ……..……..……..**7**
   b. Mesoscutum with five fine, long, vertical longitudinal hairbands ……...……..……..**8**
7. a. The mandible is brown, somewhat black in the apical and basal ……..……..... ***Tetragonula pagdeni***
   b. The mandibles are blackish brown and black at the basal ….……..... ***Tetragonula laeviceps***
8. a. Fronts with white hair. The mesoscutum is covered with pale yellow hair …… ***Tetragonula fuscobalteata***
   b. Frons with fawn-colored hair. Mesoscutum covered with blackish brown hair …..... ***Tetragonula clypearis***
9. a. The antennae are all blackish, and the scape is yellowish brown. The tergite is completely dark brown ……... ***Tetragonula sapiens***
   b. The antennae are all brown, the first to sixth is all brown and the scape is brown …… ***Tetragonula biroi***

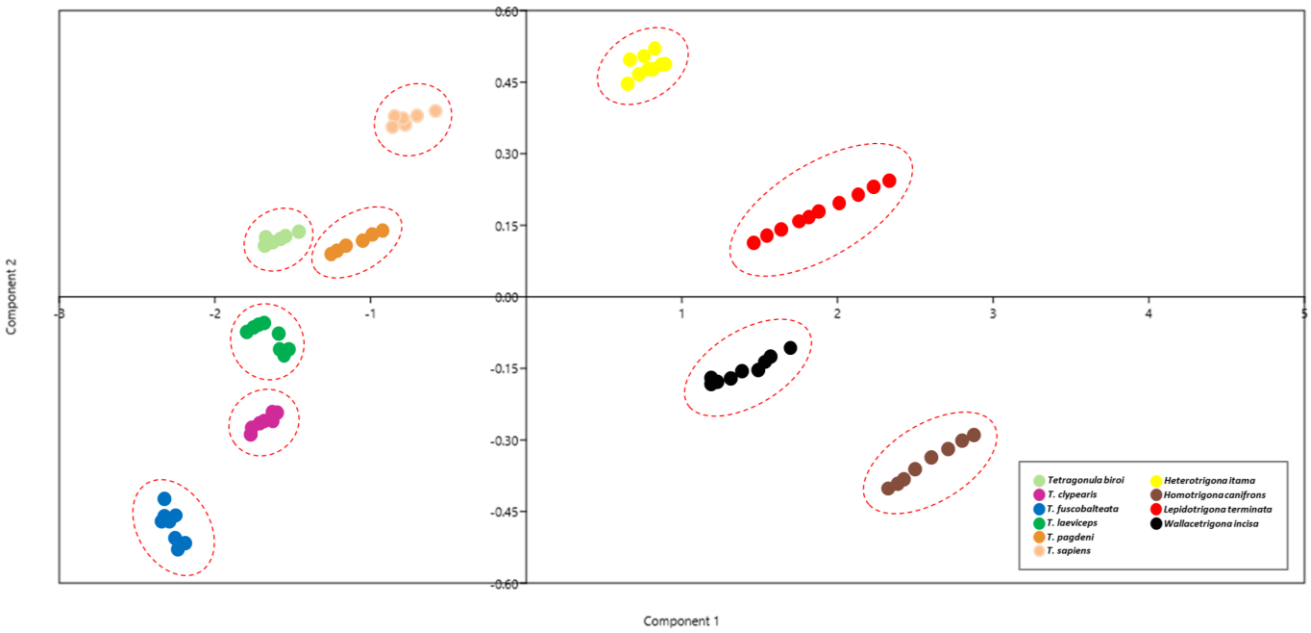

Figure 13. The PCA results of stingless bees

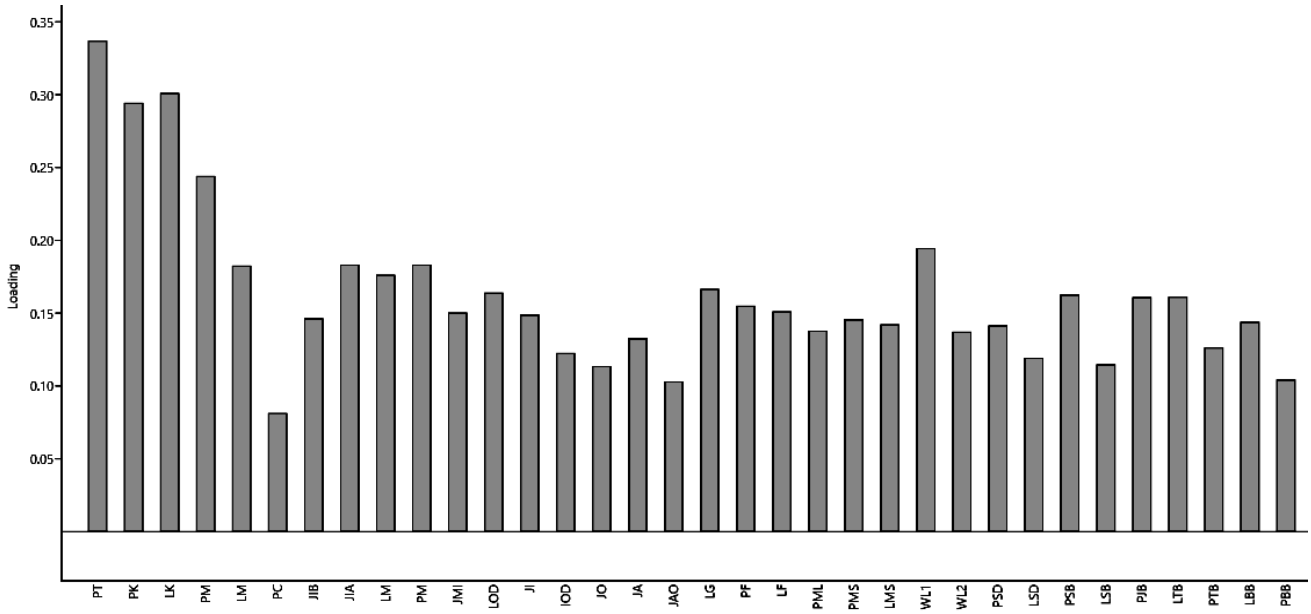

Figure 14. The loading plot of component

Table 4. Eigenvalue and % variance

PC	Eigenvalue	% Variance
1	4.28075	96.369
2	0.103373	2.3271
3	0.0323731	0.72879
4	0.0151729	0.34157
5	0.00667381	0.15024

The stingless bees' morphometrics

The morphometry of the 10 species of stingless bees obtained has a variety of sizes (Table 2; Table 3). Furthermore, the morphometric data is analyzed using the principal component analysis to see how the dominant character affects the variation of the clustering pattern of individuals (10 species) of stingless bees. Principal Component Analysis (PCA) was conducted based on the data collected. The correlation analysis between groups

results in eigenvalues and percent variances (Table 4), while the scatter plot can be seen in Figure 13. The principal components analysis shows the pattern of sample clustering based on the role of each character in the clustering process. The loading plot of the component can be seen in Figure 14. Of the 755 individual stingless bees analyzed, 10 groups formed according to the species.

Discussion

Measuring morphological characteristics was analyzed using the Principal Component Analysis (PCA) technique. PCA is often used in taxonomic research because this technique can identify the role of each character in each group formed (Yudha et al. 2019). The cumulative eigenvalue of the first two Principal Components (PCs) (>70%) was tested in the interpretation of the PCA output (Table 4). The resulting character loadings on PC1 and PC2 were used to determine the most influential characters in species separation. The PC1 and PC2 values were then plotted for visualization of the analysis results. The results of the PCA analysis showed a total value of PC1 96.369%. This can also be seen from the height of the graph, the longer height of the graph formed, the higher the role of these characters in clustering. In accordance with morphological identification, the characters of body length (PT) and head width (LK) have the highest values in PC1 and PC2 (Figure 14). Visualization of the PCA plot shows six separate *Tetragonula* species with *T. biroi*, *T. pagdeni*, and *T. sapiens* located in quadrant two, while *T. clypearis*, *T. fuscobalteata*, and *T. laeviceps* are located in quadrant three. *H. itama* and *L. terminata* are also located in quadrant one, while *H. canifrons* and *W. incisa* are located in quadrant four.

Heterotrigona itama and *H. canifrons* are new records on Sulawesi Island. These species are found in Lore Lindu National Park (TNLL), located in the eastern of Indonesia (119°90'-120°16'E and 1°8'-1°3'S), which is around 1.416 km from Java, 709 km from Borneo, and 1.958 km from Sumatra where this species was found in Indonesia. Lore Lindu National Park is a nature conservation area formed from the unification of three protected areas, namely: Lore Kalamanta Wildlife Sanctuary, Lake Lindu Tourism Forest, and Sopu River Wildlife Sanctuary. Lore Lindu National Park mostly consists of mountain and sub-mountain forests (±90%) and a small portion of lowland forest (±10%). The lowest point in TNLL is located near the northwestern tip, which is about 200 m a.s.l. The highest point is the peak of Mount Rorekatimbu 2610 m a.s.l which is on the eastern boundary of the TNLL. The maximum temperature is in the range of 26 to 35°C, while the minimum temperature is in the range of 12 to 17°C. Rainfall around the TNLL varies and is not evenly distributed throughout the year. In general, the average annual rainfall in TNLL is above 3000 mm. Even in months that are considered dry especially in areas with elevations of 1000 m or more, rainfall usually exceeds 60 mm/month (Rahmat et al. 2016).

In conclusion, we found 10 species of Sulawesi stingless bees *Tetragonula biroi, T. clypearis, T. fuscobalteata, T. laeviceps, T. pagdeni, T. sapiens, Heterotrigona itama, Homotrigona canifrons, Lepidotrigona terminata,* and *Wallacetrigona incisa.* The body size of different worker bees is generally considered a form of adaptation in foraging activities and exploiting flower resources. The research data are expected to contribute to the preservation and utilization of one of Indonesia's important biodiversity resources.

ACKNOWLEDGEMENTS

This work was supported by the Indonesian Ministry of Education and Culture research grant on the scheme of *Penelitian Disertasi Doktor* (PDD), with contract no. 0536/E5/PG.02.00/2023.

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