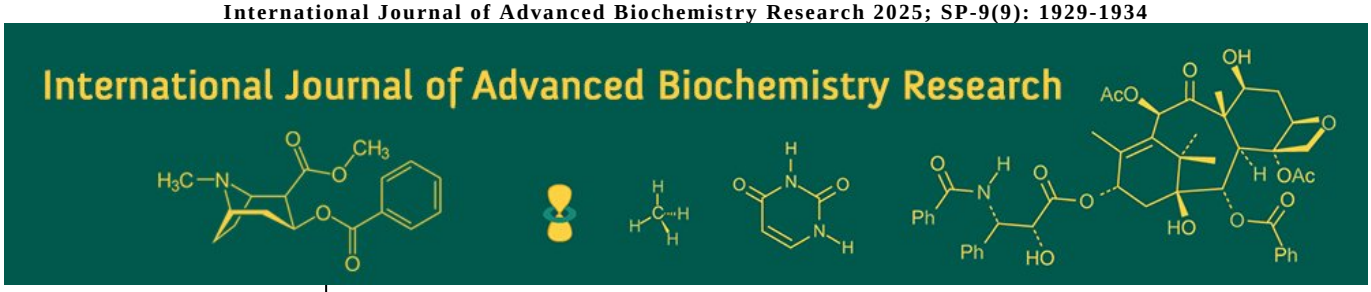

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Morphometric characterization of worker bees of *Tetragonula nr. pagdeni* from feral colonies

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Abstract
Pollination plays a vital role in enhancing the productivity and fruit quality. Among the diverse array of pollinators, stingless bees (*Tetragonula nr. pagdeni* Schwarz*)* have emerged as efficient and reliable agents, especially under enclosed or semi-enclosed cultivation systems. This study investigates the morphometric traits of *T. nr. pagdeni* across naturally occurring colonies within a confined urban and semi-urban landscape. Morphometric analysis of worker bees from seven colonies revealed moderate intra-species variation, with consistent body dimensions supporting efficient foraging and nest maintenance. The average body length was 2.151 mm, with slightly longer antennae (2.486 mm) aiding in navigation and olfaction. The head, thorax, and abdomen displayed proportional morphology suited for their ecological roles, while the elongated hind legs (5.789 mm) with robust tibiae facilitated pollen transport. The tongue length (0.564 mm) indicated adaptation to shallow floral resources, and wing morphology with five hamulii per bee ensured coordinated flight.

Keywords: Stingless bees, morphometrics, worker bees, intra-species, pollinator

Introduction
Insect pollinators are essential for the sexual reproduction of flowering plants, promoting genetic diversity and enhancing crop productivity (Tanda, 2019) [4]. Among them, bees are recognized as the most efficient pollinators, contributing to over 35% of global crop pollination services (Klein *et al*., 2007) [1]. Their role is critical for food security, biodiversity conservation, and sustainable agricultural practices (Nabhan and Buchmann, 1997) [3].
Among pollinators, stingless bees commonly referred to as dammer bees are the smallest bees found in India. They belong to the family Apidae and subfamily Meliponinae, and are characterized by vestigial stingers, reduced forewing venation, and robust mandibles that aid in nest construction and defense (Makkar *et al*., 2018) [2]. Although they produce only small amounts of honey, their ecological and economic importance as pollinators is substantial. Morphometric studies of stingless bees provide valuable insights into their taxonomy, ecology, and functional adaptations. Key traits such as body size, head width, tongue length, wing venation, and hind leg dimensions are critical for understanding their foraging efficiency, pollen transport capacity, and floral resource utilization. Variations in these parameters also help distinguish closely related species and reveal adaptations to specific ecological niches. In this context, the present study focuses on the morphometric characterization of worker bees of *Tetragonula nr. pagdeni* collected from feral colonies in urban and semi-urban habitats.

Materials and Methods
The bees were collected at Navsari Agricultural University (NAU), situated in the Navsari district of Gujarat, India. The geographical coordinates of the site are 20°57′ North latitude and 72°54′ East longitude, with an elevation of approximately 10 meters above mean sea level. The university campus consists of a mosaic of cultivated fields, gardens, patches of native and exotic tree species, old and new buildings, drainage systems, mud walls, brick structures, and shaded areas. This heterogeneous landscape provides ample nesting opportunities and floral resources for stingless bee species.

Adult stingless bees were captured at the entrance of each colony through insect net. Collected bees were immediately placed into clean vials containing 95 per cent ethanol, which preserves the external morphology. Using microscope, key features were measured Body length, Head width and length, Thorax length and width, Wing length and width, Antennal segment length, Hind tibia length and width and Proboscis length. These measurements are critical for distinguishing between closely related stingless bee species and may also reflect ecological adaptations.

Result and Discussion

The assessment was conducted on worker bees from seven stingless bee colonies to evaluate intra-species variation and establish average dimensions across key body structures. The findings revealed moderate consistency in body proportions across colonies, with minor variations indicating uniformity in colony-level phenotypic traits (Table 1, Plate 1).

Body Size and General Dimensions: The mean body length across colonies was recorded as 2.15±0.06 mm, indicating small-bodied workers typical of stingless bee species. Antennae length averaged 2.48±0.06 mm, slightly exceeding body length, highlighting their importance in tactile and olfactory sensing for navigation and foraging.

Head Morphology: Head measurements revealed a mean head length of 1.80±0.04 mm and head width of 2.18±0.06 mm, resulting in a slightly broader than long head structure, likely facilitating enhanced field vision and mandibular strength. Such morphology supports their foraging efficiency and nest construction activities.

Thoracic Measurements: The thorax length and width averaged 1.68±0.03 and 1.797±0.03 mm, respectively. These dimensions support the attachment of strong flight muscles and are consistent with their short but frequent foraging flights. The proportional thoracic build also underpins the bee agility in confined floral environments.

Abdominal Features: The abdomen length showed the highest among body regions, with a mean of 2.75±0.07 mm, while the abdomen width was 1.50±0.03 mm. The elongated abdomen accommodates internal organs, wax-producing glands, and the sting apparatus, important for colony defense and internal hive maintenance.

Mouthparts and Sensory Organs: The lapping tongue length was recorded at an average of 0.56±0.02 mm, reflecting adaptation for nectar foraging, particularly from shallow corolla flowers. The relatively short tongue suggests preference for open, accessible flowers rather than deep-tubed species.

Wing Morphology: Forewings were significantly longer than hindwings, with mean forewing length and width being 4.48±0.07 mm and 1.40±0.03 mm, respectively. Hindwing length averaged 3.32±0.06 mm, and width was 0.83±0.02 mm, revealing a typical membranous structure optimized for flight. The hamulii (wing hooks) averaged 0.24±0.01 mm, contributing to the coupling mechanism that facilitates synchronized wing movement during flight. Five hamulii present in stingless bees.

Hind Leg Adaptations: The hind leg length averaged 5.78±0.13 mm, the longest structure among all measured parts, enabling pollen collection and carrying. The tibial segment was of substantial size with a length of 1.95±0.04 mm and a width of 0.43±0.01 mm, supporting its role in pollen packing and grooming, especially in bees with corbiculae (pollen baskets).

The study on *T. laeviceps* from Yogyakarta revealed distinct morphological traits, including a shiny black body, brownish-yellow antennae, and two-toothed mandibles with body lengths of 2.14-3.76 mm and front wing lengths of 3.76-4.37 mm and hive structures featured oval-shaped funnel entrances (Trianto *et al*., 2020) [6]. Similarly, Tej *et al.* (2017) [5] reported *T. iridipennis* size from Coimbatore were largest, with head length (HL) 1.53 mm, wing length (FL) 4.00 mm, and hind tibia length (HTL) 1.60 mm, while bees from Erode were smallest (HL 1.23 mm, FL 3.32 mm, HTL 1.31 mm). All bees had 5 hamuli regardless of location.

Table 1: Morphometric Parameters of Stingless bee

Morphometrics (mm)	Colony 1	colony 2	colony 3	colony 4	colony 5	colony 6	Colony 7	Mean
Body length	2.13	2.21	2.05	2.18	2.11	2.23	2.14	2.15±0.06
Antennae length	2.48	2.53	2.43	2.6	2.46	2.5	2.39	2.48±0.06
Head length	1.79	1.88	1.75	1.81	1.77	1.83	1.79	1.80±0.04
Head width	2.17	2.24	2.12	2.18	2.27	2.19	2.1	2.18±0.06
Thorax length	1.66	1.73	1.67	1.65	1.71	1.69	1.68	1.68±0.03
Thorax width	1.78	1.85	1.77	1.79	1.81	1.83	1.75	1.79±0.03
Abdomen length	2.75	2.87	2.7	2.75	2.8	2.78	2.65	2.75±0.07
Abdomen width	1.49	1.55	1.48	1.52	1.49	1.54	1.46	1.50±0.03
Lapping tongue length	0.56	0.58	0.54	0.59	0.56	0.57	0.55	0.56±0.02
Forewing length	4.44	4.59	4.39	4.52	4.48	4.55	4.42	4.48±0.07
Forewing width	1.38	1.45	1.37	1.4	1.42	1.41	1.36	1.40±0.03
Hindwing length	3.28	3.41	3.24	3.35	3.28	3.38	3.31	3.32±0.06
Hindwing width	0.83	0.87	0.82	0.83	0.86	0.84	0.81	0.83±0.02
Hamulii length	0.24	0.25	0.23	0.24	0.26	0.24	0.23	0.24±0.01
Hind leg length	5.75	6	5.63	5.8	5.72	5.95	5.67	5.78±0.13
Hind leg tibial length	1.93	2.02	1.89	1.97	1.95	2	1.91	1.95±0.04
Hind leg tibial width	0.43	0.45	0.42	0.44	0.43	0.46	0.43	0.43±0.01

(1) Stingless Bee

(2) *Female Genitalia*

(3) *Male Genitalia*

(4) Abdomen Length

(5) Abdomen Width

(6) Thorax Width

(7) Thorax Length

(8) Tongue Length

(9) Body Length

(10) Head Length and Width

(11) Antennae Length

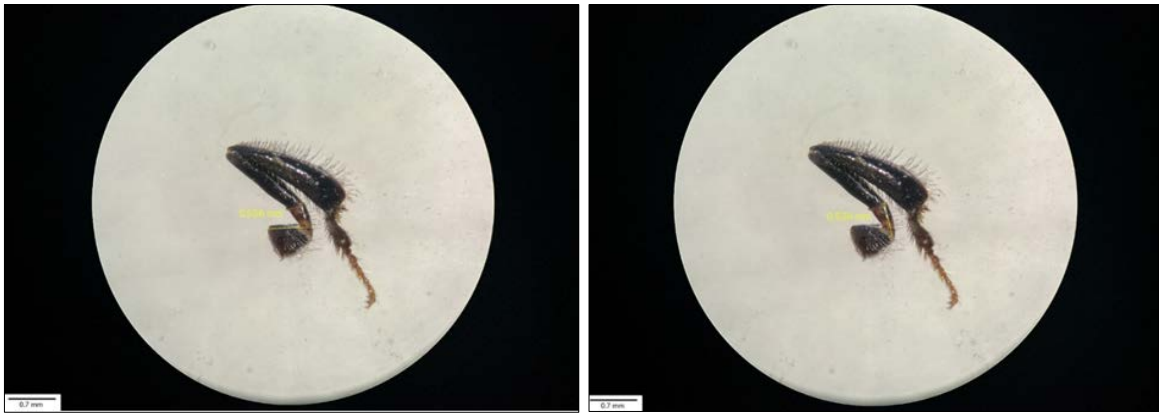
(12) Forewing Length

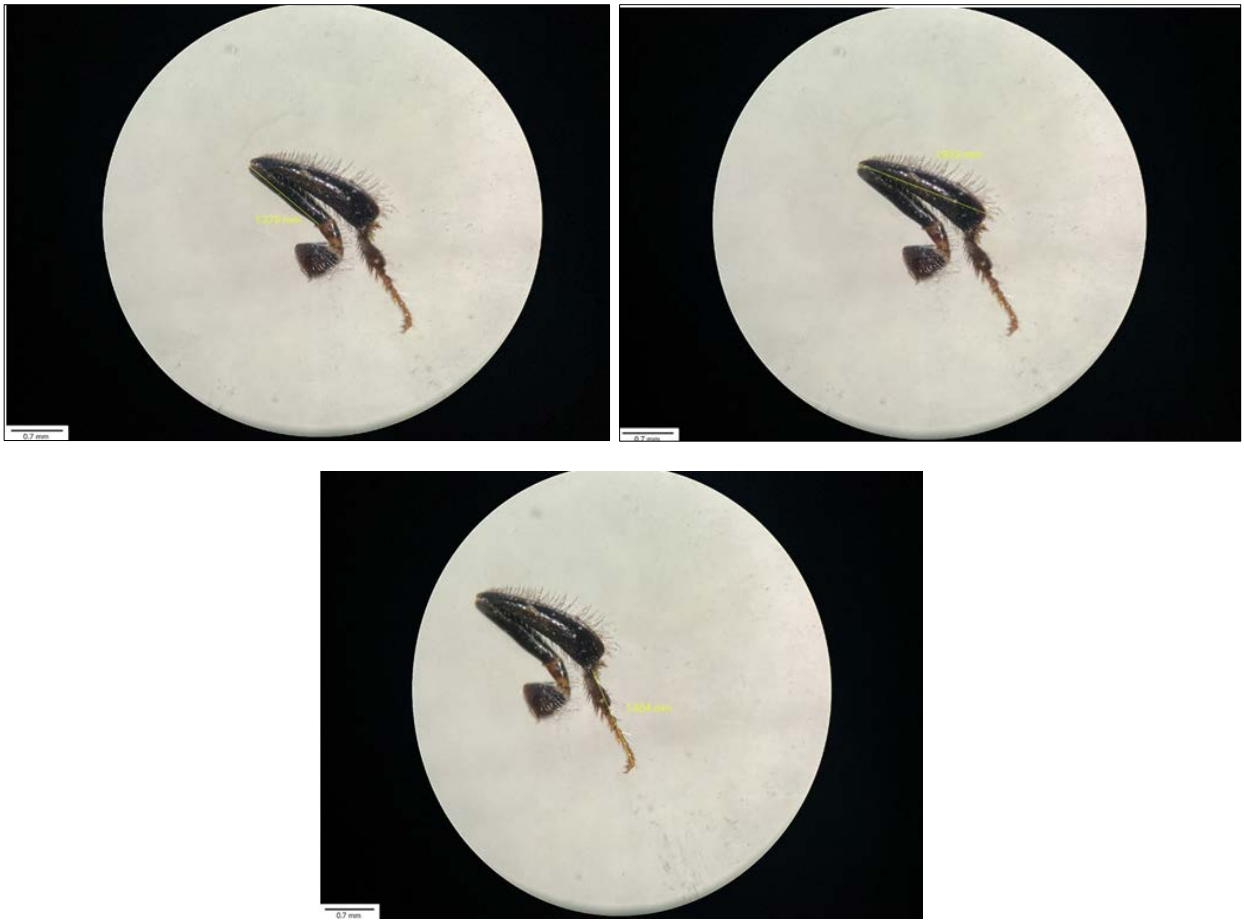
(13) Fore Wing Width

(14) Hamuli

(15) Hindwing Length

(16) Hindwing Width





(17) Hind Tibial Leg Length

Plate 1: Morphometrics of stingless bee

Conclusion

Morphometric analysis of workers from seven colonies showed low inter-colony variation, with average body length of 2.15 mm and forewing length of 4.49 mm. Other key traits included a relatively long antenna (2.49 mm), broad head (2.18 mm), and elongated hind legs (5.79 mm), adapted for effective foraging and pollen transport. The species possessed short lapping tongues (~0.56 mm), suited to shallow flowers, and five hamuli per hindwing, facilitating stable flight. These findings highlight the ecological plasticity, architectural adaptability, and functional morphology of *T. nr. pagdeni*, which together support its success in anthropogenically modified habitats.

Disclaimer (Artificial Intelligence)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

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Competing Interests

Authors have declared that no competing interests exist.

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