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Foraging Activity and Potential Forage Plant Resources Surrounding the Nests of *Tetragonula laeviceps*

Ni Kadek Deladarmi Yanti, I Made Budiarsa*, Manap Trianto, Fatmah Dhafir, Yulia Windarsih, Mursito S. Bialangi
Department of Biology Education, Faculty of Teacher Training and Education, Tadulako University.
Jl. Soekarno Hatta No KM 9, 94148, Central Sulawesi, Tel./Fax. (0451)422611, Indonesia.

Corresponding author*
budiarsa_imade@yahoo.com

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Abstract

Stingless bees are highly social insects that live in well-organized colonies characterized by a clear division of labor among individuals, including workers, queens, and males. These bees play an important ecological role as pollinators in both natural and agricultural ecosystems. One of the most commonly encountered stingless bee species in Indonesia is *Tetragonula laeviceps*, which is widely distributed and well adapted to various environmental conditions. *T. laeviceps* relies on flight activity to forage for nectar and pollen from flowering plants located around its nest. Plants that produce nectar, pollen, and resin, which are further processed into honey and propolis, serve as essential food and material resources for sustaining stingless bee colonies. This study aimed to examine the foraging activity patterns of *T. laeviceps* and to identify potential forage plant resources surrounding its nest. The research employed a descriptive exploratory design using both qualitative and quantitative approaches. Observations were conducted to record the daily flight activity of bees leaving the nest, returning with pollen, and returning without pollen, as well as to identify plant species that potentially serve as forage sources. The results showed that peak foraging activity occurred between 08:00 and 09:00 WITA, indicated by a high number of bees exiting the nest and returning with or without pollen. Foraging activity gradually declined toward the late afternoon, particularly between 16:00 and 17:00 WITA. This pattern reflects the daily rhythm of stingless bees, which includes an orientation and exploration phase in the morning, an exploitation phase during midday, and a gradual cessation of activity in the late afternoon. Observations of forage resources around the nests of *T. laeviceps* recorded a total of 13 plant species. Among these, seven species produced both nectar and pollen, three species produced only nectar, and three species produced only pollen. The diversity of forage plants indicates that the environment surrounding the nest provides sufficient and sustainable nutritional resources to support the growth and stability of the *T. laeviceps* colony.

Keywords: Foraging activity; Floral resources; Pollen; Stingless bee; *Tetragonula laeviceps*.

INTRODUCTION

Stingless bees are highly social insects that live in well-organized colonies characterized by a clear and complex division of labor among individuals, including queens, workers, and males, which ensures the efficiency and survival of the colony. To date, approximately 500 species of stingless bees have been formally identified worldwide, while more than 100 additional species are believed to remain undescribed, highlighting the still limited understanding of their global diversity (Hikmah *et al.*, 2023). Indonesia, as a tropical country with exceptionally high biodiversity and diverse ecosystems, provides highly suitable habitats for a wide variety of stingless bee species across different landscapes. One of the most commonly found stingless bee species in Indonesia is *Tetragonula laeviceps*, which is widely distributed and frequently encountered in both natural and human-modified environments (Putra *et al.*, 2017). This species is relatively small, with a body length of approximately 4 mm, and is morphologically characterized by a black to dark brown body coloration, which distinguishes it from other sympatric stingless bee species (Maryani *et al.*, 2024).

Tetragonula laeviceps constructs its nests in diverse locations, including hollow tree trunks, soil, building walls, and rock cavities, demonstrating its high adaptability to various environmental conditions and nesting substrates. In addition, stingless bees are well known for their ability to produce honey, pollen, and propolis, all of which have significant ecological functions within the colony as well as considerable economic value for human use (Abduh *et al.*, 2020). To obtain food resources in the form of nectar and pollen from a wide range of flowering plant species, *T. laeviceps* employs efficient foraging flight strategies that allow it to optimize energy expenditure and maximize resource acquisition (Masrianih *et al.*, 2022). The foraging flight activity of *T. laeviceps* follows a distinct daily rhythm, with higher levels of activity observed from morning to midday, corresponding to periods when flowers secrete greater quantities of nectar and pollen (Putra *et al.*, 2017). Generally, stingless bees exhibit a relatively shorter foraging range than honey bees (*Apis* spp.), typically ranging from approximately 300 meters to one kilometer from the nest; however, this distance may vary depending on the availability, diversity, and spatial distribution of food resources within their habitat (Prasetyo *et al.*, 2022).

Plants that produce nectar, pollen, and resin raw materials essential for the production of honey and propolis serve as critical food sources for stingless bees and directly influence colony health and productivity (Algifari, 2024). Some plant species are capable of producing both nectar and pollen simultaneously, whereas other species contribute only nectar or only pollen, resulting in variation in the nutritional resources available to foraging bees. Honey-producing stingless bees such as *T. laeviceps* are particularly attracted to plant species with brightly colored flowers, strong and fragrant floral scents, and attractive floral morphologies located around their nests, as these traits facilitate resource detection and foraging efficiency (Arifin *et al.*, 2020). Ecologically, *T. laeviceps* plays an important role in maintaining ecosystem balance, primarily by acting as a natural pollinator for various plant species within its surrounding environment, thereby supporting plant reproduction and biodiversity.

This research is important because stingless bees play a crucial role in pollination processes that directly support biodiversity conservation and ecosystem sustainability. By understanding daily flight activity patterns and identifying plant species that serve as forage resources, researchers can gain valuable insights into bee foraging preferences as well as the overall environmental quality of habitats surrounding their nests. Such information is not only beneficial for the conservation of local stingless bee populations but can also support the development of sustainable stingless bee cultivation as a source of natural honey and other hive products (Algifari, 2024). This study aimed to examine the foraging activity patterns of *T. laeviceps* and to identify potential forage plant resources surrounding its nest.

MATERIALS AND METHODS

Study area

This study was conducted in November 2025 in Dolago Village, South Parigi District, Parigi Moutong Regency, Central Sulawesi, Indonesia (Figure 1). The study site is located in an area dominated by small-scale stingless bee farming activities, where nests of *T. laeviceps* are maintained by local beekeepers in close proximity to agricultural land, home gardens, and mixed vegetation. The surrounding environment consists of a mosaic of cultivated crops, flowering ornamental plants, and naturally growing vegetation, which collectively provide diverse forage resources for stingless bees. This area represents a typical rural beekeeping landscape in Central Sulawesi, making it suitable for assessing foraging activity patterns and the availability of forage plant resources around managed *T. laeviceps* nests.

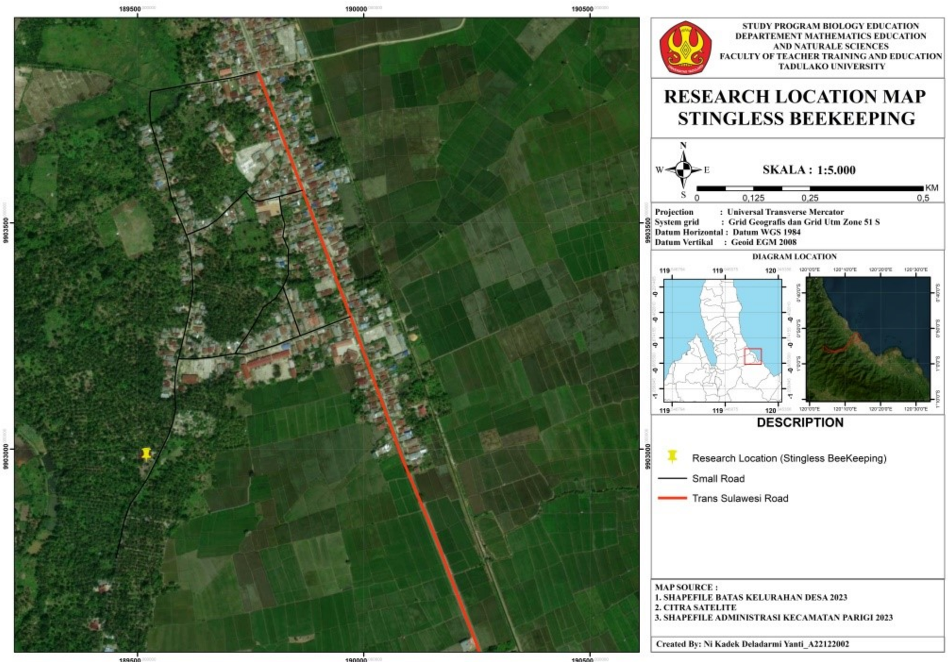

Figure 1. Map of the research location in Dolago Village, South Parigi District, Parigi Moutong Regency, Central Sulawesi, Indonesia.

Procedures

Observation of Flight Activity

Observations of the flight activity of *T. laeviceps*, including nest-exiting behavior, nest-entering behavior, and pollen transport by worker bees, were conducted through direct observation of two bee colonies. Each colony was observed for five minutes per hive at one-hour intervals. Observations were carried out for five days within one week to obtain a representative overview of daily activity patterns. The observation period ranged from 06:00 to 17:00 WITA, covering bee activity from early morning to late afternoon.

Pollen Collection

Pollen collection was performed by collecting pollen from the hind legs of worker bees originating from each observed colony. The collection process was conducted at 07:00 WITA, when foraging activity began to increase. Individual bees were placed into plastic bags to facilitate the release of pollen carried on their legs. The detached pollen was then collected and transferred into 1.5 ml microcentrifuge tubes. Each tube was labeled according to the colony of origin to ensure proper sample identification.

Acetolysis Method for Pollen Preparation

Pollen samples stored in 1.5 ml microcentrifuge tubes were treated with 1 ml of acetolysis solution consisting of a mixture of acetic anhydride and sulfuric acid in a ratio of 9:1. The supernatant was allowed to stand for approximately five minutes before being added to the samples. The samples were then heated in a water bath at 80°C for five minutes and subsequently centrifuged for ten minutes at 3,500 rpm. The acidic supernatant was discarded, and 1 ml of distilled water was added, followed by centrifugation under the same conditions. The washing step with distilled water was repeated two to three times until the residue was clean. The pollen sediment was then dried in an oven at 60°C overnight. After drying, pollen preparation was completed by adding 1 ml of 30% glycerin to the pollen and mixing thoroughly. One drop of the pollen suspension was placed onto a microscope slide using a dropper, covered with a cover slip, and prepared for microscopic observation.

Data analysis

Analysis of Flight Activity

The analysis of flight activity data of *T. laeviceps* was conducted using simple descriptive calculations to describe the bees' daily activity patterns. Observational data, including the number of bees leaving the nest, returning with pollen, and returning without pollen, were processed using Microsoft Excel software. The processed data were presented in the form of tables and graphs to facilitate interpretation of flight activity patterns across different observation time intervals.

Pollen Identification

Pollen identification was carried out using two complementary approaches to improve identification accuracy. First, collected pollen samples were compared with reference pollen collections obtained from plant species growing around the bee nests. Second, pollen identification was performed by matching pollen morphological characteristics with reference data from the *Australasian Pollen and Spore Atlas*, accessed via http://apsa.anu.edu.au/, and by referring to the *Pollen Flora of Taiwan*. Identification was based on pollen morphological features, including shape, size, aperture type, and exine ornamentation.

RESULTS AND DISCUSSION

Flight Activity of *Tetragonula laeviceps*

The flight activity of *T. laeviceps* was observed in two bee colonies during the observation period from 06:00 to 07:00 WITA and is presented in graphical form. The use of graphical representation facilitates clearer visualization and interpretation of the bees' flight activity patterns during the early daily observation period. Figures 2 and 3 illustrate the daily rhythm of nest-exiting and nest-entering flight activities of the two *T. laeviceps* colonies, highlighting both similarities and differences in activity patterns between colonies during the observation period.

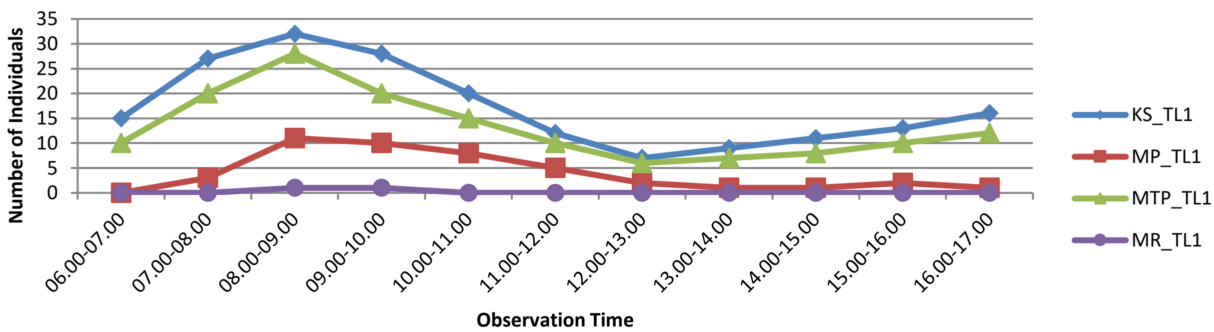

Figure 2. Mean daily flight activity of *T. laeviceps* in colony 1.

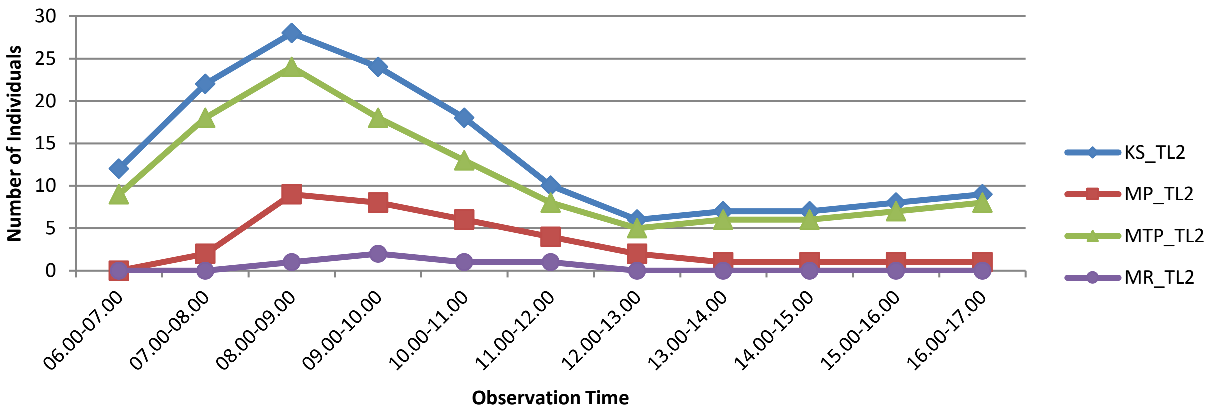

Figure 3. Mean daily flight activity of *T. laeviceps* in colony 2.

Forage Plant Resources of *Tetragonula laeviceps*

The availability of adequate food resources and the abundance of flowering plants around the stingless bee farming area are important factors supporting the survival and productivity of *Tetragonula laeviceps* colonies. An environment characterized by a diversity of plants producing nectar, pollen, and resin plays a crucial role in meeting the nutritional requirements of stingless bees in a sustainable manner. Based on field observations conducted around the nests of *T. laeviceps*, a total of 13 plant species were identified as potential forage resources. The presence of these diverse plant species indicates that the area surrounding the nests provides a varied and supportive foraging environment for stingless bees.pakan lebah serta melimpahnya tumbuhan sumber pakan di sekitar lokasi budidaya lebah *T. laeviceps* merupakan faktor penting yang menunjang keberlangsungan hidup lebah *T. laeviceps* Berdasarkan hasil pengamatan, teridentifikasi sebanyak 13 jenis tumbuhan sumber pakan yang terdapat di sekitar sarang *T. laeviceps* (Table 1).

Table 1. Nectar and pollen producing plants surrounding the nests of *T. laeviceps.*

No	Species	Local Name	Producer	References	Habitus
1	*Acacia* sp.	Akasia	Nectar, pollen	Agussalim *et al.* (2017)	Tree
2	*A. gangetica*	Rumput coromandel	Pollen	Asbur *et al.* (2024)	Herbs
3	*A. racemosa*	Menteng	Nectar	Rahayu *et al.* (2025)	Tree
4	*A. gigantea*	Biduri	Nectar	Anita *et al.* (2022)	Bush
5	*G. gnemon*	melinjo	Nectar, pollen	Agussalim *et al.* (2017)	Tree
6	*I. quamoclit*	Rincik bumi	Pollen	Raihandhany *et al.* (2023)	Bush
7	*L. domesticum*	Kokosan	Nectar, pollen	Mayanti *et al.* (2022)	Tree
8	*M. indica*	Mangga	Nectar, pollen	Primawati *et al.* (2022)	Tree
9	*P. urinaria*	Meniran	Nectar, pollen	Gama *et al.* (2016)	Bush
10	*P. spicatus*	Kaki gajah palsu	Nectar, pollen	Agustiani *et al.* (2024)	Herbs
11	*Spathiphyllum*	Lili perdamaian	Pollen	Torres *et al.* (2015)	Bush
12	*S. trilobata*	Seruni	Nectar, Pollen	Kamilya *et al.* (2024)	Bush
13	*T. subulata*	Bunga pukul 8	Nectar	Husna *et al.* (2020)	Bush

Discussion

Tetragonula laeviceps is a stingless bee species that remains active from morning until late afternoon. Its foraging flight activity around the nest follows a distinct daily rhythm, with higher activity levels observed from morning to midday, coinciding with periods when flowers secrete greater amounts of nectar (Putra *et al.*, 2017). In general, stingless bees have a relatively shorter foraging range compared to honey bees (*Apis* spp.), typically ranging from approximately 300 meters to one kilometer from the nest. However, this distance may vary depending on the availability and spatial distribution of food resources within the surrounding habitat (Prasetyo *et al.*, 2022). In this study, daily flight activity observations were conducted on two *T. laeviceps* colonies during the time interval of 06:00–07:00 WITA.

The first colony (Figure 2) initiated nest-exiting activity (KS) at 06:00 WITA with 16 worker bees, while the second colony (Figure 3) showed a similar pattern with 12 worker bees. Peak nest-exiting activity occurred between 08:00 and 09:00 WITA in both colonies, with 32 worker bees recorded in the first colony and 28 in the second colony. This increase in activity coincided with sunrise and the onset of nectar production by flowering plants. Nest-exiting activity gradually declined toward the afternoon and ended at 17:00 WITA, with 16 worker bees recorded in the first colony and 9 in the second colony. The increase in the number of workers leaving the nest indicates an active phase of food resource exploration and utilization.

The activity of workers returning to the nest carrying pollen (MP) also exhibited a clear daily pattern. Foraging activity began early in the morning, with the number of pollen-carrying workers increasing markedly between 08:00 and 09:00 WITA. During this period, 11 pollen-carrying workers were recorded in the first colony and 9 in the second colony. In subsequent hours, the number of pollen carriers gradually decreased toward the late afternoon. This pattern suggests that pollen foraging activity peaks during morning to midday when environmental conditions are optimal for foraging (Hasan *et al.*, 2024). Many plant species produce higher quantities of pollen and nectar during this time, prompting worker bees to maximize foraging efforts during these favorable conditions (Erwan *et al.*, 2022). This pattern reflects the diurnal nature of trigona bees, with peak activity occurring under optimal light and temperature conditions.

Nest-entering activity without pollen (MTP) displayed fluctuating patterns throughout the day. Peak MTP activity was recorded between 08:00 and 09:00 WITA, with 28 workers in the first colony and 24 in the second colony. The number of workers entering without pollen decreased significantly between 12:00 and 13:00 WITA, with only 6 and 5 workers recorded in the first and second colonies, respectively. Toward the late afternoon, between 16:00 and 17:00 WITA, MTP activity increased again, reaching 12 workers in the first colony and 8 in the second colony. The high frequency of workers entering the nest without pollen in the early morning is likely associated with the initial phase of daily colony activity, during which workers perform orientation and exploratory flights to assess environmental conditions and locate potential food sources (Indriyani *et al.*, 2025). By midday, workers shift to an exploitation phase, resulting in a higher proportion of individuals returning with pollen or nectar (Khikmanisa *et al.*, 2024). The renewed increase in MTP activity in the late afternoon reflects the cessation of foraging activity as light intensity decreases, prompting workers to return to the nest without continuing food collection (Budiarsa *et al.*, 2024). Overall, this pattern illustrates the daily rhythm of trigona bees, which separates orientation and exploration phases in the morning, exploitation phases during midday, and activity cessation in the late afternoon.

Resin-carrying activity (MR) was observed at relatively lower frequencies in both colonies compared to pollen-carrying and pollen-free nest-entering activities. Resin is a non-food material that plays an essential role in nest construction, protection against pathogens, and colony defense (Wahyuningsih *et al.*, 2022). The low frequency of resin-carrying activity suggests that resin collection is opportunistic and conducted according to colony needs rather than as a primary daily activity such as nectar and pollen foraging. The absence of a distinct peak in resin collection further indicates that this activity is not directly dependent on flower phenology but is instead influenced by structural and defensive requirements of the colony (Hirmarizqi *et al.*, 2019). Nest-entering activity without pollen also includes nectar and water collection, as well as orientation and intra-colony communication activities.

A total of 13 plant species were identified as potential forage resources for *T. laeviceps* at the study site. Seven species produced both nectar and pollen, namely *Acacia* sp., *Gnetum gnemon*, *Lansium domesticum*, *Mangifera indica*, *Phyllanthus urinaria*, *Pennisetum spicatus*, and *Sphagneticola trilobata*. Three species produced only pollen (*Asystasia gangetica*, *Ipomoea quamoclit*, and *Spathiphyllum* sp.), while three species produced only nectar (*Barringtonia racemosa*, *Calotropis gigantea*, and *Turnera subulata*). These findings indicate that plant species producing both nectar and pollen were more abundant than those producing only one type of resource. The diversity of forage plants suggests that the environment surrounding the nests provides sufficient and sustainable nutritional resources for the colony (Wahyuningsih *et al.*, 2022).

Various plant species surrounding *T. laeviceps* nests produce nectar and pollen that play critical roles in plant–pollinator interactions. Nectar functions as a primary attractant for pollinating insects (Wibowo *et al.*, 2022), whereas pollen serves as the male gamete that must be transferred between flowers to ensure successful pollination (Ferdyan *et al.*, 2021). The simultaneous production of nectar and pollen enhances the likelihood of effective pollen transfer by pollinators, including trigona bees, thereby supporting fertilization, fruit and seed formation, and the sustainability of plant regeneration. In addition to food resources, several woody plant species surrounding the nests may also serve as potential sources of resin, either through natural exudates or plant injuries. Resin is essential for stingless bees as it is used as an adhesive material, for sealing nest cavities, and as a primary component of propolis, which functions as a natural antibacterial and antifungal agent (Hirmarizqi *et al.*, 2019).

CONCLUSIONS

The results of this study indicate that the peak activity of *Tetragonula laeviceps* occurred between 08:00 and 09:00 WITA, including bees leaving the nest, returning with pollen, and returning without pollen in both observed colonies. A total of 13 forage plant species were identified around the nest, consisting of seven species producing both nectar and pollen, three species producing only nectar, and three species producing only pollen. These findings demonstrate that the surrounding environment provides sufficient and diverse food resources to support the daily foraging activity and sustainability of colonies.

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Competing Interests: The authors declare that there are no competing interests.

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