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Visitation patterns of cultivated *Tetragonula biroi* colonies on *Xanthostemon chrysanthus* flowers

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A B S T R A C T

Tetragonula biroi is a cultivated stingless bee widely used in meliponiculture due to its high honey and propolis production. One recommended forage plant is *Xanthostemon chrysanthus*, yet quantitative data on visitation dynamics and environmental drivers remain limited. This study addressed the following research questions Does visitation frequency of *T. biroi* vary across time of day? And which environmental factors influence visitation activity? We hypothesized that visitation frequency would peak under optimal morning microclimatic conditions and correlate positively with temperature and light intensity. The study was conducted in June 2025 in Banyumas, Central Java, using 10 managed colonies and flowering *X. chrysanthus* trees observed over 12 sampling days. Bee visitation was recorded at 10-minute intervals during morning (07.00 – 10.00), midday (11.00 – 13.00), and afternoon (14.00 – 16.00) periods. Data were analyzed using one-way ANOVA and Principal Component Analysis (PCA). Visitation frequency showed a descriptive peak in the morning (6.11 ± 2.25 visits/10 min) but did not differ significantly among periods ($F = 0.850$; $p = 0.437$). Visit duration displayed a similar non-significant pattern ($F = 0.541$; $p = 0.587$). The number of flowers visited increased from morning to afternoon, indicating compensatory exploratory foraging as nectar availability declined. PCA revealed that temperature and light intensity were positively associated with visitation frequency, whereas humidity was negatively associated. These findings indicate that *T. biroi* exhibits flexible foraging behavior across a broad range of microclimates. In practice, placing colonies in warm, moderately humid environments may optimize foraging efficiency and support stingless bee productivity.

Keywords: foraging behavior; meliponiculture; microclimatic factors; stingless bee.

1. INTRODUCTION

Indonesia has a diverse range of bee species that produce honey. Currently, many beekeepers are beginning to cultivate stingless bees, also known as Meliponini bees. Cultivating stingless bees is considered to increase community income. Furthermore, bees play a vital role in ecosystems and agriculture. Bees play a role in plant pollination. Plants in plantation areas produce nectar, which serves as a food source for bees, while bees assist in the pollination process (Saepudin et al., 2011).

One type of stingless bee that can produce honey and is now being cultivated is *Tetragonula biroi*. This species originates from Sulawesi and is now widely cultivated on Java due to its adaptability, non-aggressive nature, and ability to produce high-quality honey and propolis, making it highly economically viable. (Setyaningsih, 2024). The morphological characteristics of the *T. biroi* bee include a jet-black caput, black thorax, and black abdomen. The body length of *T. biroi* ranges from 2.75 to 3.25 mm. (Purba et al., 2023). The relatively small body of *T. biroi* enables them to visit small flowers in search of nectar and pollen, making them effective pollinators across various flowering plant species.

Bees feed on nectar from flowers that contain a sweet liquid. The nectar collected contains water, glucose, and sucrose, which serve as an energy source for the bee (Agussalim et al., 2017).. The bee will convert the flower nectar obtained into honey, which is stored in the beehive. In general, nectar is maximally produced by flowering plants in the morning. The criteria for flowers that serve as a food source for bees are determined by several factors, including flower colour, nectar and pollen availability, and flower morphology (Rianti et al., 2010). In general, bees are attracted to small flowers that tend to be open and have a long flowering period. Based on research results, several plant species that serve as food sources for *T. biroi* bees and can promote better colony growth include *Dombeya cayuxi*, *Dombeya natalensis*, *Xanthostemon chrysanthus*, and *Antigonon leptosus* (Widhiono et al., 2024).

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However, despite numerous reports describing plant species visited by stingless bees, most studies remain descriptive and focus on listing floral resources rather than quantitatively examining visitation frequency, temporal patterns, and the influence of abiotic factors on foraging behaviour. Specifically, empirical data on the interaction between *T. biroi* and *X. chrysanthus* under field conditions are still limited. Previous studies recommend *X. chrysanthus* as a forage plant due to its prolonged flowering period. (Widhiono et al., 2024) yet the dynamics of visitation intensity and the role of microclimatic variables (temperature, humidity, and light intensity) in shaping these patterns have not been thoroughly investigated.

Xanthostemon chrysanthus, commonly known as santos lemon, produces conspicuous yellow flowers with abundant stamens and nectar, making it potentially attractive to stingless bees. (Saputri et al., 2024). Although this plant is widely recommended for stingless bee cultivation systems (Alpian et al., 2022). Scientific evidence quantifying its ecological value as a foraging resource for *T. biroi* remains insufficient. Based on these limitations, this study addresses the following research questions: What is the frequency and temporal pattern of *T. biroi* visitation to *X. chrysanthus* flowers, and which environmental factors significantly influence visitation activity?

We hypothesize that the visitation frequency of *T. biroi* varies significantly across time of day, with peak activity occurring during optimal microclimatic conditions. Temperature and light intensity positively correlate with visitation frequency, while excessive humidity negatively affects foraging activity. This study contributes not only to practical meliponiculture management but also to the ecological understanding of plant–pollinator interactions involving stingless bees in tropical agroecosystems. By quantifying visitation dynamics and environmental drivers, this research provides empirical evidence supporting the functional role of *X. chrysanthus* in sustaining *T. biroi* colonies. It strengthens the theoretical framework of stingless bee foraging ecology.

2. Materials and Methods

2.1. Study area

This research was conducted in Pabuwaran Village, North Purwokerto District, Banyumas Regency, Central Java Province, in June 2025. The study site consisted of residential home gardens. The observed *X. chrysanthus* trees were located in open areas with high exposure to sunlight, while nearby vegetation included fruiting and ornamental plants that may serve as alternative floral resources. *T. biroi* colonies were maintained in wooden hive boxes placed 1–2 m above ground under partial shade, approximately 2–10 m from the observed trees.

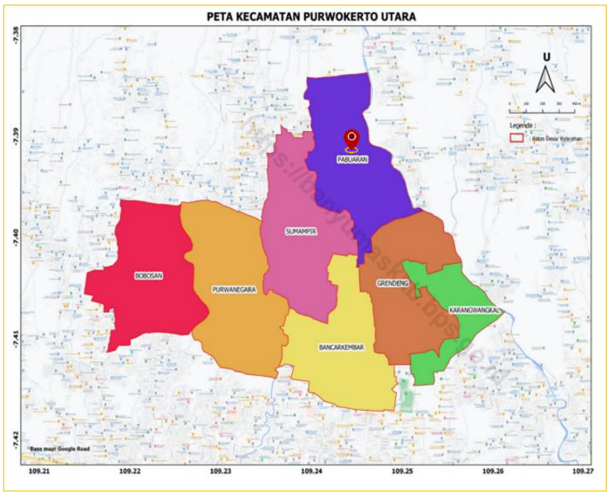

Figure 1. Research location map (BPS Kab. Banyumas, 2022)

2.2. Materials

The tools used in this study were a thermohygrometer, a luxmeter, an anemometer, a hand counter, writing instruments, a stopwatch, and a camera. The materials used in this study were 10 boxes of stingless honeybee colonies (*Tetragonula biroi*) and 10 plants of Santos (*Xanthostemon chrysanthus*). Colonies were selected based on the following criteria: (1) similar colony strength indicated by comparable numbers of brood cells and worker activity at the hive entrance, (2) absence of visible disease or parasite infestation, and (3) active foraging behavior before observation. The selected *X. chrysanthus* trees were in bloom, with comparable canopy size and flower abundance, and were located within a 2 - 10 m radius from the hives to minimize variation in foraging distance.

2.3. Methods

2.3.1. Observation *Tetragonula biroi*

The research method employed a survey approach, complemented by direct observation and random sampling. Observations of the activity of *T.biroi* bees visiting *X.chrysanthus* plants were conducted for 12 days. Observations were limited to every 10-minute visit time, with three repetitions at each observation time: morning (07.00-10.00 WIB), afternoon (11.00-13.00 WIB), and evening (14.00-16.00 WIB) (Umar et al., 2019). The number of *T. biroi* bee colonies used was 10 colonies (10 boxes). *T. biroi* bee colonies visiting *X.chrysanthus* plants were counted using a hand counter and documented using a camera. The frequency of visits was calculated every 10 minutes/colony with three repetitions at each observation time.

2.3.2. Sampling *Xanthostemon chrysanthus*

Flower sampling on *Xanthostemon chrysanthus* plants was conducted using a random sampling method to ensure each flower had an equal chance of being selected as an observation unit. Selected flowers were then marked for easy identification and consistent observation throughout the study. For each sampled flower, bee visitation activity was observed, including the number of flowers visited per minute and the duration of each visit (Indraswari et al., 2016). Observations lasted 30 minutes per period.

2.3.3. Environmental Parameter Measurement

Environmental parameter measurements were conducted to obtain data on microhabitat conditions that could influence bee visitation activity. Observed parameters included air temperature, humidity, and light intensity around flowering plants, which serve as a food source for bees (Shullia et al., 2024). The measurements were conducted by placing a thermohygrometer and a luxmeter at the exact location of the bee activity observation site, around the flowers. The measurement results were documented with a camera to ensure accurate, verifiable data. Furthermore, all instrument readings were recorded on an observation tally sheet. This data was used as supporting variables to analyze the relationship between environmental conditions and bee visitation frequency throughout the study.

2.3.4. Data analysis

Data were analyzed using IBM SPSS Statistics version 27 and PAST software. The effect of observation time (morning, midday, and afternoon) on bee visitation frequency was tested using one-way analysis of variance (ANOVA). Before ANOVA, statistical assumptions were evaluated using normality and homogeneity tests. When assumptions were met, ANOVA was performed, followed by Tukey's HSD post hoc test to identify significant differences among time periods ($\alpha = 0.05$). If assumptions were violated, data transformation was applied, or a non-parametric alternative (Kruskal–Wallis test) was used.

Principal Component Analysis (PCA) was conducted in PAST to explore relationships among environmental variables (temperature, relative humidity, light intensity, and wind speed) and the visitation frequency of Tetragonula biroi. PCA was selected as a multivariate exploratory approach to reduce dimensionality and identify dominant environmental gradients influencing visitation patterns. Before analysis, data were standardized to eliminate scale differences among variables. The interpretation of principal components was based on eigenvalues (>1) and loading scores to determine the most influential environmental factors.

3. Results and Discussion

3.1 Bee visit activity

Based on the observation results (Figure 2), the frequency of *Tetragonula biroi* bee visits to *Xanthostemon chrysanthus* flowers tends to be higher in the morning (7:00-10:00 WIB) compared to the afternoon (11:00-1:00 PM WIB) or evening (2:00-4:00 PM WIB). The average frequency of morning visits was 6.11 ± 2.25, higher than the afternoon (5.19 ± 1.23) and evening (4.72 ± 3.25) visits. This pattern indicates that the morning period is a more optimal time for *T. biroi* bees to forage.

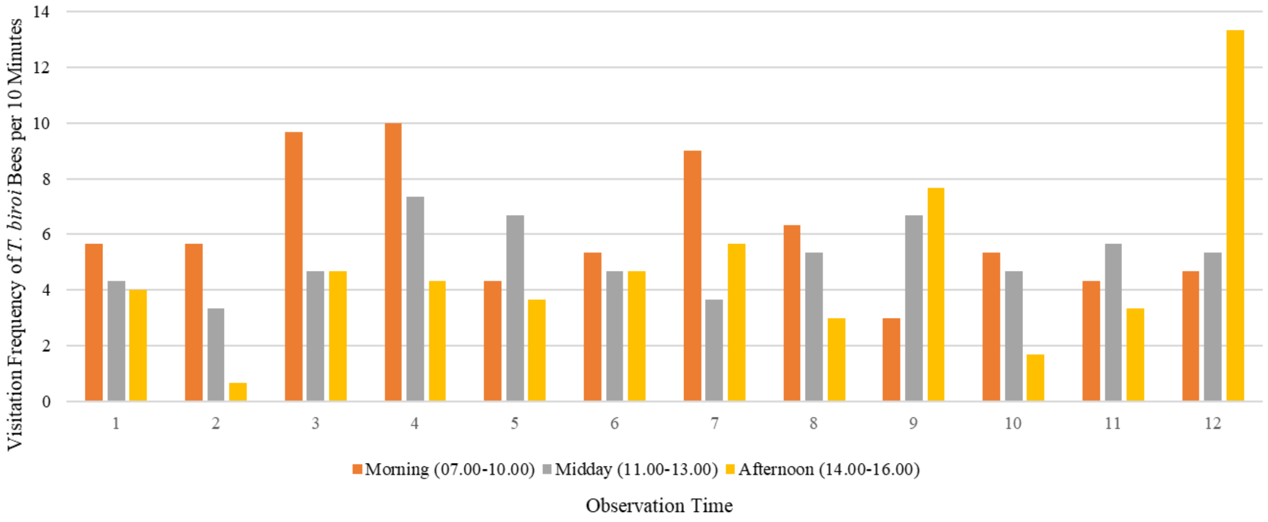

Figure 2. Diagram of the visitation frequency of *Tetragonula biroi* on *Xanthostemon chrysanthus* flowers.

Descriptively, the frequency of visits by *Tetragonula biroi* bees to *Xanthostemon chrysanthus* flowers appears to be higher in the morning than during the day. Still, the results of the statistical analysis using One-Way ANOVA (Table 1) show a significance value (sig) of 0.437 (>0.05). These results indicate no significant difference in the average frequency of bee visits across the three observation times (morning, afternoon, and evening). The trend of *T. biroi* bee visit activity is high in the morning. Still, the difference is not significant (sig value = 0.437). These results suggest that although temporal variation in visitation activity was observed, the differences were not strong enough to indicate a distinct peak in foraging time. This result was also found in research. (Ramadani et al., 2021), which observed the daily activities of stingless bees, *Sundatrigona moorei* and *Lepidotrigona terminata*, in oil palm and rubber plantations, showing that foraging activity by time is not statistically different.

Table 1. One-way ANOVA results of the visitation frequency and duration of *Tetragonula biroi* on *Xanthostemon chrysanthus*

Variable	F-value	sig.
Visitation Frequency	0, 850	0.437
Visitation Duration	0, 541	0, 587

The absence of statistical significance indicates that *T. biroi* maintains relatively stable visitation activity across daytime periods under the observed environmental range. This pattern may reflect behavioral flexibility rather than strict temporal specialization. Stingless bees are known to adjust their foraging schedules dynamically in response to short-term microclimatic fluctuations, nectar availability, and colony energy demand. Therefore, the slightly higher morning activity observed in this study should be interpreted as a tendency rather than a definitive behavioral peak.

Environmental measurements showed that morning conditions were characterized by increasing light intensity and moderate temperature, which physiologically support flight activity and visual navigation. In the morning, light intensity begins to increase, making it easier for bees to find target flowers, as temperatures and humidity are lower than during the day. During the day, air temperatures tend to be higher and humidity lower, which can reduce bee activity because bees need to conserve energy and avoid stress from excessively high temperatures. Observations made in the afternoon showed more fluctuation in visits. The microclimatic contrast among time periods may not have been strong enough to generate statistically distinct visitation patterns. This suggests that *T. biroi* can sustain foraging activity across a relatively broad microclimatic window.

The results obtained in this study are in line with those of research. (Agus et al., 2019), which reported that the daily foraging activity of *Tetragonula laeviceps* in the morning (07:00-11:00) was higher than in the afternoon. Similarly, several research results on stingless bees, such as those conducted by (Bharath et al., 2020), where the foraging activity of *Tetragonula iridipennis* bees was highest in the morning (between 08:00 and 11:00), and (Zeballos et al., 2022).It was reported thatin *Plebeia catamarcensis* bees, the highest nectar-searching intensity was concentrated during the morning period. This comparison confirms that, in general, stingless bees prefer morning foraging. Sabatina et al., 2025 They reported that stingless bees start foraging around 06:00-08:00. Environmental factors also play a role, with the maximum temperature being significantly positively correlated with potential foraging activity. At the same time, relative humidity shows a negative correlation. Additionally, high rainfall limits bees’ flight, so foraging behavior occurs only during the most favorable periods of the day.

Methodological factors may also explain the non-significant results. The relatively short observation period (a single month), the limited number of colonies, and natural variability in flower nectar production may have reduced statistical power. Thus, temporal differences in visitation may become more apparent under more extreme seasonal or climatic variation.

3.2 Bee visit duration

Based on the observation results (Figure 3), it is evident that the average length of visits by *Tetragonula biroi* to *Xanthostemon chrysanthus* flowers is longer in the morning (07:00-10:00 WIB) than it decreases during the day and increases slightly again in the afternoon. This pattern of visiting activity indicates that nectar and pollen are still abundant in the morning, so bees need more time to collect them. This is in line with research.(Takkis et al., 2018), which reported that very high temperatures (during the day) are negatively correlated with nectar secretion (changing sugar concentration due to water loss).

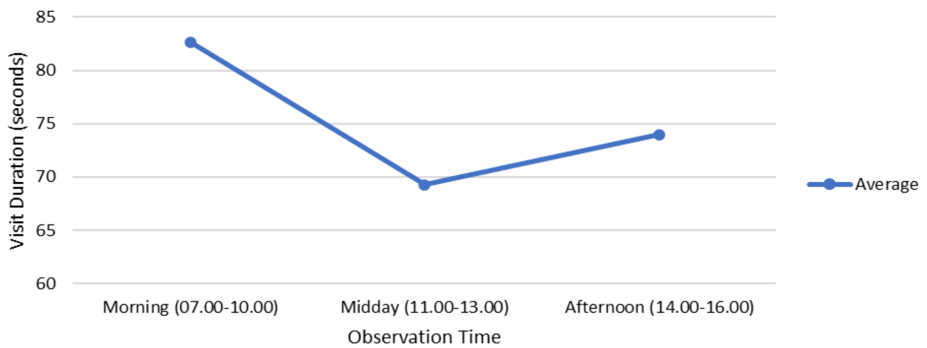

Figure 3. Graph of the average visitation duration of *Tetragonula biroi* on *Xanthostemon chrysanthus* flowers.

More extended visits by bees to flowers in the morning may be linked to foraging efficiency. When temperature and humidity are optimal in the morning, bees can maximize their proboscis activity and energy metabolism in nectar collection. Conversely, during the day, when temperatures are higher, bee activity can be hampered by increased heat stress, resulting in shorter visits. This supports the idea that stingless bee foraging behavior is strongly influenced by the surrounding microclimate, including temperature and relative humidity (Hilário et al., 2000).

The average duration of visits tended to be longer in the morning and shorter during midday, with a slight increase again in the afternoon. Nevertheless, statistical analysis showed no significant difference among time periods ($F = 0.541$; $p = 0.587 > 0.05$). This indicates that visit duration remained relatively consistent despite fluctuations in environmental conditions.

The duration of a bee visit essentially depends on the bee species, flower morphology, and environmental conditions. Based on research by Chuttong et al., 2022 Honey bees spend more time visiting each flower due to their larger body size and higher nectar storage capacity. Meanwhile, stingless bees (*Tetragonula*) use a faster, more repetitive foraging strategy. Nevertheless, *Tetragonula biroi* bees play a crucial role in the pollination of X. chrysanthus through intensive morning visits, when the availability of food sources (nectar) is at its optimal.

The results of this study confirm that the duration of *T. biroi* visits to *X. chrysanthus* flowers remains relatively stable over time, with indications of longer activity in the morning; however, the difference is not statistically significant. This reinforces the understanding that stingless bees exhibit adaptive foraging behavior that supports plant pollination in tropical ecosystems. Because environmental variables did not exceed physiological tolerance limits, microclimatic pressure may have been insufficient to produce statistically significant behavioral shifts. This reinforces the interpretation that *T. biroi* exhibits adaptive foraging plasticity rather than strict temporal dependency.

3.3 Number of flowers visited

In contrast to visitation duration, the number of flowers visited per individual increased from morning (12.61 ± 7.54) to afternoon (15.92 ± 7.74). This pattern suggests a shift in foraging strategy rather than a change in overall activity intensity. When nectar availability per flower decreases over time, bees may compensate by visiting more flowers to maintain net energy intake.

Table 2. Number of *Xanthostemon chrysanthus* flowers visited by *Tetragonula biroi*.

Time	Min	Max	Mean±SD
Morning	5.00	35.00	12.61±7.54
Midday	5.00	35.33	14.67±7.69
Afternoon	7.33	35.33	15.92±7.74

This behavioral adjustment aligns with optimal foraging theory, where pollinators balance resource depletion and energetic efficiency. Instead of increasing visit duration, bees expand spatial exploration. Such compensatory behavior may explain why visitation frequency remained statistically similar across periods, while the number of flowers explored increased. Several field studies on stingless bees have also shown that flower visitation patterns change throughout the day, with pollen collection peaking in the morning. In contrast, nectar collection and visitation times can shift to the afternoon and evening when the supply of each flower begins to decline. This increases the colony's exploration of alternative sources (by visiting more flowers (Basari et al., 2018; Hilário et al., 2000; León et al., 2015). Therefore, the increased number of flowers visited during the day and evening can increase the opportunity for cross-pollination because pollen is carried to different individual flowers.

Figure 4 . *Xanthostemon chrysanthus* as a forage source for *Tetragonula biroi*

Stingless bee visitation activity is not only influenced by the availability of nectar and pollen in flowers. Still, it can also be influenced by a combination of flower morphology factors and environmental conditions. For example, observations on *Tetragonula laeviceps* revealed that it collected more pollen from rotundifolious and salverform flowers, which are generally small, arranged in groups, and bloom between 06:00 and 16:00 (Sulistiyaningsih et al., 2023). Another study also reported that *Tetragonula* colonies tend to make high numbers of visits to small or grouped flowers (Tierney et al., 2023). Additionally, the frequency of *T. laeviceps* visits is also significantly influenced by temperature, relative humidity, and light intensity during the flowering period (Nurdiansyah et al., 2023). Flower morphology and clustered floral arrangement in *X. chrysanthus* may further facilitate rapid inter-flower movement, enabling efficient exploitation without prolonged handling. Thus, both internal flower factors (shape, size, and bloom pattern) and external environmental factors (microclimate) play a crucial role in determining the number of flowers visited by stingless bees.

3.4 Influence of environmental factors

Various environmental factors can also influence variations in bee foraging activity patterns. Temperatures range from morning to afternoon between 28 °C and 39°C, with a relative humidity of 50–66%. High-temperature conditions accompanied by decreased humidity during the day reduce the intensity of bee exploration of each flower, causing bees to increase the number of visits and shorten their durations. In the afternoon, the temperature drops (28–31°C) and humidity increases (63–77%). These conditions are consistent with bees' physiological preferences, which require moderate temperatures and high relative humidity to maintain metabolic efficiency and flight stability. This is in line with Abrol (2012) report that pollinator activity reaches optimal levels at temperatures of 25–32°C with high relative humidity.

Table 3. Environmental parameter measurements

Observation Time	Environmental Parameters			
	Temperature Min–Max (°C)	Humidity Min-Max (%)	Light Intensity Min-Max (Lux)	Wind Speed Min-Max (m/s)
Morning (07.00-10.00)	28-39	50-75	543-1535	0-0.3
Midday (11:00-13:00)	29-35	58-66	496-1322	0-0.4
Afternoon (2:00 PM - 4:00 PM)	28-31	63-77	237-1085	0-0.2

Light intensity was recorded as high from morning to midday (496–1535 lux), decreasing in the afternoon (237–1085 lux). Light plays a crucial role in bees' visual orientation and navigation, enabling them to detect flowers and return to the hive. Observational data indicate that although light intensity in the afternoon is lower than during the day, it remains within a threshold that allows optimal foraging activity. The decrease in light intensity in the afternoon is offset by an increase in the number of flowers visited, indicating behavioral compensation by bees to maintain access to food sources.

During the observation, wind speed ranged from 0 to 0.4 m/s. This value falls into the low category and does not impact flight stability or bee orientation. Balfour & Ratnieks, 2025 Reported that high wind speeds can interfere with bee flight activity and cause bee foraging rates to decrease. Still, the conditions of this study suggest that wind factors do not significantly limit *the activity of T. biroi*. To further understand the influence of environmental factors on bee visiting activity, a Principal Component Analysis (PCA) was conducted to identify the most significant ecological parameters during the daily observation period (Figure 5).

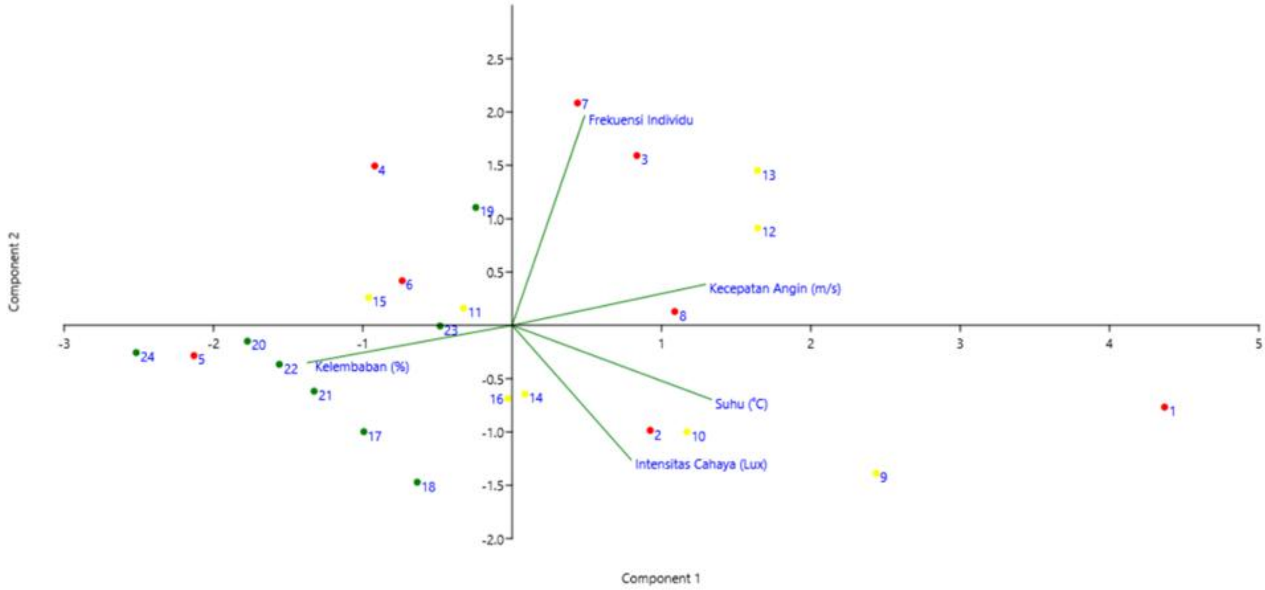

Figure 5. Biplot showing the relationship among environmental parameters based on PCA analysis

Component 1 describes the gradient of environmental physical conditions, primarily influenced by temperature, light intensity, and wind speed. Positive values in Component 1 represent hot, bright, and windy conditions (daytime). Negative values in Component 1 represent humid and dim conditions (morning/evening). Component 2 (PC2) more accurately represents bee visitation activity (individual frequency) and its variation with environmental humidity. Visitation frequency aligns with the vectors of temperature, light intensity, and wind speed. The biplot results show that visitation frequency increases under conditions of high temperature and light intensity, and when wind speed remains low to moderate. In other words, *T. biroi* bees actively visit during the morning-to-midday period, when environmental conditions are bright and warm.

Environmental factors, Temperature (°C) and Light Intensity (Lux), are located close together and in the same direction, indicating that the two variables are highly positively correlated. Increased temperature is typically accompanied by increased light intensity, and both are positively correlated with increased bee visiting activity. This condition indicates that bees are more active when light is available for visual navigation and body temperature is optimal for flight. Wind Speed (m/s) has a vector direction aligned with temperature and light, but is shorter, indicating a moderate effect. Light winds help spread floral scent (improving flower detection), but too strong winds can also inhibit bee flying activity. Humidity (%) is in the opposite direction (to the bottom-left) of the frequency of visits; these results indicate a strong negative relationship between humidity and visit frequency. This means that the higher the humidity, the lower the bee foraging activity. Humid conditions usually occur in the early morning or after rain, when bees tend to be inactive due to the risk of wet wings and low temperatures. Overall, these results indicate that the foraging activity of *T. biroi* is strongly influenced by environmental dynamics, particularly temperature, light intensity, and humidity, which synergistically determine the level of bee visitation to *X. chrysanthus* flowers.

The visitation activity of *T. biroi* bees to *X. chrysanthus* flowers exhibited a pattern of peak activity in the morning (07:00–10:00 WIB), with a more extended visit duration, followed by a decrease during the day and a slight increase again in the afternoon. The number of flowers visited increased from morning to afternoon as a form of compensation for the decrease in nectar availability per flower. Although the differences between times were not statistically significant, this pattern reflects the bees' adaptive response to changes in microclimate conditions. PCA analysis revealed that temperature and light intensity were positively correlated with visit frequency, while humidity was negatively correlated, and wind speed had a moderate effect on visit frequency. These results confirm that *T. biroi* is more active in foraging in warm, bright, and moderately humid environments, reflecting its adaptability to the dynamics of tropical microclimates.

Furthermore, the results of this study are helpful for stingless bee breeders as a basis for determining the optimal time for bee activity for honey and propolis production, as well as adjusting colony placement to favorable microclimate conditions (morning to midday, with warm temperatures and sufficient light). Thus, this study not only deepens understanding of the behavioral ecology of T. biroi but also provides practical implications for more efficient and productive stingless bee cultivation.

4. CONCLUSION

The foraging activity of *Tetragonula biroi* on *Xanthostemon chrysanthus* flowers exhibited apparent temporal variation, with the highest visitation frequency occurring in the morning (07:00–10:00 WIB). During this period, bees exhibited longer visitation durations, which coincided with optimal nectar and pollen availability. Although the number of visits per time interval tended to decrease toward midday, the total number of flowers visited increased through the afternoon, indicating that T. biroi expanded its foraging range to compensate for declining floral resource quality. Environmental factors, particularly temperature and humidity, played a significant role in shaping bee foraging behavior. Warmer temperatures and moderate humidity in the morning promoted higher visitation, whereas high humidity or excessive heat reduced flight and foraging efficiency. PCA analysis further confirmed that temperature and light intensity were positively correlated with visitation frequency, while humidity showed a strong negative relationship. This pattern reflects the adaptive behavior of *T. biroi* in response to the tropical microclimate, enabling efficient resource utilization and maximizing pollination success on *X. chrysanthus* plants. Such adaptability underscores the ecological significance of stingless bees in maintaining pollination networks in tropical ecosystems. In practice, the findings can guide meliponiculture management by optimizing colony placement, activity timing, and forage plant selection to enhance the efficiency of honey and propolis production.

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REFERENCES

Abrol, D.P. 2012. *Pollination Biology: Biodiversity Conservation and Agricultural Production.* Springer, Dordrecht, 792 p.

Agus, A., Agussalim, A., Umami, N., & Budisatria, I. G. S. 2019. Effect of Different Beehives Size and Daily Activity of Stingless Bee Tetragonula Laeviceps on Bee-Pollen Production. *Buletin Peternakan*, *43*(4). https://doi.org/10.21059/buletinpeternak.v43i4.47865

Agus, A. 2017. Variation of Honeybees Forages as Source of Nectar and Pollen Based on Altitude in Yogyakarta. Buletin Peternakan. https://doi.org/10.21059/BULETINPETERNAK.V41I4.13593

Alpian, Yoga, Y. K., Yulianti, R., & Joni, H. 2022. Identifikasi Jenis Tanaman Sebagai Pakan Lebah Madu Kelulut (*Trigona* spp.) di KPHP KATINGAN HULU Identification of Plant Types as Feed for Kelulut Honey Bees (*Trigona* Spp.) at KPHP Katingan Hulu Unit XVII. *Jurnal Hutan Tropis*, *10*(3), 277–283. https://doi.org/10.20527/jht.v10i3.14970

Balfour, N. J., & Ratnieks, F. L. W. 2025. Wind alters plant-pollinator community structure, bee foraging rate & movements between plants. *Behavioral Ecology*, *36*(4). https://doi.org/10.1093/beheco/araf067

Basari, N., Ramli, S. N., & Khairi, N. 'Aina S. M. 2018. Food reward and distance influence the foraging pattern of stingless bee, heterotrigona itama. *Insects*, *9*(4). https://doi.org/10.3390/insects9040138

Bharath, M. P., Jayaraj, J., Vellaikumar, S., Chinniah, C., Suresh, K., & Balamohan, T. N. 2020. Foraging activity of stingless bee, *Tetragonula iridipennis* smith (Hymenoptera: Apidae) during summer season in Madurai district of Tamil Nadu, India. *J Pharmacogn Phytochem* 2020;9(1):1144-1148.

Chuttong, B., Panyaraksa, L., Tiyayon, C., Kumpoun, W., Chantrasri, P., Lertlakkanawat, P., Jung, C., & Burgett, M. (2022). Foraging behavior and pollination efficiency of honey bees (*Apis mellifera* L.) and stingless bees (*Tetragonula laeviceps* species complex) on mango (*Mangifera indica* L., cv. Nam Dokmai) in Northern Thailand. *Journal of Ecology and Environment*, *46*. https://doi.org/10.5141/jee.22.012

Hilário, S. D., Imperatriz-Fonseca, V. L., & Kleinert, A. De M. P. 2000. Flight activity and colony strength in the stingless bee Melipona bicolor bicolor (Apidae, Meliponinae). *Revista Brasileira de Biologia*, *60*(2), 299–306. https://doi.org/10.1590/s0034-71082000000200014

Indraswari, A. G. M., Atmowidi, T., & Kahono, S. 2016. Keanekaragaman, aktivitas kunjungan, dan keefektifan lebah penyerbuk pada tanaman tomat. *Jurnal Entomologi Indonesia*, *13*, 21–29. https://doi.org/10.5994/jei.13.1.21

León, A., Arias-Castro, C., Rodríguez-Mendiola, M. A., Meza-Gordillo, R., Gutiérrez-Miceli, F. A., & Nieh, J. C. 2015. Colony foraging allocation is finely tuned to food distance and sweetness even close to a bee colony. *Entomologia Experimentalis et Applicata*, *155*(1), 47–53. https://doi.org/10.1111/eea.12283

Nurdiansyah, M. A., Abduh, M. Y., & Permana, A. D. 2023. Effects of meliponiculture Tetragonula laeviceps on pollinator diversity and visitation rate and citrus productivity in West Java, Indonesia. *Biodiversitas*, *24*(10), 5757–5763. https://doi.org/10.13057/biodiv/d241058

Purba, M., Lamerkabel, J. S. A., & Patty, J. A. 2023. Karakter Morfologi Dan Morfometrik Lebah Sosial (Apidae) Di Lingkungan Pertanian Organik (Morphological and Morphometric Characters in the Social (Apidae) in the Organic Agriculture of BEEMA Honey, Bogor) Indonesia memiliki biodiversitas. *Jurnal Pertanian Kepulauan*, *7*(2), 97–103. https://doi.org/10.30598/jpk.2023.7.2.97

Ramadani, R. F., Raffiudin, R., Ariyanti, N. S., Biagioni, S., Treanore, E., & Behling, H. 2021. Stingless bee foraging behavior and pollen resource use in oil palm and rubber plantations in Sumatra. *Jurnal Entomologi Indonesia*, *18*(2), 81–92. https://doi.org/10.5994/jei.18.2.81

Rianti, P., Suryobroto, B., & Atmowidi, T. R. I. 2010. Diversity and Effectiveness of Insect Pollinators of *Jatropha curcas* L. (Euphorbiaceae). *HAYATI Journal of Biosciences March*, *17*(1), 38–42. https://doi.org/10.4308/hjb.17.1.38

Sabatina, P., Srinivasan, M. R., Murugan, M., & Saminathan, V. R. 2025. Sunny days and busy bees: Unveiling the weather-driven foraging patterns of Tetragonula iridipennis and their role in tomato pollination. *Environmental Science and Pollution Research*, *32*(3), 1640–1652. https://doi.org/10.1007/s11356-024-35849-4

Saepudin, R., Fuah, A. M., & Abdullah, L. 2011. Peningkatan Produktivitas Lebah Madu Melalui Penerapan Sistem Integrasi dengan Kebun Kopi. In *Jurnal Sain Peternakan Indonesia* (Vol. 6, Number 2, pp. 115–124). https://doi.org/10.31186/jspi.id.6.2.115-124

Saputri, T. B., Anggraini, D., Pratiwi, A., & Permata, M. 2024. Jurnal Biologi Tropis Identification of Nocturnal Visitor Insects on Penda Emas Plants (Xanthostemon chrysanthus). *Jurnal Biologi Tropis*, *24*(1), 303–312.

Setyaningsih, G. 2024. *Aktivitas Harian Lebah Tetragonula biroi dalam Mencari Resin Pinus* [Universitas Jenderal Soedirman]. https://repository.unsoed.ac.id/26963/?utm_source=

Shullia, N. I., Subchan, W., Raffiudin, R., Atmowidi, T., Priawandiputra, W., Ariani, N. S., Pujiastuti, Dewi, A. N., Sabella, Y. N., Siffahk, L. N., Nisa, W. K., & Novidayanti, A. A. 2024. Temporal resource partitioning of the flight activities of three bee species in East Java. *Jurnal Entomologi Indonesia*, *21*(Vol. 21 No. 3 (2024): November). https://doi.org/https://doi.org/10.5994/jei.21.3.234

Sulistiyaningsih, Y. C., Raffiudin, R., & Umiyati. 2023. *Eksplorasi Morfologi, Waktu Bunga Mekar dan Polen yang Dikoleksi oleh Lebah Tetragonula laeviceps di Kebun Biofarmaka IPB*. Institut Pertanian Bogor.

Takkis, K., Tscheulin, T., & Petanidou, T. (2018). Differential effects of climate warming on the nectar secretion of early-and late-flowering mediterranean plants. *Frontiers in Plant Science*, *9*. https://doi.org/10.3389/fpls.2018.00874

Tierney, S. M., Bernauer, O. M., King, L., Spooner-Hart, R., & Cook, J. M. 2023. Bee pollination services and the burden of biogeography. *Proceedings of the Royal Society B: Biological Sciences*, *290*(2000). https://doi.org/10.1098/rspb.2023.0747

Umar, M., Aqeel, A., Hassan, W. U., Bashir, N. H., Ullah, I., Nazir, T., & Hanan, A. 2019. Evaluation of foraging activity and pollen collection by Apis mellifera L. on linseed crop at different day timings. *~ 264 ~ Journal of Entomology and Zoology Studies*, *7*(1), 264–269.

Widhiono, I., Sudiana, E., Proklamasiningsih, E., Nurfitri, F., Budisantoso, I., Studi, P., Ilmu, M., Biologi, F., & Soedirman, U. J. 2024. Penerapan Hasil Penelitian Budidaya Lebah Klanceng Tetragonula biroi Bagi Kelompok Tani Hutan "Jembaran". *Journal of Innovation and Sustainable Empowerment*, *3*(2), 117–125.

Zeballos, M., Calviño, A. A., & Zamudio, F. 2022. Is the flight and foraging activity of small-size stingless bee affected by the urban heat island? The case of Plebeia catamarcensis (Meliponini) in Cordoba city (Argentina). *Journal of Apicultural Research*, *61*(5), 632–641. https://doi.org/10.1080/00218839.2022.2110431