Pertanika J. Trop. Agric. Sci. 44 (2): 485 - 502 (2021)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Foraging Behaviour of *Heterotrigona itama* (Apidae: Meliponini) in Residential Areas

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ABSTRACT

This study aims to investigate the foraging behaviour of *Heterotrigona itama* in exploiting food resources at a residential area, and the viability of this species to adapt to urban microclimatic conditions. *Heterotrigona itama* prefers to forage at areas closer to their nesting site, where diverse food sources are found. The marked bees of *H. itama* prefer to forage on various resources available at a 500-metre radius from the house yard. The obtained results indicate that the active foraging pattern of *H. itama* is negatively correlated to the time phases of a day ($p < 0.05$). This phenomenon was contributed by the three peaks of foraging hours, which reached a peak in the early morning (6:30 to 8:00 a.m.), moderately peaked towards the evening (2:30 to 3:30 p.m.), and was greatest towards the afternoon (10:30 a.m. to 12:00 p.m.). The ambient temperature and relative humidity were not the primary factors influencing the average number of foragers exiting from and returning to the hives (temperature, $p > 0.05$; and humidity, $p > 0.05$). There was a difference between the varieties of content resources collected by the bees ($p < 0.05$). The nectar or water sources was the highest material (51.39%) that was brought back to the hive by foragers, followed by resin (34.73%) and pollen (13.87%). There was a significant difference in foraging time

ARTICLE INFO

Article history:
Received: 8 September 2020
Accepted: 22 February 2021
Published: 28 May 2021

DOI: https://doi.org/10.47836/pjtas.44.2.13

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ISSN: 0128-7680
e-ISSN: 2231-8526

phases by returning foragers for collecting resin ($p < 0.05$) and nectar or water ($p < 0.02$), but there was no significant difference in foraging time phases found for pollen ($p > 0.05$). The results showed that *H. itama* is able to withstand urban microclimate conditions, and successfully incorporated pollen, nectar or water, and resin obtained from floral and non-floral resources into their diet.

Keywords: Abiotic factors, foraging behaviour, *Heterotrigona itama*, residential area, stingless bees

INTRODUCTION

Compared to honeybees, stingless bees are relatively easier to handle, less aggressive as they do not have a functional stinger, and are efficient in foraging ability, thus making them ideal to be reared in residential areas. Nowadays, urban beekeeping in residential areas demonstrates a rise in popularity in Malaysia (Basari et al., 2018). Beehives require minimal land, and can be placed almost anywhere, including house yards and orchards. However, the foraging activity of stingless bees in an urban environment remains unclear. In the State of Sabah, beekeeping with *Heterotrigona itama* has induced a massive growth in interest, particularly on the west coast where many beekeepers want to keep colonies of bees in residential areas as a hobby, income opportunity, or for their own source of authentic honey. The direct contributions of stingless beekeeping include the value of the output produced such as honey, beebread, and one of essential ingredients in cosmetics and medicine, known as propolis (Yaacob et al., 2018). The indirect but significant contribution of beekeeping is through floral pollination in agricultural and natural environments (Heard, 1999; Roubik, 2006). The flora of the residential area wherein the beehives are situated is highly benefitted due to pollination activities by the bees (Roubik & Buchmann, 1984).

Heterotrigona itama is a common stingless bee species found in Southeast Asia, and is among the most popular species in meliponiculture (Heard, 1999; Mustafa et al., 2018). Due to its popularity, it has been selected as a model organism in this study. This species can be easily identified from other commonly encountered species with similar colouration, as it has a wider and longer body (Samsudin et al., 2018). For example, the main feature of the genus *Tetrigona* spp. (e.g. *Tetrigona apicalis* and *Tetrigona binghami*) is its large white-tipped wings, while the *Tetragonula* spp. (*Tetragonula laeviceps* and *Tetragonula fuscobalteata*) is much smaller than other genera of stingless bees. Thus far, the effects of climatic factors (e.g. temperature and relative humidity) towards the flight activity of *H. itama* in urban areas remains poorly understood. Temperature and relative humidity are vital environmental factors that may affect the foraging activity of stingless bees (Hilário et al., 2000). The climatic factors have been reported to influence the flight activity of *Tetragonula carbonaria* (Heard, 1999). Keppner and Jarau (2016) also found that the foraging activity of *Partamona* *orizabaensis* escalated in weather conditions such as colder temperatures and increased relative humidity, as well as during rainfall. The climatic factors aid honeybees and bumblebees in orientating and navigating their environments, as successful orientation is vital for foragers to return to their nest after foraging (Moore & Rankin, 1983; Stelzer et al., 2010).

Previous studies have shown that eusocial bees exhibit high preference in exploiting material sources for the survival of their colonies (Moore & Rankin, 1983; Nagamitsu & Inoue, 2002; Stelzer et al., 2010). Thus, urbanisation may affect the bees' flight activities due to changes in the availability of local resources. However, data remains limited. The bees require floral resources to survive, and therefore, private gardens, parks, and wild floral habitats within urban landscapes may support food and nesting resources (Ropars et al., 2019; Udy et al., 2020). Although urban beekeeping is growing in popularity in Sabah, the bees' foraging activity in residential areas has been poorly investigated. Therefore, this study aims to investigate the foraging behaviour of *H. itama* in exploiting food resources in residential areas, and the viability of species to adapt to urban microclimatic conditions.

MATERIALS AND METHODS

Study Site

This study was conducted in one of the residential areas located in Lot 19, Taman Sejati Ujana, Sandakan, Sabah, which has side a yard size of 500 square feet (Figure 1). The surrounding areas of Taman Sejati Ujana comprise many old and new housing project developments (Figure 1). The type of floral landscape is described in Table 1.

Beehives Placement and Hives Management in House Yard

Fourteen colonies of *H. itama* were reared for 22 months (January 2018 to October 2019). All methods were standardised for all studied beehives, and the layout and orientation of the stingless beehives within the house yard are shown in Figure 2. These beehives comprise bee colonies with weak and strong colonials' nests development. Strong bee colonies can be distinguished by beehives having active foraging traffic and well-formed nest entrance tubes, with many bee guards defending the nest. All the beehives were placed on wood stands at a height of 50 to 60 cm above the ground.

All beehives were placed under a tree canopy or in the shade. Beehives placed under open light were covered with a plywood roof lined with rubber mats or aluminium. The roof was designed to protect the bee colony from the sun and rain (Figure 3).

Sites Foraging Preferences of *Heterotrigona itama* within a Residential Area

The insects visiting the vegetation were observed for 30 minutes in each of the sites of A, B, C, D, E, F, G, and around residential areas (Site H) (Figure 1), from 8:00 a.m. to 5:00 p.m., twice a week, for five months. Two observers were trained to spot and

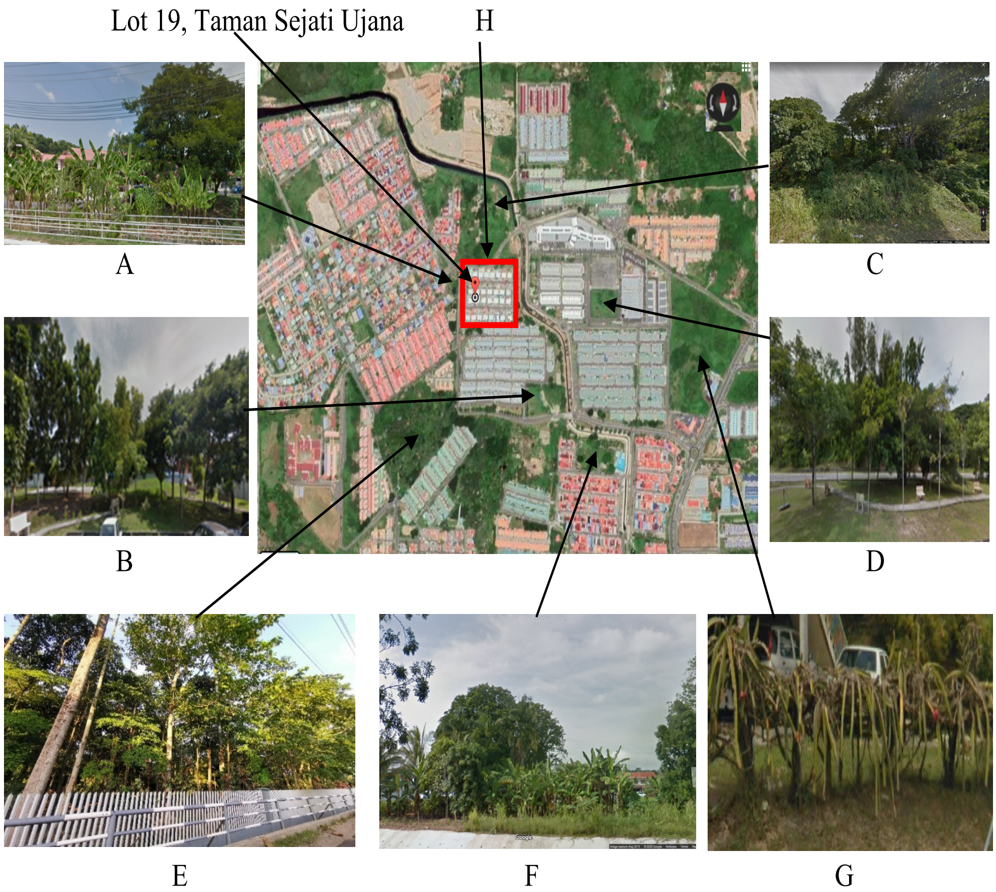

Figure 1. Location of bee colonies in Lot 19, Taman Sejati Ujana, Sandakan, Sabah and the distribution of floral areas

Table 1

Categories of floral landscape observed within and outside the residential area

Study sites	Floral categories	Floral types	Straight line distance measured from study site (m)
A	Private agriculture area 1	Banana, mango, papaya, shrubs, leafy vegetables, tapioca, sugarcane, corn, citrus, coconut, legumes, *Tunera* sp., *Passiflora* sp., and fruity vegetables	50
B	Park 1	Park (Landscape trees)	60

Table 1 *(Continued)*

Study sites	Floral categories	Floral types	Straight line distance measured from study site (m)
C	Unmanaged landscape	*Acacia* sp., *Macaranga* sp., *Melastoma malabathricum*, *Mimosa pudica*, *Ageratum* sp., *Passiflora* sp., *Imperata cylindrica*, *Mikania micrantha*, and unknown wild plants	95
D	Park 2	Park (Landscape trees)	90
E	Natural forest	Class IV Forest Reserve Timber trees, exotic and indigenous trees, shrubs and bamboo	350
F	Private agriculture area 2	Banana, mango, shrubs, vegetables, tapioca, coconut and seasonal flowering trees	500
G	Private garden	Dragon fruit	1000
H	Taman Sejati Ujana	Banana, mango, papaya, shrubs, leafy vegetables, citrus, guava, mulberry, chilli, tapioca, coconut, coral vines, *Tunera* sp., *Ixora* sp., and seasonal flowering trees	0 – 40

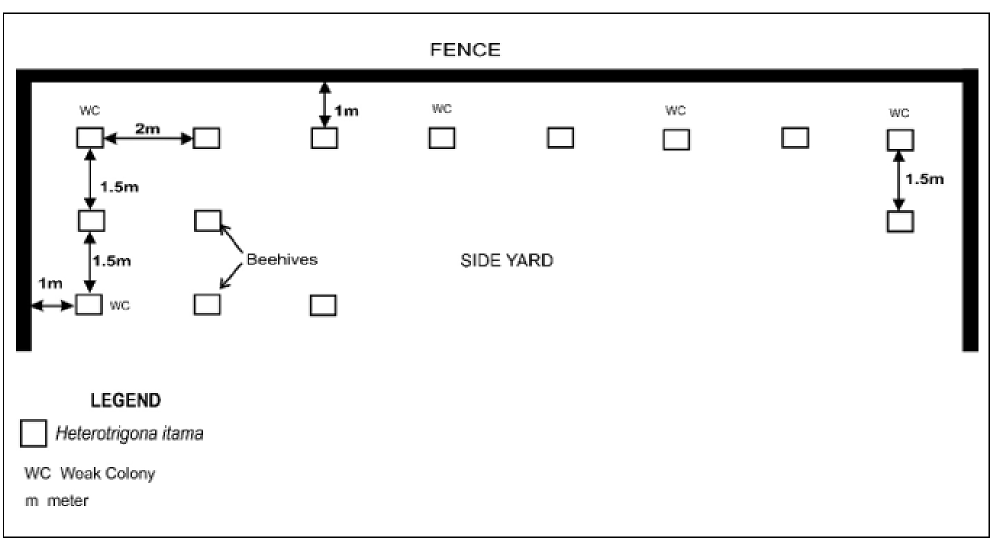

Figure 2. Layout and orientation of hives within the house yard area in Lot 19, Taman Sejati Ujana

Figure 3. A beehive with a roof lined with a rubber mat or aluminium and placed on wood stand at a height of 50 to 60 cm above the ground

follow the marked bees in the studied sites, prior to the beginning of data collection. Twenty individuals of stingless bees from each of the beehives were marked on the thoraces using white correction liquid and then immediately released. This method is described by Peakal and Schiestl (2004). The search for *marked* individuals was done through inspection from tree to tree canopy, tree trunks, agricultural foliage, vegetable farms, gardens, and shrubs, among other areas. This observation was repeated 16 times in each of the sites. To examine the stingless bees' foraging height on the tree canopies, observations were made at close range with a portable 80 x 100 magnification monocular telescope for wildlife watchers (HaleBor model C74153). The flight height by bees was estimated based on the height of the tree canopy visited by foragers, and was measured using ImageMeter software version 3.5.0 (2).

Foraging Behaviour and Time by Marked Bees, and Measurement of Abiotic Factors

The foraging behaviour of bees was observed in front of the hive entrance tube, and recorded 272 times on rain-free days using a Huawei Mate P20 Pro smartphone digital video recorder. A video recording of the foraging traffic from three selected beehives in Lot 19, Taman Sejati Ujana, Sandakan, Sabah was done before the first foraging departure at 5:30 a.m., and ended at 6:30 p.m., after the termination of foraging activities. The foraging activity was determined from the video sequences, using real-time playback, and the counting methods were carried out as described by Kaluza et al. (2016). A stopwatch and a hand tally counter were used to count the number of foragers. To obtain the active foraging data, the number of exiting and returning foragers for the selected three beehives was measured for three minutes during each hour, from 5:30 a.m. until 6:30 p.m..

To obtain floral or non-floral material data collected by foragers, only the number of returning foragers for each material load was counted for three minutes each hour, from 5:30 a.m. until 6:30 p.m.. These data were then combined according to the following time phases: (i) early morning (5:30 to 9:30 a.m.); (ii) morning to afternoon (10:00 a.m. to 12:30 p.m.); (iii) afternoon to evening (1:00 to 3:30 p.m.); and (iv) evening by to dusk (4:00 to 6:30 p.m.). The foragers returning to the beehives without pollen and resin loads on their tibia were recorded as liquid foragers. These liquid foragers, which were suspected to forage nectar and water, could be distinguished from the rest by having a swollen abdomen (Figure 4). In this study, the nectar and water loads were not individually determined. To test the relationship between bees' foraging patterns and abiotic factors, the temperature (^{o}C) and relative humidity (RH) were measured over two months from May 2019 until June 2019, using a Hobo® U23-002 PV2 data logger that was kept in Site H at Lot 19, Taman Sejati Ujana.

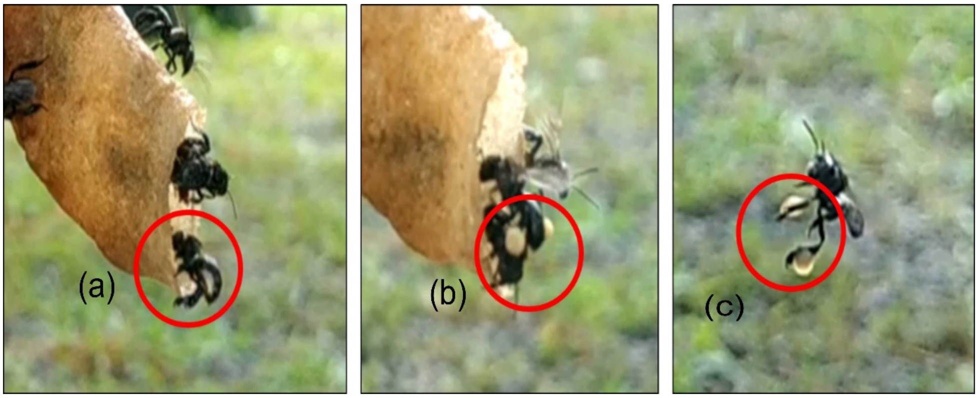

Figure 4. Returning foragers with (a) swollen abdomen, (b) pollen, and (c) resin loads on their tibia

Statistical Analysis

Statistical analysis tests were carried out using Microsoft Excel and IBM Statistics SPSS for Windows, version 24. The data was sorted by sample date and pooled within the study sites to simplify the presentation. All data were tested for normality using Kolmogorov-Smirnov one-sample tests, before applying parametric analyses. Analysis of variance (ANOVA) was used to test whether there was a significant difference in the foraging preferences by marked bees between the study sites; whether there was a significant difference in a variety of content resources collected by foragers; and to test whether there was a significant difference in the type of loads collected by foragers at distinct time phases of the day. To obtain whether the abiotic factors influence the bees' foraging behaviour in the residential area, the relationships between the active foraging pattern of *H. itama* and phases of daylight cycle, ambient temperature and relative humidity were investigated using Pearson's correlation.

RESULTS AND DISCUSSION

Sites Foraging Preferences of *Heterotrigona itama* within a Residential Area

There was a significant difference in the visitations per day foraged by marked bees among the study sites (Table 2; one-way AVOVA; $F_{7, 319}$=85.64, p < 0.001). Table 2 shows that the marked foragers of *H. itama* most preferred to forage at Site H (average visitations per day = 8.5), followed by Site A (average visitations per day = 8.07), and Site C (average visitations per day = 3). Ciar et al. (2013) reported that *Tetragonula carbonaria* were observed to travel up to 500 m, but preferred to exploit food sources closer to their hive (1 m). Overall, the marked bees of *H. itama* preferred to forage the various resources available within a 500 metres radius from the house yard (Lot 19, Taman Sejati Ujana in Site H), particularly where food sources were more diverse and closer to their hives. Among the known flowering plants visited by *H. itama* in Sites A, C, F, and H were banana, mango, papaya, shrubs, leafy vegetables, citrus, guava, mulberry, chilli, tapioca, coconut, coral vines, *Tunera* sp., *Ixora* sp., *Acacia* sp., *Macaranga* sp., *Melastoma malabathricum*, *Mimosa pudica*, *Ageratum* sp., *Passiflora* sp., *Imperata cylindrica*, and *Mikania micrantha.* The least preferred foraged sites by marked foragers of *H. itama* were Site G (average visitations per day = 0.03), followed by Site D (average visitations per day = 0.38) and Site B (average visitations per day = 0.63). The lower number of marked bees visiting Sites B and D compared to other sites was likely to be influenced by the flowering season of ornamental trees in parks, which rarely occur during the sampling time (Table 2). Whilst for Site G, the marked bees visiting this area was likely because of the dragon fruit flowers blooming in the early morning (6:30 to 7:00 a.m.), which occurred only once throughout the study.

Bees usually prefer to forage in semi-natural habitats consisting of a mixture of natural forest areas, parks and agricultural landscapes, since these habitats provide more diversified food resources (Steffan-Dewenter & Tscharntke, 2001). Table 2 shows that *H. itama* is a generalist species, as they visited all known plant species, regardless of the landscape type around the residential area. Study by Md Zaki and Abd. Razak (2018) in the rubber smallholder environment also found that *H. itama* was able to forage more than 29 species of identified plants from 22 families. Landaverde-González et al. (2017) also found that the stingless bee species of *Partamona bilineata* in Guatemala could survive well and efficiently forage floral resources in modified landscape areas. During the study, *H. itama* was also observed to be able to find pollen in the canopy of pioneer trees of *Macaranga* sp. on Site C, and coconut trees on Site A, which have a tree height of about 10 m. Therefore, this suggests that the height of the tree was not a barrier for this species to gather material resources from the canopy level. This situation shows that this species is not only able to exploit various food sources in urban areas, but it was also able to fly high in search of food in the tree canopy.

Table 2

Sites foraging preferences by marked foragers of Heterotrigona itama *from Lot 19, Taman Sejati Ujana (Site H), measured for 40 days*

Study sites	Straight line distance measurement from Site H (m)	Total marked foragers (n)	Average visitations per day by marked foragers (SE)
A	50	323	8.07^{d} (0.53)
B	60	25	0.63^{ab} (0.17)
C	95	120	3^{c} (0.43)
D	90	15	0.38^{a} (0.99)
E	350	55	1.37^{ab} (0.26)
F	500	75	1.88^{bc} (1.67)
G	1000	1	0.03^{a} (0.03)
H	0 – 40	340	8.5 (0.66)

Note. Letters indicate significance differences measured by post hoc Tukey B test ($p < 0.05$). SE = Standard error, A = Private agriculture area 1, B = Park 1, C = Unmanaged landscape, D = Park 2, E = Natural forest, F = Private agriculture area 2, G = Private garden, and H = Taman Sejati Ujana

Foraging Behaviour of *Heterotrigona itama* in A Residential Area

Type of Materials Resources Foraged by the Marked Bees. There was a significant difference between the variety of content resources collected by bees (Figure 5; one-way ANOVA; $F_{2,59} = 8.95$, $p < 0.001$). Figure 5 shows that the nectar or water sources was the highest material (51.39%), which was brought back to the hive by foragers, followed by resin (34.73%) and pollen (13.87%). The stingless bee workers usually foraged pollen, resinous plants, and nectar or water sources, to meet the needs of the colony (Gaona et al., 2019). Nectar, which is converted by bees into honey, serves as the primary source of carbohydrates to supply energy for the colony's survival and foraging activities (Kajobe, 2007). The higher number of nectar or water foragers found in this study shows that *H. itama* was likely more attracted to both nectar-rich inflorescence and water resources. Studies on the mineral-foraging of *Trigona silvestriana* in Costa Rica showed that foragers were highly attracted to essential minerals from mineralised water than deionised water (Dorian & Bonoan, 2016). These mineral salts such as sodium, magnesium and potassium which obtained from water, are crucial for developing larvae and brood food (Lau & Nieh, 2016). Prominent studies about water collection by stingless bees are those by Bijlsma et al. (2006), Cham et al. (2019), and Roubik (2006). In this study, *H. itama* was also observed to have taken water from the wet soil around the house yard. Roubik (1989) indicated that other non-floral materials collected by bees comprise oils, honeydew, sap, gums, wax, plant parts, mud, fungi, spores, and water. Lorenzon and Matrangolo (2005) reported that 12 species of stingless bees in the Caatinga region were observed to forage non-floral resources such as muddy water to seek mineral salts. According to Requier and Leonhardt (2020), the bees need non-floral resources for nest building, defence, protection, and colony health. Dreisig (2012) found that bees continued to visit the flowers that have massive amounts of nectar, but left an unrewarding plant quickly.

Figure 4 shows that the foragers returning with fluid loads, which could be nectar or water stored in their crops, did not bring pollen or resin together. The liquid loads of resin and pollen were deposited on the corbiculae structure that is located in the hindlegs tibia of foragers (Figure 4). For stingless bees, plant resins are crucial resources for nest defence and construction (Leonhardt & Bluthgen, 2009; Wallace & Lee, 2010). Additionally, the resin has rich antifungal, antibacterial, and antiviral properties (Leonhardt &

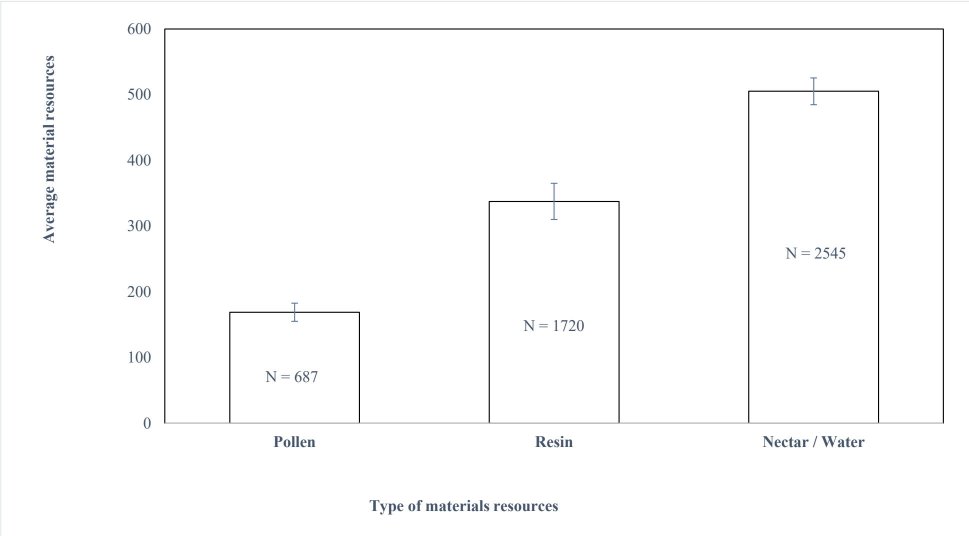

Figure 5. Type of materials resources collected by *Heterotrigona itama* in the environment
Note. Letters indicate significance differences measured by post hoc Tukey B test ($p < 0.05$)

Bluthgen, 2009). This species was found to have taken resin from tapioca leaf stalks and resinous liquids on the bark of mango trees planted at about 50 m from the house yard. Simone-Finstrom et al. (2017) found that the increase in resin foraging activities by *Apis mellifera* was related to nest development, and acted as a defence mechanism against parasites and predators attacking the colony. According to Leonhardt and Bluthgen (2009), foragers preferred floral resin that does not harden quickly, so that bees can reuse it for construction within the nest. The pollen from flowering plants is vital as a source of protein and lipids essential for growth, development, and reproduction of the bee colony (Karuppasamy & Jeyaraaj, 2016). Unlike nectar and resin, pollen is a limited resource that cannot be continuously replenished by plants, and can be quickly depleted during the day (Di Pasquale et al., 2016). Thus, this likely explains why pollen had the lowest average collected by foragers in this study.

Foraging Behaviour in Relation to Abiotic Factors and Time Phases. *Heterotrigona itama* started foraging at 5:30 a.m., and the foraging activity fluctuated during the day from the morning until the evening at 6:30 p.m. (Figure 6). This study indicates that the active foraging pattern of *H. itama* was negatively correlated to the time phases of the day (Pearson's correlation; r_p = -0.371, $p < 0.001$). This phenomenon was contributed by the three peaks of foraging hours, which reached a peak in the early morning (6:30 to 8:00 a.m.), moderately peaked towards the evening (2:30 to 3:30 p.m.), and was the highest towards the afternoon (10:30 a.m. to 12:00 p.m.). A study on similar species by Basari et al. (2018) in Terengganu, Peninsular Malaysia showed that the peaked foraging hours occurred at 7:00 a.m. to 12:00 p.m., and from 2:00 p.m. to 3:00 p.m.. Both studies of *H. itama* conducted in the east and west of Malaysia showed a peak of foraging activities in the morning. Morning peaked foraging for both floral and non-floral resources have also been reported in many other species of tropical stingless bees, including *Tetragonula collina*, *Tetragonula rufibasalis*, *Tetragonula melanocephala*, and *Tetragonula melina* (Nagamitsu & Inoue, 2002). Some stingless bees (i.e. *Trigona sapiens* and *Trigona hockingsi*) may show early morning and mid-afternoon peaks in floral or non-floral materials collection (Wallace & Lee, 2010). Differences in hours of foraging activity within a day may vary depending on resource availability, distance, and ecological factors (Basari et al., 2018; Wallace & Lee, 2010). The foraging activity can also correspond to both plant pollination-related characteristics and eusocial bees (Lichtenberg et al., 2016). According to Lau et al. (2019), the interaction between plants and insect pollinators could occur at a certain period during the day that can affect various ecological processes in the environment.

The ambient temperature and relative humidity were not the main

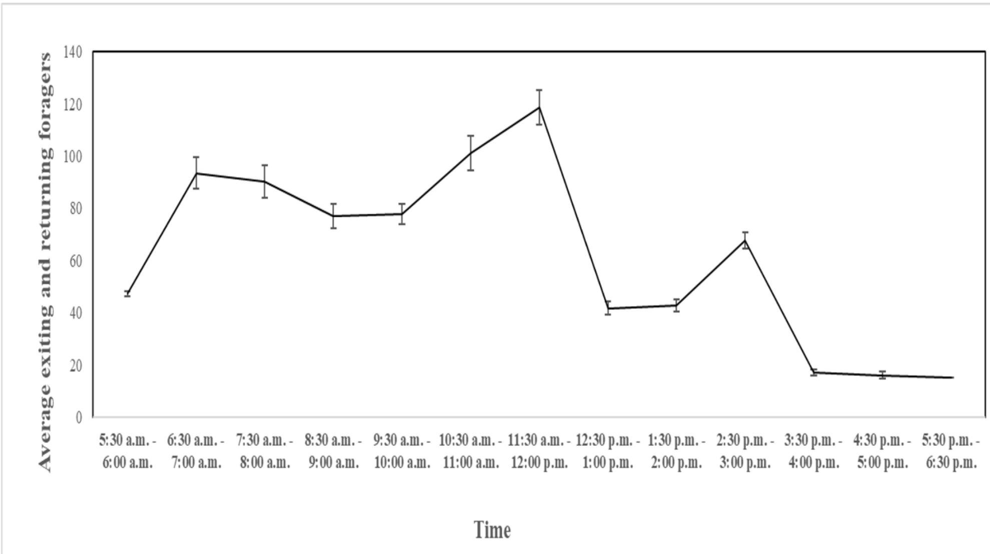

Figure 6. *Heterotrigona itama* foraging pattern during a day

factors influencing the overall average of foragers exiting and returning to the hives [temperature (Pearson's correlation: r_p = -0.06, N = 13, p = 0.84) and humidity (Pearson's correlation: r_p = 0.03, N = 13, p = 0.92)]. Similar foraging patterns were also observed in *Melipona asilvai*, whereby temperature and humidity were not the main factors influencing the bees' foraging activity (do Nascimento & Nascimento, 2012). However, a closer examination of the data in Table 3 show that the activity of *H. itama* started to peak from 10:30 a.m. until 12:00 p.m., when the relative humidity was between 62.8% to 67.8%, and the temperature was between 31.7°C to 32.6°C (Table 3). The ideal temperature and relative humidity ranges for foraging activity vary between bees of different species, some of which may be affected by changes in microclimatic conditions (Abou-Shaara et al., 2012; Hilário et al., 2001; Li et al., 2019). Li et al. (2019) found that *Apis mellifera* and *Apis cerana* were intolerant to high temperature ranges of 54 to 60°C, and 57 to 60°C, respectively, particularly when their body water loss rate increases. Abou-Shaara et al. (2012) found that Yemeni honeybees, *Apis mellifera jemenitica*, were more tolerant to high temperature and low humidity conditions in the desert, compared to Carniolan honeybees, *Apis mellifera carnica*. In this study, *H. itama* seem to be better adapted to the heat and humidity conditions of urban environments, making them suitable for rearing in the house yard (Table 2). A closer examination of the data in Table 3 shows that the optimum temperature and humidity conditions for active tropical stingless bee activities in the urban environment range from 25.1 to 33.3°C, and 61.8 to

Table 3

Foraging behaviour of Heterotrigona itama *in relation to temperature and relative humidity, measured from May 2019 until June 2019 in Lot 19, Taman Sejati Ujana*

Observed time	Average of exiting and returning foragers (SE)		Average temperature (°C) (SE)		Average relative humidity (%) (SE)	
5:30 a.m. – 6:00 a.m.	47.3	(2.1)	25.2	(0.10)	94.3	(0.48)
6:30 a.m. – 7:00 a.m.	93.5	(12.2)	25.1	(0.03)	95.0	(0.41)
7:30 a.m. – 8:00 a.m.	90.3	(12.4)	26.7	(0.24)	87.3	(0.75)
8:30 a.m. – 9:00 a.m.	77.2	(9.4)	28.9	(0.03)	78.8	(1.25)
9:30 a.m. – 10:00 a.m.	77.7	(7.6)	31.0	(0.09)	71.8	(0.25)
10:30 a.m. – 11:00 a.m.	101.1	(13.4)	31.7	(0.10)	67.8	(0.85)
11:30 a.m. – 12:00 p.m.	118.5	(13.2)	32.6	(0.13)	62.8	(0.25)
12:30 p.m. – 1:00 p.m.	41.8	(5.1)	33.2	(0.06)	61.8	(0.25)
1:30 p.m. – 2:00 p.m.	42.8	(5.0)	33.3	(0.09)	61.8	(0.25)
2:30 p.m. - 3:00 p.m.	67.5	(6.1)	33.1	(0.03)	71.8	(0.25)
3:30 p.m. – 4:00 p.m.	17.1	(2.3)	31.8	(0.06)	69.0	(0.41)
4:30 p.m. – 5:00 p.m.	16.1	(2.4)	30.4	(0.27)	74.8	(0.25)
5:30 p.m. – 6:30 p.m.	15.0	(0.0)	27.9	(0.03)	82.8	(0.25)

Note. SE = Standard error

95%, respectively. Li et al. (2019) stated that the survival rates of *A. mellifera* and *A. cerana* at high temperatures in the environment depend on the duration of exposure and relative humidity. Heat stress in the environment significantly reduces the colony growth of bees and their workers' survival (Abou-Shaara et al., 2012; Hilário et al., 2000).

There was a significant difference in foraging time phases by returning foragers for collecting resin (one-way ANOVA; $F_{3,19} = 4.50$, $p = 0.02$) and nectar or water (one-way ANOVA; $F_{3,19} = 4.31$, $p = 0.02$) (Figure 7). However, there was no significant difference in foraging time phases found for pollen (one-way ANOVA; $F_{3,19} = 1.41$, $p = 0.28$) (Figure 7). Thus, stingless bees' foraging behaviour could be influenced by the availability and quality of floral or non-floral materials in the environment (Roubik et al., 1995), which can vary depending on the time of day. Ghosh et al. (2020) indicate that the trend of active bees' foraging activity depends on the time during which foragers can obtain the highest reward from their visit to a flower. Figure 7 shows that peaks of *H. itama* foraging for resin and nectar or water occur from 10:00 a.m. to 12:30 p.m. (morning to noon), slightly decreased from 1:00 to 3:30 p.m. (noon to evening), and were lowest towards 4:00 p.m. to 6:30

p.m. (evening to dusk). The peaks of pollen collection occurred early in the morning, while a fluctuation in the peaks occurred in the afternoon and evening. Some authors demonstrated the same pattern for stingless bees, whereby the activity of foraging peaks in the morning, when a greater availability of food rewards are available (Roubik et al., 1995; Roubik & Aluja, 1983; Roubik & Buchmann, 1984). Fidalgo and Kleinert (2007) found that stingless bees, *Melipona rufiventris*, can optimise their foraging behaviour by learning the times of the day during which flowers secrete pollen. Some species of stingless bees can shift the time of pollen collection during the day, which could be correlated to the floral phenology of the area such as a blooming peak (Bruijn & Sommeijer, 1997).

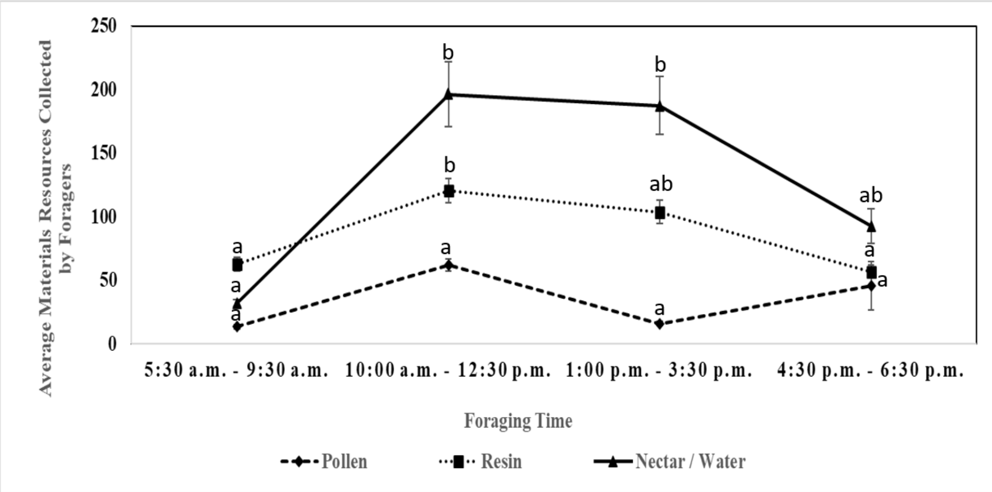

Figure 7. Type of materials resources collected by returning foragers in relation to phases of time during a day
Note. Letters indicate significance differences measured by post hoc Tukey B test ($p < 0.05$)

CONCLUSION

This study investigated the foraging ecology of *Heterotrigona itama* in the house yard, which has not being well-explored in prior work. The colonies of *H. itama* were kept in a house yard, and were shown to be a generalist species because they were able to exploit a wide variety of food resources and landscape types around the residential area. However, they preferred to forage various resources available within a 500-metre radius from the house yard, particularly where food sources were more diverse and closer to their hives. The high number of nectar or water foragers found in this study shows that *H. itama* were more attracted to both nectar-rich inflorescence and water resources, compared to resin and pollen sources. The foraging activity by *H. itama* at the house yard was generally active throughout the study period, and the ambient temperature and humidity were not the main factors influencing the bees' foraging activity. The *H. itama* foraging time phases were influenced by the availability and quality of food resources in the environment, which varied depending on the time of day. Thus, this study highlighted some essential criteria that needed to be considered for beekeeping in residential areas, which include an in-depth understanding of the species' foraging ability in exploiting food resources in an urban environment, and the viability of the species to adapt to urban microclimatic conditions.

ACKNOWLEDGMENTS

The authors are grateful to Nasir bin Abdul Majid for his assistance and patience in the set-up and performance of these experiments. In addition, Valna Nana Velentine @ Rengers is acknowledged for the photographs of the bees' foraging activity. This work was supported by grants from the Knowledge Transfer Programme and UMS Internal Grant.

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