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Food Preferences and Foraging Activity of Asian Weaver Ants, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae)

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Highlights

- In this study, the weaver ants were nocturnal and foraged more intensively between 2 a.m. and 6 a.m.
- In the case of food preference, the weaver ants highly preferred tuna followed by chicken skin and milk.
- The foraging activity of weaver ants was influenced by both temperature and relative humidity.

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Food Preferences and Foraging Activity of Asian Weaver Ants, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae)

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Abstrak: Kerengga (*Oecophylla smaragdina*) adalah satu komuniti serangga yang penting di kanopi pokok. Walau bagaimanapun, kajian tentang aktiviti pencarian makanan kerengga adalah terhad. Oleh sebab itu, satu kajian lapangan dijalankan untuk mengkaji pemilihan makanan dan aktiviti pencarian makanan oleh semut ini dijalankan selama tiga hari. Pemilihan makanan oleh kerengga ini dikaji dengan menggunakan tiga jenis makanan (tuna, kulit ayam, dan susu tepung) yang mengandungi protein, lipid, dan karbohidrat. Aktiviti pencarian makanan dikaji berdasarkan dua parameter iaitu suhu persekitaran dan kelembapan relatif yang direkod sepanjang tempoh experimen. Keputusan experimen menunjukkan *O. smaragdina* lebih menggemari makanan berprotein berbanding makanan berlipid dan berkabohidrat, serta aktiviti pencarian makanan dipengaruhi oleh suhu persekitaran dan kelembapan relatif. Hasil kajian ini menunjukkan bagaimana kerengga bertindak balas terhadap tiga jenis makanan yang berbeza dan secara tidak langsung, menunjukkan aktiviti pencarian makanan yang strategik untuk memaksimumkan bekalan makanan kepada koloni mereka.

Kata kunci: *Oecophylla smaragdina*, kerengga, koloni, pilihan makanan, aktiviti pencarian makanan

Abstract: Weaver ant (*Oecophylla smaragdina*) is an important insect community in tree canopies, but little is known about their foraging behaviours. Therefore, a field experiment was conducted in order to assess the food preferences and foraging activity of weaver ants for three consecutive days. The food preferences of the weaver ants were evaluated using three types of foods (tuna, chicken skin, and milk powder) containing varying contents of protein, lipid, and carbohydrate. The foraging activity was examined based on two parameters, namely temperature and relative humidity which were recorded throughout the study. Results revealed that food higher in protein content was highly preferred by the

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O. smaragdina compared to foods with lipid and carbohydrate contents, and the foraging activity of the *O. smaragdina* was significantly influenced by both temperature and relative humidity. The present study exhibits how the weaver ants respond to different types of foods and indirectly, forming a strategic foraging activity to maximise their food supplies for their colony.

Keywords: *Oecophylla smaragdina*, weaver ant, colony, food preference, foraging pattern

INTRODUCTION

Weaver ants, *Oecophylla smaragdina* (Hymenoptera: Formicidae) are obligate arboreal and are known for their unique nest building behaviour where workers construct nests by weaving together leaves using larval silk (Hölldobler & Wilson 1990). The weaver ant (also widely known as 'kerengga' in Malaysia and Thailand), is widely distributed throughout most of the Oriental region from India to Queensland, Australia, and the Solomon Islands (Greenslade 1972). They are also common in the lowlands of Peninsular Malaysia and have become an important ant species in the tree canopies of the humid tropics of Southeast Malaysia, Australia, and the Pacific islands (Jander & Jander 1979; Bluthgen & Fiedler 2002).

The distribution of *O. smaragdina* in Malaysia is abundant (Jander & Jander 1979; Blüthgen & Fiedler 2002), but little is known about their foraging activities (Peng *et al*. 2012a) and food preferences (Nene *et al*. 2016), particularly in this region. However, there are some researches on their colony structures (Offenberg *et al*. 2012; Marcela *et al*. 2012), ecology (Offenberg *et al*. 2004), predation behaviours (Pierre & Idris 2013; Gathalkar & Barsagade 2016), their benefit as biological control agent (Offenberg *et al*. 2013; Rodríguez-Gironés *et al*. 2013), and nuisances caused by this species (Van Mele *et al*. 2009). *Oecophylla smaragdina* is a well-known biological control agent used to control mango seed weevil, yellow looper, bush cricket, fruit-spotting bug, and red-banded thrips populations in the Northern Territory of Australia (Peng & Christian 2004, 2007; Peng *et al*. 2012b, 2013). They have been harvested and sold as a delicacy, a prized bird feed and as traditional medicine (Offenberg & Wiwatwitaya 2010). However, they can also become pest to farmers when *Oecophylla* workers start attacking many animals as well as human beings (Van Mele *et al*. 2009). The aggressive behaviours and painful bites cause problems to many workers and farmers in many plantations (e.g. cocoa, citrus, and cashew) across Malaysia, Asia, and Africa (Way & Khoo 1992; Van Mele *et al*. 2009; Pierre & Idris 2013).

One of the more conspicuous ways in which species of ants differ is the time of day when the foragers actively seek food (Sudd 1967). They display rhythm in their foraging activities (Saunders 1982). Foraging activities of ants are divided into two types, namely daily foraging activity and seasonal foraging activity. The daily foraging pattern is the daily routine of ants within 24 hours such as foragers seeking foods outside their nests and bring back the food to their colonies,

whereas the seasonal foraging pattern reflects the response to seasonal variation like winter and summer (Ashikin & Hashim 2015). Various biotic and abiotic factors can influence both daily and seasonal foraging activity of ants. Biotic factors such as natural enemies, inter-specific competition, and resource availability affect both daily and seasonal activities of many ant species (Raimundo *et al*. 2009; Zhou *et al*. 2014). In the case of abiotic factors, both temperature and relative humidity have been reported as major factors affecting the foraging patterns of many ant species. For examples, the daily foraging activities of *Tapinoma indicum* and *Linepithema humile* were negatively correlated with temperature and positively correlated with relative humidity (Chong & Lee 2006; Abril *et al*. 2007). Therefore, more ants foraged during night time because of lower temperature and higher relative humidity (Chong & Lee 2006; Abril *et al*. 2007). By studying daily foraging patterns, ants can be categorised as active during daytime (diurnal), nighttime (nocturnal), or active during both dusk and dawn (crepuscular) (Ashikin & Hashim 2015).

Different ant species exhibit varying responses towards different types of food. An experiment of food preference usually been carried out to identify attractive bait for effective pest management (Chong & Lee 2006; Annie & Lee 2007). Several studies reported that different food baits used on index cards are different in their attractiveness for tropical ants (Chong & Lee 2006; Annie & Lee 2007). For examples, *Monomorium pharaonis* preferred both proteinaceous and oily foods (Annie & Lee 2007), *T*. *indicum* chose tuna among other proteinaceous foods (Chong & Lee 2006), whereas *Oecophylla longinoda* preferred anchovy to other foods provided (Nene *et al*. 2016). In the case of successful crop protection, whereby weaver ants are widely applied as a biological control agent, understanding the food preference of weaver ants is essential to identify supplementary food for sustaining stable colonies during the scarcity of natural foods, as well as to boost population size (Nene *et al*. 2016). Moreover, regulation of nutrient intake is important for foraging workers to cater for different nutritional requirements of broods and queens (Lee 2002). As such, adequate knowledge of the food preferences of weaver ants can contribute towards an efficient pest management, crop protection, and colony maintenance.

Taken together, understanding the foraging behaviours and food preferences of ants is crucial in pest management because it helps to locate nest sites, provide cues for effective bait preparation, and determine an ideal time to manage the ants (Loke & Lee 2005; Chong & Lee 2009). Furthermore, an effective application of *O. smaragdina* as a biocontrol agent requires farmers and officers of weaver ants' farming to know the best time of the day to identify and transplant the ant colonies (Peng *et al*. 2012a). Since there is a lack of information on the foraging activities and food preferences of *O. smaragdina*, we sought to examine the influences of environmental parameters, namely temperature and relative humidity on the daily foraging activities of *O. smaragdina*, as well as evaluating their food preferences using three types of foods (tuna, chicken skin, and milk).

MATERIALS AND METHODS

This study was conducted at Universiti Sains Malaysia (5°21'N, 100°18'E), Penang Island, Malaysia. A preliminary observation was conducted to identify stable colonies of *O. smaragdina* (colonies that did not move to another nest site within two weeks of observation) before conducting the experiments of foraging activities and food preferences. The field experiment was carried out on a site whereby the *O. smaragdina* builds their nests on five mango trees (*Mangisfera indica*). The weaver ants were found foraging between mango trees in our study site. The mango trees in this area have been invaded by the weaver ants, which probably occurred in 2008 (Tan *et al*. 2009). Three main trails on the study site were identified and selected as sampling site to evaluate the food preferences and foraging activity pattern. The experiment of foraging activity and food preferences of *O. smaragdina* was repeated three times on the same site.

To assess the food preferences and foraging activity of *O. smaragdina*, this study employed a previous method conducted by Chong and Lee (2006). Three types of foods with varying nutrient contents (i.e., protein, carbohydrate, and lipid) were selected for this experiment. The food attractants were: tuna (Clouet and Co KL Sdn. Bhd.) representing a food higher in protein content but with a mixed of protein and lipid (ratio 5:1), milk powder (Nestle Products Sdn. Bhd.) representing a food higher in carbohydrate content but with the presence of lipid and protein (ratio 2:1:1), and chicken skin (Keesong organic chicken), a lipid-protein food (ratio 2:1) with higher lipid content. The tuna and chicken skin were freshly prepared while the milk used was in powder form (Chong & Lee 2006; Annie & Lee 2007).

Four grams of each food type were weighed and placed randomly on index cards (15 cm x 10.5 cm) on three select trails of the *O. smaragdina*. Each trail was provided with the three types of foods described previously. The foods were replaced every 8 hours to sustain freshness. The food preferences and foraging pattern were observed for three consecutive days (72 hours) starting from 8 a.m. on the first day. Digital images of *O. smaragdina* foraging on each food were captured on a camera (Lumix DMC-TZ7) at one-hour interval continuously up to 72 hours. All digital images of the foraging ant captured from the camera were transferred into a computer (Dell Inc.). Subsequently, the number of ants on each food type was manually counted by checking the digital images on the computer (Chong & Lee 2006; 2009). This manual counting was conducted twice by two researchers to avoid possible counting errors. Throughout this study, the temperature (°C) and relative humidity (%) were recorded using a whirling psychrometer (GH Zeal Ltd., England, Model BS 2842).

The present study gathered two types of data, namely (1) the number of ants visiting three different food types (tuna, chicken skin, and milk) at hourly interval for three consecutive days, and (2) the number of ants foraging at one-hour interval (three days consecutively) along with the readings of temperature and relative humidity. All data was subjected to Kolmogorov-Smirnov normality test prior to analyses. As the data of weaver ants' food visitation was not normally distributed (even after data transformation), Kruskal-Wallis test ($p = 0.05$) was used

to evaluate the food preferences of *O. smaragdina*. A multiple pairwise comparison was applied using Dunn's test with Bonferroni correction (Dinno 2015). The influences of temperature and relative humidity on the temporal foraging activity of *O. smaragdina* were assessed using multiple linear regression analysis (Chong & Lee 2006; 2009; Ashikin & Hashim 2015). Data of ant foraging was square-root transformed prior to regression analysis (Ashikin & Hashim 2015; Anato *et al*. 2015). All statistical analysis was performed using SPSS version 20 (IBM® SPSS Inc.).

RESULTS

The food preferences of *O. smaragdina* were statistically significant difference across three food types (Kruskal-Wallis, $\chi^2(2)= 129.84$, $p < 0.05$). Dunn's pairwise test with a Bonferroni correction showed a significant difference between the tuna, chicken skin, and milk ($p < 0.05$). In this regard, the tuna was highly preferred by *O. smaragdina* (69.51 ± 3.15%) compared to the chicken skin (28.94 ± 2.15%) and milk (1.55 ± 0.15%) (Table 1). The food preferences of *O. smaragdina* fluctuated throughout the study (Fig. 1). A multiple linear regression analysis showed the foraging activity of *O. smaragdina* was influenced by both temperature and relative humidity. The number of *O. smaragdina* ants that foraged out was negatively correlated with the temperature ($F_{1,71} = 21.36$, $r^2= - 0.626$, $p < 0.05$), but it was positively correlated with the relative humidity ($F_{1,71} = 27.49$, $r^2 = 0.452$, $p < 0.05$).

The temperature fluctuated throughout 72 hours with the highest mean temperature was recorded at 32.03 ± 0.86°C, mostly during 1 p.m. to 4 p.m. (Fig. 2). In addition, when the temperature rose above 30°C, the mean number of foragers reduced to approximately below 150 weaver ants (Fig. 2). Compare to the temperature that fluctuated and peak daily temperature generally occurred during afternoon, the relative humidity fluctuated with peak daily relative humidity generally occurred during early morning from 4 a.m. to 8 a.m. (Fig. 3). Therefore, unlike the temperature, the weaver ants foraged primarily when the humidity was above 80%. Regulated by both parameters, the peak foraging hour of *O. smaragdina* was between 2 a.m. to 6 a.m., whereas the lowest foraging was between 2 p.m. to 4 p.m.

Table 1: Mean number of *O. smaragdina* attracted to tuna, chicken skin, and milk.

Foods	Mean ants ± S.E.M (%)	Mean ants ± S.E.M
Tuna	69.51 ± 3.15	73.45 ± 5.05[a]
Chicken skin	28.94 ± 2.15	30.58 ± 4.44[b]
Milk	1.55 ± 0.15	1.64 ± 0.23[c]

Mean values are calculated based on three replicates. Mean ants with different letters are significantly different (Dunn's test, $p < 0.05$).

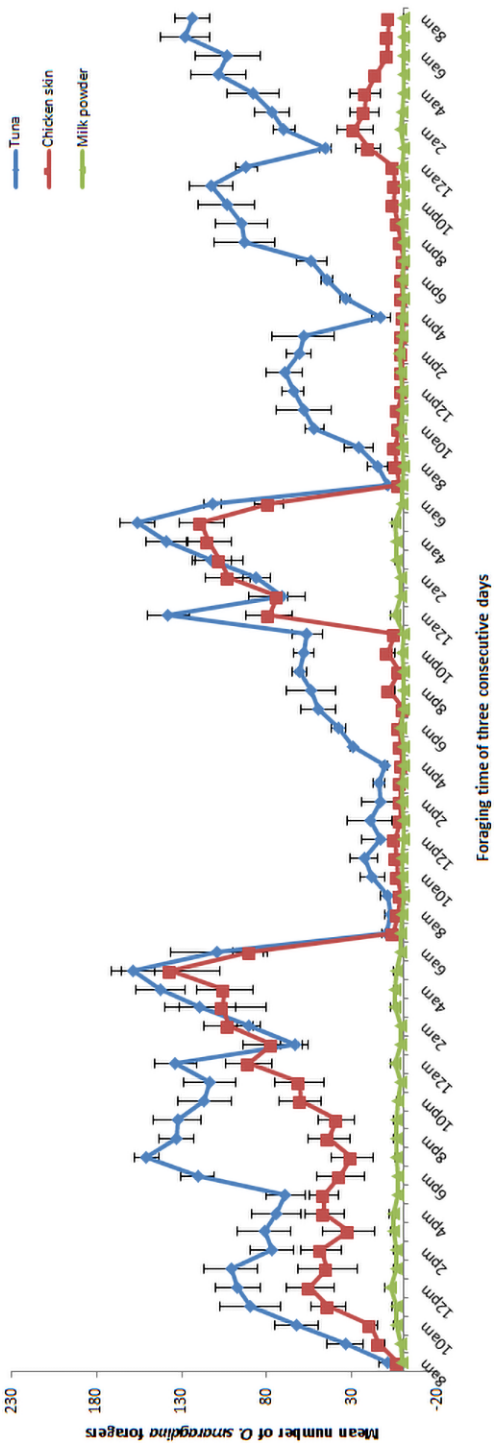

Figure 1: Mean number of *O. smaragdina* foraging on tuna, chicken skin, and milk for three consecutive days.

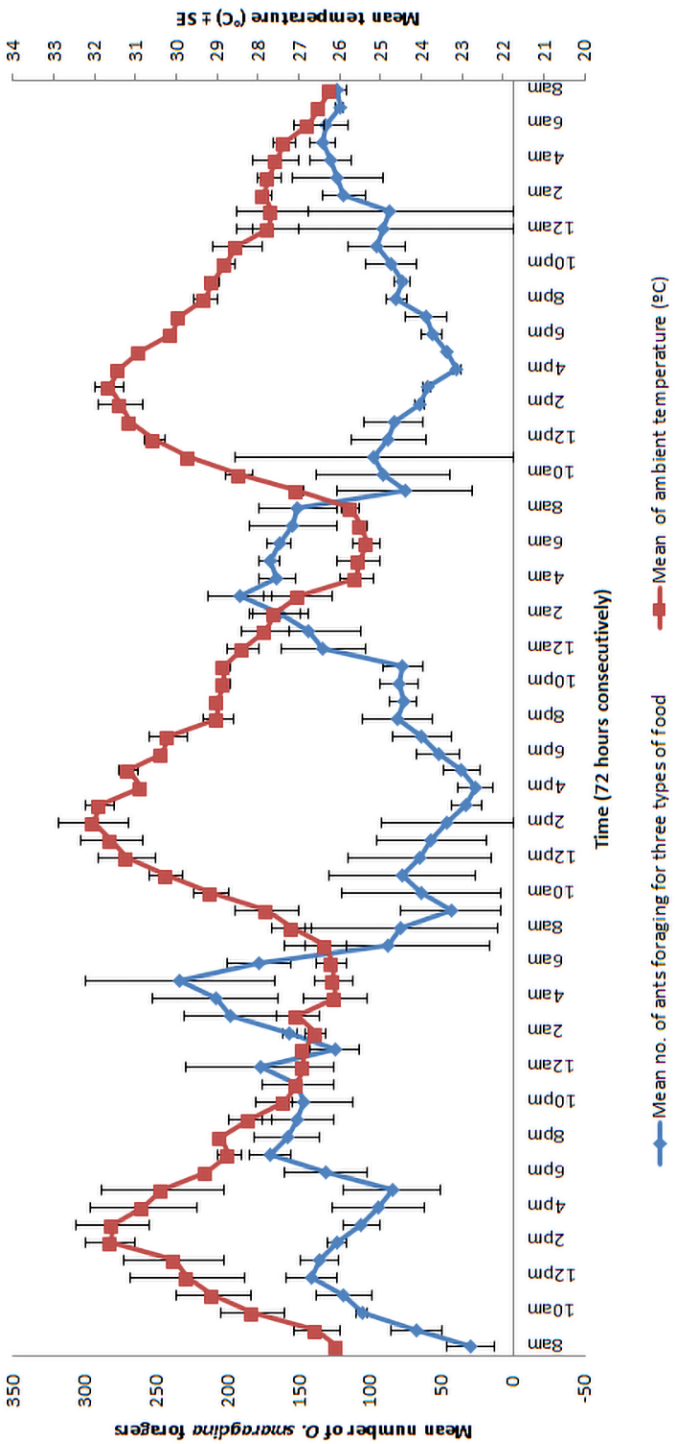

Figure 2: Foraging activities and temperature relationship of the *O. smaragdina* for three consecutive days.

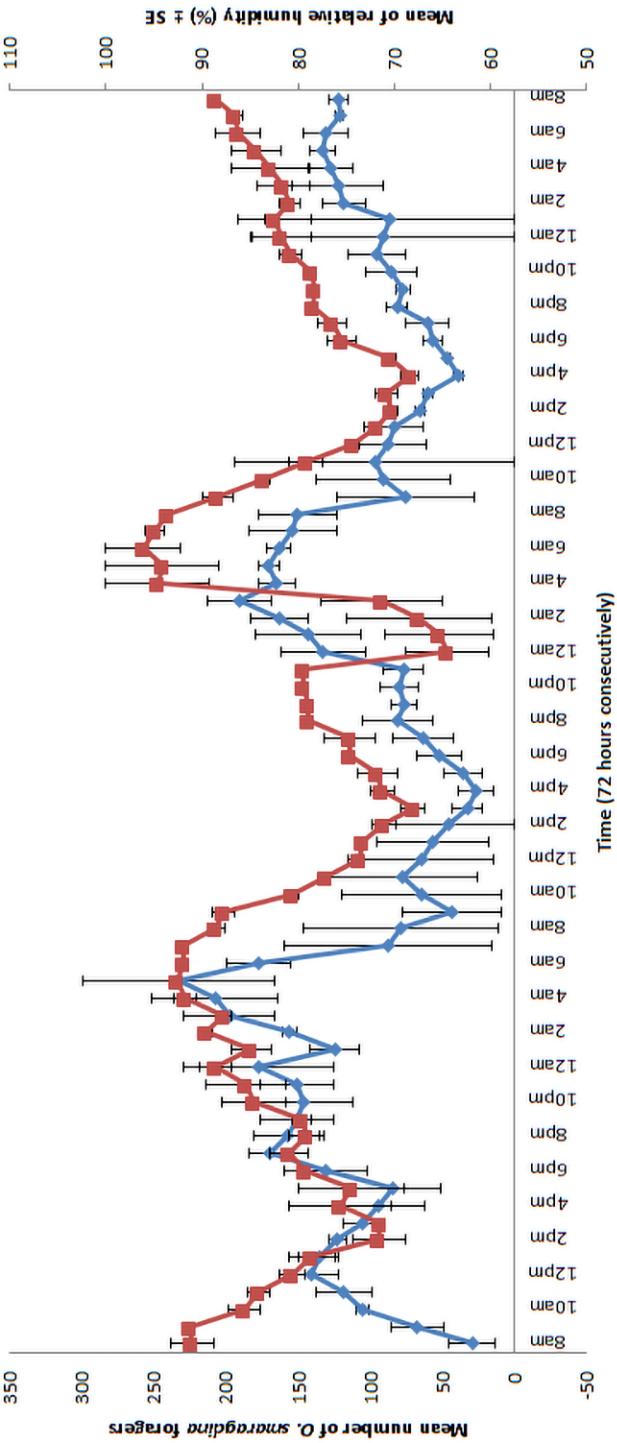

Figure 3: Foraging activities and relative humidity relationship of the *O. smaragdina* for three consecutive days.

DISCUSSION

In the present study, we revealed how the weaver ants responded to three types of foods – tuna (proteinaceous), chicken skin (lipid-protein), and milk (a well-balanced food but higher in carbohydrate), as well as the environmental parameters such as ambient temperature and relative humidity in the field. *Oecophylla smaragdina* was highly attracted to protein-based food followed by lipid- and carbohydrate-based food; this result was consistent throughout the duration of the study. In addition, the ants foraged intensively when the temperature was approximately between 25°C and 27°C, with ambient humidity above 80%. The lowest foraging activity was observed between 2 p.m. and 4 p.m., clearly due to hot weather when the temperature reached approximately 32°C.

One notable observation, on the first day, when the foods were placed along the foraging trails, the ants slightly diverted their normal routes and the number of *O. smaragdina* visiting the foods increased almost instantly, particularly on the tuna food. Similarly, Lim (2007) stated *O. smaragdina* immediately established foraging trails to food resource and continue to forage throughout the day and night until the resource was depleted or was no longer desirable. Brown (2000) reported *O. smaragdina* belong to Myrmicinae functional group which rapidly recruit and defend clumped food resources. In addition, an olfactory effect might influences the food preference of the weaver ants whereby the smell of tuna is stronger than that of chicken skin and milk powder. Previous studies showed the use of olfactory cues by *Lasius niger* ants to identify foods and *Cataglyphis fortis* ants to locate foods in the Sahara Desert, respectively (Beckers *et al*. 1994; Buehlmann *et al*. 2014). The current study cannot confirm this effect as this is outside the scope of the study, but future investigation incorporating olfactory cues in food choices would help us better understand the decision making of weaver ants during foraging.

The foraging pattern of *O. smaragdina* showed fluctuations over the course of study. Higher number of *O. smaragdina* visited the foods on the first day compared to the following days. On the second day of the experiment, the number of foragers reduced due to strong winds and rain. However, unlike this field experiment, the foraging activity of ants in the laboratory was more consistent. Ant foraging activity was continuous and no distinct peaks were observed as constant temperature was maintained at approximately 25°C (Barbani 2003). Similarly, foraging activities of other ant species such as *Linepithema humile* and *Tapinoma indicum* were also influenced by such abiotic conditions (Chong & Lee 2006; Abril *et al*. 2007; Peng *et al*. 2012a).

Different ant species adopt different foraging patterns; they can be categorised as nocturnal, diurnal and crepuscular species according to their circadian rhythm of foraging activity (Sudd 1967; Chong & Lee 2009). Peng *et al*. (2012a) claimed that peak foraging activity of *O. smaragdina* was between 4 p.m. and 9 p.m. during wet and dry seasons in Australia. Meanwhile, a study in the Solomon Islands showed that *O. smaragdina* was diurnal and their foraging activity ceased abruptly after 6 p.m. and resumed after 6 a.m. (Greenslade 1972).

Another species of weaver ants, *O. longinoda* was reported to be diurnal in their foraging activity with the foraging ant population reached a peak in the late morning (Hölldobler & Wilson 1978). In our study, *O. smaragdina* was considered to be a nocturnal species because they foraged most intensively after midnight until late morning (2 a.m. to 6 a.m.). However, the research was conducted at one site, hence further study required to confirm the foraging activity of *O. smaragdina* at different location.

The current study revealed *O. smaragdina* highly preferred tuna followed by chicken skin and milk powder. In addition, they did not switch their food preferences and consistently preferred tuna over other foods for three consecutive days. The study showed the food preferences of *O. smaragdina* were influenced by both food freshness and particle size. Based on preliminary observation, the foods (i.e. tuna, chicken skin, and milk powder) which became dry after eight hours were less preferred by *O. smaragdina* compared to their fresh form. Therefore, the study changed the foods every eight hours to sustain freshness. Similar to this finding, Lim (2007) stated that *O. smaragdina* preferred fresh foods and they were not responsive to dry foods. Furthermore, we observed the weaver ants had difficulty to collect and remove milk powder using their mandibles. Nene et al. (2016) explained that *O. longinoda* faced difficulty in collecting small particles back to their nest due to large mandibles. The current study showed *O. smaragdina* preferred tuna and chicken skin which had a high nutrient combination of protein and lipid contents, but they were not interested in milk powder which contains 2:1:1 ratio of carbohydrate, protein, and lipid. However, the food preferences of weaver ants based on nutritional composition must be interpreted with caution because the study did not directly examine its effect based on colony needs such as queen, worker, and larvae.

The current study contributes to a better understanding of the foraging activity and food preferences of weaver ants which can be applied in pest management and crop protection. In the case of pest management, the ideal time to apply chemical control of *O. smaragdina* was during their peak foraging activity – between 2 a.m. to 6 a.m. to maximise the number of ant foragers recruited to bait and thereby maximise the bait consumption (Chong & Lee 2006; 2009). On the contrary, for crop protection, weaver ant colonies should be transplanted when the ants were least active (between 2 p.m. and 4 p.m. according to current study) to maximise the number of ants inside the nest (Van Mele *et al*. 2009; Peng *et al*. 2012a).

CONCLUSION

The daily foraging pattern of *O. smaragdina* was significantly influenced by both temperature and relative humidity. The weaver ants foraged more intensively between 2 a.m. to 6 a.m. (nocturnal) and ceased their activities between 2 p.m. to 4 p.m. Throughout three consecutive days, proteinaceous-based food (tuna) was

highly preferred by this species over lipid-protein food (chicken skin) and well-balanced food (milk powder).

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