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RESEARCH ARTICLE

Controlling household ants in the field using coffee extract impregnated gel baits

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ABSTRACT

Household ant infestations are a common nuisance in urban environments, particularly in food service areas such as cafeterias. This study investigates the efficacy of using coffee extract impregnated in gel baits for controlling household ants, focusing on three species of coffee: *Coffea arabica* L., *Coffea canephora* Pierre ex A. Froehner, and *Coffea liberica* W. Bull ex Hiern. The field study was conducted on Penang Island, Malaysia, using a randomized complete block design in 13 cafeterias. Crude coffee extracts were prepared using Soxhlet extraction and incorporated into sugar-based gel baits. Quantitative results showed that gel bait containing *C. arabica* achieved the highest reduction in ant population, with a significant decrease in abundance 2 mo post-treatment compared to *C. canephora*, *C. liberica*, and a commercial control bait (Makfor Q). Specifically, *C. arabica*-treated areas recorded the significant ($p < 0.05$) lowest mean number of ants. These findings suggest that coffee extract gel baits, particularly those using *C. arabica*, offer a promising natural alternative to conventional insecticides for urban ant management.

Key words: *Coffea arabica*, *Coffea canephora*, coffee extract, *Coffea liberica*, gel baits, household ants.

INTRODUCTION

Ants, renowned for their unparalleled ecological prowess, stand as a pinnacle of diversity among eusocial insects (Romiguier et al., 2022). Barring the extreme polar zones of Antarctica and the Arctic, their global ubiquity is a testament to their adaptability across diverse ecosystems (Parr and Bishop, 2022). Playing pivotal roles as efficient scavengers and vital food sources for numerous organisms, ants contribute significantly to organic matter decomposition and nutrient cycling, shaping the dynamics of their habitats (Farji-Brener and Werenkraut, 2017; Luo et al., 2023). Additionally, their involvement in seed dispersal, soil aeration, and pest control further underscores their ecological importance (Tarsa et al., 2018; Ortiz et al., 2021; Anjos et al., 2022).

However, in urban settings, the omnipresence of ants often poses challenges and inconveniences for human inhabitants. Their sheer abundance and propensity to infiltrate homes, businesses, and public spaces render them persistent nuisances, particularly when they encroach upon food storage and preparation areas (Ab Majid et al., 2016). Such intrusion induces discomfort and raises concerns about food safety and hygiene. Moreover, ant infestations in healthcare facilities jeopardize sterility, which could harm patient safety (Oliveira et al., 2017).

In Malaysia, the escalating ant infestation has become a significant concern (Ab Majid et al., 2017), particularly due to the country's tropical climate and diverse ecosystems that favor ant populations (Pierre et al., 2023). This widespread problem disrupts daily life and necessitates the implementation of effective pest management strategies to mitigate the adverse impacts on public health, sanitation, and infrastructure (Ab Majid et al., 2016).

Insecticide spraying typically targets ant foragers, which represent only a small fraction of the total colony, often fails to eliminate the underlying colony problem. While perimeter and barrier sprays can provide significant short-term reductions in visible ant activity, their effects are usually temporary, as the majority of the colony, including queens and brood, remains protected underground or in inaccessible locations, allowing the colony to recover or relocate after treatment. Moreover, spraying can disrupt the local ant community, sometimes leading to secondary invasions by other ant species, further complicating pest management (Buczkowski, 2024). In contrast, insecticidal baits, which are carried back to the nest and shared among colony members, have demonstrated greater efficacy in achieving colony-level suppression or elimination, especially when properly placed to ensure exposure to all affected colonies (Gandra et al., 2016; Shults et al., 2022).

However, the use of chemical baits raises concerns about chemical resistance and environmental safety, prompting the exploration of natural substances for pest control (Ab Majid et al., 2018). Coffee, which contains a variety of chemical compounds including caffeine, has shown significant potential in pest control across different organisms. Extracts from spent coffee grounds have demonstrated insecticidal, repellent, and oviposition deterrent effects against major agricultural pests such as *Spodoptera littoralis*, *Agrotis ipsilon*, *Bemisia tabaci*, *Empoasca fabae*, and *Aphis craccivora*, with mortality rates reaching up to 76% depending on concentration and application method (Hussein et al., 2022). Specifically, caffeine-based formulations have proven highly effective against the coffee berry borer (*Hypothenemus hampei*) and other coffee pests, achieving over 90% mortality in laboratory tests and substantial reductions in field infestations without phytotoxic effects on coffee plants (Góngora et al., 2023). Additionally, aqueous coffee and caffeine extracts have shown efficacy in controlling various phytophagous heteropteran species, supporting their use in sustainable pest management (Jurić et al., 2023). These findings suggest that coffee-derived compounds, particularly caffeine and certain phenolics, can serve as effective, natural pest control agents, providing safer alternatives to synthetic pesticides. Therefore, the objective of this study was to test the effectiveness of three species of coffee, *C. arabica* (Arabica coffee), *C. canephora* (Robusta coffee), and *C. liberica* (Liberian coffee), impregnated in the gel bait, on controlling household ants.

MATERIALS AND METHODS

Identified tested areas and collected ant species

Baiting was employed to identify the presence of ants and determine the species inhabiting specific areas. Thirteen cafeterias within the Universiti Sains Malaysia (USM) campus, Penang, Malaysia, were selected as trapping sites: Indah Kembara 1, Indah Kembara 2, Aman, Damai, Cahaya Gemilang, Tekun, Restu, Saujana, Fajar Harapan, Bakti Permai, Sains Farmasi, Siswa, and Subaidah. Ants were lured using a mixed honey and peanut butter bait strategically positioned around the cafeteria perimeters. Traps were deployed during the evening (17:30-19:00 h) and retrieved approximately 1 h later. This process was repeated thrice. Collected samples were preserved in 70% ethanol for subsequent morphological identification. Characteristics such as body segmentation, the number of petiole nodes, and the thorax spine were examined.

Coffee extraction

This research utilized three species of coffee: *Coffea arabica* L. (Arabica), *Coffea canephora* Pierre ex A. Froehner (Robusta), and *Coffea liberica* W. Bull ex Hiern (Liberica), sourced from Cap Kuda Coffee Company in Sabah, Malaysia. These coffees were procured in a sugar-free, roasted state. Subsequently, the coffee beans underwent grinding until achieving a fine consistency before being packaged and transported to USM.

For extraction purposes, 1 to 3 g crude material were extracted from 30 to 40 g coffee powder using Soxhlet extraction with 250 mL methanol. The process was carried out continuously for approximately 5 h. Upon completion, the obtained solution was allowed to cool before being put inside an oven to dry the solvent. After drying, the resulting extract was ready to use.

Preparation of coffee impregnated in gel baits

The coffee extract was added to a 20% sugar solution (Yeoh et al., 2018). The concentration of the resulting solution was set at 1.0 g L^{-1}, achieved by blending 0.1 g extract with 100 mL 20% sugar solution. Subsequently, the solution was thoroughly stirred using a spatula until the coffee extract was completely dissolved. Following this, a water crystal gel (super absorbent polymer, SAP) was introduced into prepared solution. The gel would absorb the solution, facilitating the integration of coffee extract into the gel. The gel was allowed to be immersed for 12 h and expanded to its maximum size. All gel baits were standardized to a constant mass of 1.0 g.

Field testing

Field experiments were conducted at the USM cafeterias to evaluate the efficacy of various coffee extracts in controlling household ants. Initially, traps were strategically positioned within the cafeteria perimeter to ascertain the ant population, serving as a baseline measurement before treatment implementation.

The selection of treatment sites followed a randomized complete block design (RCBD). During the treatment phase, ten coffee (tested bait) and commercial gel baits (serving as the control) were strategically placed around the cafeteria area for each treatment. Each treatment consisted of one type of bait in one cafeteria, with three replicates per treatment, as outlined in Table 1. These baits remained in position for 48 h before being removed.

After the treatment, traps were placed within the perimeter of the tested area again to determine whether the ant population had reduced. This procedure was repeated 1, 3, 7, 14 d, and 1 and 2 mo after treatment.

Table 1. Treatment area with their respective baits. Due to the minimal number of ants found in cafeteria Saujana, this area was excluded from the ant treatment.

Coffee/Bait	Name of cafeteria
Coffea arabica	Aman
	Siswa
	Tekun
Coffea canephora	Cahaya Gemilang
	Subaidah
	Restu
Coffea liberica	Indah Kembara 1
	Damai
	CSains Farmasi
Makfor Q (commercial gel bait/positive control)	Indah Kembara 2
	Fajar Harapan
	Bakti Permai

Data analysis

The ant species diversity and abundance in each tested area were assessed using the Shannon-Wiener index, Margalef richness index, and Pielou's evenness index. A PC-ORD (McCune and Mefford, 2011) analysis was employed to calculate these indices. A diversity t-test was conducted using PAST software (Hammer et al., 2001) to compare the diversity between two community samples based on the Shannon diversity index results. One-way ANOVA followed by the Tukey's test for post hoc comparison was utilized to compare the mean abundance of ants across different tested locations and the mean abundance among the three different types of coffee and control.

RESULTS

Identified treatment sites

Table 2 outlines the species and the abundance of ants that could be found across all tested locations. A total of seven species were identified, including *Monomorium pharaonis* (Linnaeus, 1758) (Hymenoptera: Formicidae), *Pheidole megacephala* (Fabricius, 1793) (Hymenoptera: Formicidae), *Paratrechina longicornis* (Latreille, 1802) (Hymenoptera: Formicidae), *Tapinoma melanocephalum* (Fabricius, 1793) (Hymenoptera: Formicidae), *Tapinoma indicum* (Forel, 1895) (Hymenoptera: Formicidae), *Solenopsis geminata* (Fabricius, 1804) (Hymenoptera: Formicidae), and one species remained unidentified. Due to the minimal number of ants found in café Saujana, this area was excluded from the ant treatment. Table 3 shows the number of species (S), the total number of individuals of all found species (N), the Shannon diversity index (H'), Pielou's evenness index (E'), and Margalef species richness index (R') of each tested area.

Table 2. Ant species, number of individuals, and percentage of ant abundance in various cafeterias. Mp: *Monomorium pharaonis*; Pm: *Pheidole megacephala*; Pl: *Paratrechina longicornis*; Tm: *Tapinoma melanocephalum*; Ti: *Tapinoma indicum*; Sg: *Solenopsis geminata*.

Location	Mp	Pm	Pl	Tm	Ti	Sg	Unidentified	Total N	%
Saujana	25	27	0	0	0	0	0	52	1.58
Restu	0	39	9	113	52	0	0	213	6.47
Tekun	18	75	9	0	0	0	0	102	3.1
Indah Kembara 1	0	77	215	86	27	0	0	405	12.3
Indah Kembara 2	0	91	96	79	11	44	8	329	9.99
Aman	3	447	0	146	3	0	0	599	18.19
Damai	149	347	26	0	0	0	0	522	15.85
Fajar Harapan	63	70	20	1	9	0	0	163	4.95
Bakti Permai	16	88	31	5	0	0	0	140	4.25
Cahaya Gemilang	0	162	65	48	47	0	0	322	9.78
Siswa	48	16	0	8	2	8	0	82	2.49
Subaidah	0	37	130	53	0	0	0	220	6.68
Sains Farmasi	65	32	0	0	47	0	0	144	4.37

Table 3. Diversity and abundance of ant species within various cafeterias. The Shannon diversity index (H') with different letter is significantly different. S: Number of species; N: total number of individuals of all found species; E': Pielou's evenness; R': Margalef species richness index.

Cafeteria	S	N	H'	E'	R'
Saujana	2	52	0.692[a]	0.999	0.253
Restu	4	213	1.125[ab]	0.812	0.560
Tekun	3	102	0.746[c]	0.679	0.432
Indah Kembara 1	4	405	1.161[ab]	0.838	0.500
Indah Kembara 2	6	329	1.530[c]	0.854	0.863
Aman	4	599	0.616[b]	0.444	0.469
Damai	3	522	0.779[b]	0.709	0.320
Fajar Harapan	5	163	1.179[ab]	0.733	0.785
Bakti Permai	4	140	0.993[c]	0.716	0.607
Cahaya Gemilang	4	322	1.233[d]	0.890	0.520
Siswa	5	82	1.177[ab]	0.731	0.908
Subaidah	3	220	0.954[c]	0.868	0.371
Sains Farmasi	3	144	1.059[ab]	0.964	0.402
Average	3.8	253.3	1.019	0.787	0.538

Post-treatment

Based on Figure 1, tested coffee baits showed lower ant reduction percentages than Makfor Q (Control) on days 0, 1, and 7. On day 14, *C. liberica* showed the highest ant reduction percentage, followed closely by Makfor Q. *Coffea arabica* exhibited intermediate reduction, while *C. canephora* showed no reduction. After 1 mo, *C. arabica* and *C. liberica* demonstrated higher reduction percentages than Makfor Q, while *C. canephora* showed no reduction. After 2 mo, Makfor Q showed lower ant reduction percentages than the other three tested coffee baits. Based on the overall post-treatment ant population, areas treated with *C. arabica* had the lowest abundance of ants and were significantly lower than the other two coffee baits (Figure 2).

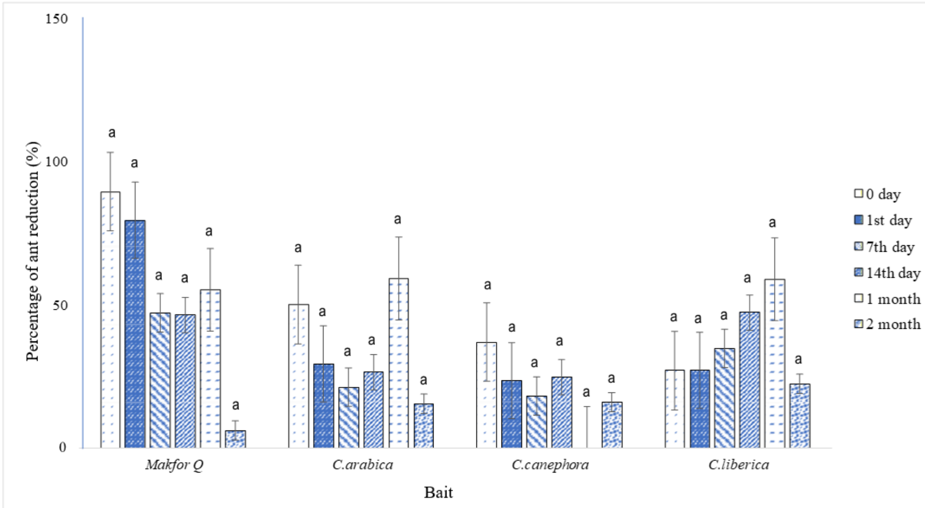

Figure 1. Mean percentage of ants reduction over days after bait treatments: *Coffea arabica*, *C. canephora*, *C. liberica*, and a commercial control bait Makfor Q. Means with different letter are significantly different according to Tukey's test ($p < 0.05$).

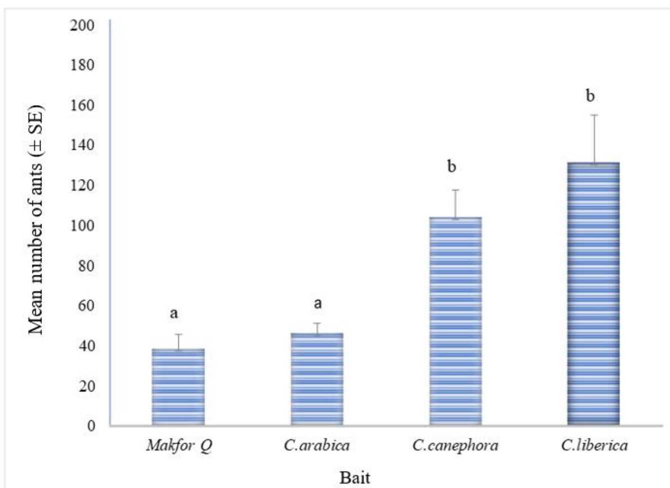

Figure 2. Mean number of ants (± SE) after bait treatments: *Coffea arabica*, *C. canephora*, *C. liberica*, and a commercial control bait Makfor Q. Means with different letter are significantly different according to Tukey's test ($p < 0.05$).

DISCUSSION

The ant species recorded across the Universiti Sains Malaysia (USM) campus cafeterias exhibit modest diversity, with a total of seven species (six identified and one unidentified). As shown in Table 3, each cafeteria hosted a unique assemblage of ants, contributing to the overall biodiversity profile of the study site. Among the tested areas, Café Indah Kembara 2 exhibited the highest number of species (S = 6), indicating the richest raw species count. However, this numerical richness did not translate into the highest values for diversity indices. Instead, Café Fajar Harapan recorded the highest Shannon diversity index (H' = 1.179), while Café Siswa showed the highest Margalef species richness index (R' = 0.908). These results underscore a critical ecological principle: Species count alone does not fully capture the complexity of biological diversity.

Shannon's index (H') accounts for both richness and evenness, meaning a location with a moderate number of species but a more balanced distribution of individuals among them can surpass a site with more species that are unevenly represented. In this case, although Indah Kembara 2 hosted more species, its community was likely skewed by dominant species, lowering its evenness and thus its Shannon index. Similarly, the Margalef index (R') adjusts species richness relative to the number of individuals sampled. While Siswa had fewer species than Indah Kembara 2, it also had a much smaller total ant population (N = 82 compared to N = 329). This smaller sample size, combined with a reasonably high species count, resulted in a higher R' value for Siswa, reflecting a richer species yield per individual sampled.

These findings align with ecological studies showing that species richness, when unadjusted for abundance, can be misleading, particularly in urban or disturbed habitats. In such environments, community composition may be inflated by the presence of both native and invasive species, but actual ecological diversity may decline if dominant or aggressive ants outcompete others (Castro et al., 2020; Lanhoso et al., 2024). In this study, most of the frequently encountered ants, including *Pheidole megacephala*, *Monomorium pharaonis*, *Tapinoma melanocephalum*, and *Paratrechina longicornis*, are known invasive species with a global distribution (Guerrero, 2018; Hasin and Tasen, 2020; Ke et al., 2024). Their presence likely contributed to uneven species distributions in sites such as Indah Kembara 2, where large populations of *P. megacephala* were recorded.

The number of individuals (N) found in each location reflects the abundance of ants in those areas. Among these cafeterias, Café Aman displays the highest ant abundance, suggesting potentially higher food availability, and it is a habitat more conducive to ant population dynamics (Pringle et al., 2019; Lach et al., 2020).

Pielou's evenness index (E') indicates the even distribution of individuals among different ant species in a location, with higher values suggesting a more balanced distribution. While the E' values of all tested cafés are relatively similar, Café Aman notably exhibits a lower evenness index (0.444). Based on Table 2, ant species found in this café, including *M. pharaonis*, *P. megacephala*, *T. melanocephalum*, and *T. indicum* with *P. megacephala*, hold the highest abundance. This could be an indicator that its colony is nearby and it is suppressing the development of the other species.

Interestingly, although *P. megacephala* was most abundant in Café Aman, it was also detected in all other tested cafeterias, indicating that this species may have established widespread colonies throughout the study area. Its presence across all sites aligns with its known ecological traits, particularly its highly efficient foraging behavior and adaptability to various environmental conditions (Schulze-Makuch et al., 2017). These characteristics enable *P. megacephala* to outcompete other ants, contributing to its status as one of the most invasive and dominant species in urban environments.

Areas treated with *C. arabica* displayed the lowest ant abundance post-treatment compared to the other two coffee baits, suggesting more effective suppression of ant populations (Figure 2). The result is aligned with the study by Yeoh et al. (2018) that extracts from *C. arabica* cause higher mortality in household ants compared to the other two species, especially at higher concentrations. This suggested that the specific blend of bioactive compounds in *C. arabica* is more toxic or less repellent to ants, allowing for greater ingestion and effectiveness as an insecticide.

CONCLUSIONS

Coffea arabica was the most effective coffee species in controlling household ants. This study contributes to the growing body of research on sustainable pest management strategies and highlights the potential of utilizing natural products like coffee extract to control household ants.

Author contribution

Conceptualization: A.H.A.M. Methodology: A.H.A.M. Software: L.L. Validation: L.L. Formal analysis: L.L. Investigation: L.L. Resources: A.H.A.M. Data curation: L.L. Writing-original draft: L.L. Writing-review & editing: A.H.A.M. Visualization: A.H.A.M. Supervision: A.H.A.M. Project administration: A.H.A.M. Funding acquisition: A.H.A.M. All coauthors reviewed the final version and approved the manuscript before submission.

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