Research Article

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Termite cuticular extracts improve acceptance of bait for controlling invasive Asian needle ants, *Brachyponera chinensis*

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Abstract

BACKGROUND: The Asian needle ant, *Brachyponera chinensis*, is an invasive ant currently spreading in urban and natural habitats throughout the eastern United States. Recent studies have documented the negative impact of *B. chinensis* on native ecosystems and human health, yet effective control strategies are lacking. Control difficulties are, in part, due to the unique biology of *B. chinensis*, which is a predatory ant and a termite specialist. Given that subterranean termites are an important nutritional resource for *B. chinensis*, the current study evaluated the potential of termite cuticular extract to improve the target-specificity and efficacy of commercial bait used for *B. chinensis* control.

RESULTS: The efficacy of bait augmented with termite cuticular extracts was evaluated in laboratory and field trials. In laboratory assays, *B. chinensis* colonies were offered granular bait treated with termite cuticular extract. Results demonstrated that the acceptance of commercial bait is significantly increased by the addition of termite cuticular extract or synthetic (*Z*)-9-pentacosene, a major component of termite cuticular extract. Foraging activity of Asian needle ants was significantly greater on baits augmented with termite cuticular extract or (*Z*)-9-pentacosene relative to standard bait. Furthermore, bait augmented with termite cuticular extract worked substantially faster relative to standard bait. To evaluate population effects, field studies were conducted in forested areas invaded by *B. chinensis*. Bait treated with termite cuticular extract scattered on the forest floor provided rapid control of *B. chinensis* and ant densities throughout the treated plots declined by 98% within 14 days.

CONCLUSION: The incorporation of termite cuticular extracts and individual cuticular hydrocarbons such as (*Z*)-9-pentacosene into traditional baits used for *B. chinensis* control may offer a novel tool to manage this increasingly problematic invasive ant.

Keywords: Asian needle ant; bait; control; cuticular hydrocarbons; *Brachyponera chinensis*; hydramethylnon; *Reticulitermes flavipes*; termite

1 INTRODUCTION

Social insects are ecologically dominant predators, pollinators, herbivores, and detritivores in many terrestrial ecosystems and are key providers of ecosystem services.[1] Many are also highly invasive and cause significant economic, environmental, and social impacts.[2,3] Among social insects, invasive ants are a major threat to urban, agricultural, and natural habitats worldwide.[3,4] This is mainly due to the unique life-history traits of invasive ants including high biomass and numerical abundance, high prevalence of polygyny and polydomy, habitat and nest generalism, mutualistic associations, and high potential to cause ecological damage through the displacement of native species.[3,5]

The spread and impact of invasive ants is often controlled using chemical management tools, predominantly toxic baits. Broadcast application of toxic bait is generally considered the most effective and efficient method of controlling invasive ants over large areas[6,7] and toxic baits have been used to control a wide range of species.[8–12] In theory, ants collect the bait granules, take them back to the colony, transfer the toxicant to colony members through trophallaxis, and eliminate the entire colony. In practice, however, there are many technical obstacles to developing effective baits, and control failures with toxic baits are common.[7,13] Baits have a number of disadvantages that limit their use including relatively short life span under field conditions, lack of attractiveness in the presence of competing food sources, susceptibility to environmental factors, incompatibility with target species feeding preferences, lack of effective dispensers, and potential non-target effects.[7] A wide range of effective bait toxicants including boric acid, fipronil, hydramethylnon, indoxacarb, and thiamethoxam are available for use in toxic baits for control and eradication of invasive ants.[7] However, the main challenge is formulating these toxicants into baits that are attractive to the target species, effective across species with different feeding preferences and life histories, and effective over an extended dose

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range. Recently, new developments have been made in bait delivery methods including hydrogel baits,[11,14] prey-baiting based on the use of toxicant-laden prey,[15–17] and pheromone-assisted baiting.[18,19] Despite the availability of effective toxicants and novel baiting technologies, ant eradication programs are in need of research and development particularly with regard to increasing efficacy, scale of application, and cost-effectiveness.

The Asian needle ant, *Brachyponera chinensis*, is ponerine ant with a venomous sting and potential for global spread.[20] It is a predatory ant and a termite specialist.[21] Predictive modeling demonstrates that climate change may significantly increase the global spread of *B. chinensis* by increasing the amount of habitat suitable to their invasion by 65% worldwide.[20] Interestingly, invasive termites are predicted to spread with climate change as well[22] which could fuel the global spread of *B. chinensis* given that termites are the main food source for *B. chinensis*.[21] In North America, *B. chinensis* is rapidly spreading in urban and natural areas in the south-eastern United States and has emerged as an important invasive species.[23–25] Recent work demonstrates a unique life history trait where native *B. chinensis* populations possess high inbreeding tolerance which acts as a pre-adapted trait for the success of invasive populations.[25] In urban areas, *B. chinensis* is commonly found close to human habitation[26] and is a threat to human health due to its painful stings.[27] It forms dense and expansive colonies which are often polydomous and polygynous.[23] In natural areas, *B. chinensis* occurs in undisturbed forests where it has detrimental effects on native ants as well as on ant-seed dispersal mechanisms.[23,28,29]

Despite the highly sustained range expansion in *B. chinensis* and its ability to overcome a broad range of ecological impacts, effective management approaches are lacking. Control difficulties are, in part, due to the highly unique biology of *B. chinensis*. There is no evidence that *B. chinensis* consumes liquid carbohydrates such as honeydew or nectar which precludes the use of liquid baits and many commercially formulated liquid, granular, and gel baits are ineffective against *B. chinensis*.[30] Furthermore, most invasive ants use mass recruitment to collect toxic baits. In contrast, no trail pheromone has been detected in *B. chinensis*. Instead, *B. chinensis* employs a unique yet relatively slow recruitment process called tandem carrying whereby foraging workers carry nestmates from the nest to the food source which is subsequently retrieved.[31] Finally, unlike colonies of many invasive ants which dominate urban and disturbed habitats, colonies of *B. chinensis* typically invade undisturbed forested habitats where control is challenging due to conservation concerns. These factors complicate management efforts for *B. chinensis* and warrant the search for novel management tools and approaches to combat this invasive species.

Spicer Rice *et al*.[32] demonstrated effective control of *B. chinensis* using a commercial bait. However, control was relatively slow and incomplete. Given that *B. chinensis* is a termitophagous species, the current study examined the potential of termite cuticular extracts to improve the target-specificity and efficacy of commercial baits used for *B. chinensis* control. Termite cuticular extracts might be effective in improving the efficacy of baits used for controlling *B. chinensis* for several reasons. A previous study demonstrated that subterranean termites are an important nutritional resource for *B. chinensis* and highly preferred over other prey.[21] Olfactometer studies show that *B. chinensis* can detect termite odors from a distance of at least 7 cm and orient towards termite prey.[21] Previous studies evaluated the potential of termite prey to control *B. chinensis* and demonstrated that termites topically treated with the insecticide fipronil and scattered in areas invaded by *B. chinensis* provided effective control.[15,17] Therefore, the incorporation of termite extracts into traditional baits used for *B. chinensis* control might offer a novel tool to manage this increasingly problematic invasive ant.

2 METHODS

2.1 Preparation of termite cuticular extracts

A colony of eastern subterranean termites, *Reticulitermes flavipes*, was collected from cardboard-baited traps buried next to live trees infested with termites on the campus of Purdue University, West Lafayette, IN, USA.[33] The termites were brought into the laboratory and allowed to migrate into plastic containers with moistened pine wood provided as food and harborage. Colonies were maintained at 27° ± 1 °C, > 80% relative humidity (RH), and constant darkness. A group of 50 fifth- through seventh-instar termite workers was freeze-killed for 10 min at −20 °C and placed in a glass vial containing 5 mL hexane. Cuticular lipids were extracted by immersing the termites in three successive portions of 5 mL hexane for 5 min each with intermittent mixing. The extracts were combined and concentrated under nitrogen to 1 mL. Extracted cuticular lipids were stored at −20 °C in hexane until use.

2.2 Bait selection and preparation

Previous reports demonstrated that Maxforce Complete Granular Insect Bait (1% hydramethylnon; Bayer Environmental Science, Cary, NC, USA) is effective against *B. chinensis* in laboratory and field trials.[32] Therefore, Maxforce Complete was selected for use in the current study. To prepare bait treated with termite cuticular extract 1 mL of extracted cuticular lipids (as earlier; containing 50 termite equivalents) were uniformly pipetted over 1.0 g of bait. This concentration was selected based on results of preliminary dose–response tests. The bait granules were thoroughly mixed and hexane was allowed to evaporate for 1 h. Previous studies have examined the composition of cuticular hydrocarbons in the eastern subterranean termite (*R. flavipes*) and demonstrated that (*Z*)-9-pentacosene is the most abundant cuticular hydrocarbon of all *R. flavipes* castes and accounts for 25% of all cuticular hydrocarbons in workers.[34,35] The efficacy of (*Z*)-9-pentacosene as *B. chinensis* bait attractant was tested. To prepare bait treated with (*Z*)-9-pentacosene 1.0 g of bait was treated with 2 mL of hexane containing 0.1 mg of (*Z*)-9-pentacosene (Cayman Chemical, Ann Arbor, MI, USA; Cat. No. 9002807). The amount of 0.1 mg was chosen based on Howard *et al*.[34] which reported that the amount of cuticular hydrocarbons in *R. flavipes* workers is 0.2 mg per gram of live biomass. Bait granules were thoroughly mixed and hexane was allowed to evaporate for 2 h.

2.3 Evaluation of bait attractiveness and efficacy – laboratory study

Colonies of *B. chinensis*, were collected from rotting logs in wooded areas at Carl Alwin Schenck Memorial Forest in Wake County, NC, USA (35.81° N, −78.72° W) and William B. Umstead State Park in Wake County, NC, USA (35.85° N, −78.76° W) under a scientific research and collecting permit issued by the North Carolina State Parks System. The colonies were transported to the laboratory and experimental colonies were set up by aspirating 100 workers and several brood from stock colonies and transferring them into artificial nests consisting of a glass test tube (15 mm diameter × 150 mm long) half filled with moist soil. The tube was wrapped in aluminum foil to provide darkness preferred

Table 1. Total number of *Brachyponera chinensis* workers recorded feeding on standard and augmented baits in laboratory assays

	Time (min)								
Treatment	5	10	15	30	60	90	120	180	Total
Bait	14 a	19 a	23 a	18 a	21 b	16 a	18 a	6 a	135 a
Bait + cuticular extract	22 b	38 b	50 c	29 b	29 b	17 a	18 a	17 b	220 c
Bait + pentacosene	18 a	35 b	35 b	30 b	16 a	15 a	17 a	8 a	174 b

Note: Totals within columns followed by the same letter are not significantly different ($P \leq 0.05$) based on Tukey's HSD test.

by the ants and closed with a cork with a 2 mm diameter hole to allow entry. Experimental colonies were placed in 30 cm × 25 cm × 9 cm high Fluon-coated plastic boxes and allowed to acclimate to the box for 24 h without food. After acclimation, 0.5 g of bait was introduced outside the nest in a shallow weigh boat. The attractiveness and efficacy of four treatments was evaluated: (i) Maxforce Complete, (ii) Maxforce Complete treated with termite cuticular extract (prepared as earlier), (iii) Maxforce Complete treated with (*Z*)-9-pentacosene (prepared as earlier), and (iv) untreated control. Each treatment was replicated six times. All experiments were performed at 27 ± 1 °C, 50 ± 2% RH, and 14 h:10 h light/dark cycle. Bait attractiveness was assessed by counting the number of workers foraging on the bait at 5, 15, 30 min and every 30 min thereafter for 5 h. Bait efficacy was determined by counting the number of dead *B. chinensis* workers daily for 8 days.

2.4 Field study

Field plots containing colonies of *B. chinensis* were established at Schenck Forest and Umstead Park as stated earlier. All plots were 6 m by 6 m and test plots were separated by at least 25 m buffer zones. To estimate initial ant densities (day 0) the plots were sampled on a 3 m by 3 m grid (four sub-plots; nine baits per plot) using note cards baited with a blend of canned tuna and corn syrup.[36] The note cards were placed on the ground and collected 2 h after placement to record the presence of *B. chinensis*. Following census baiting, each 36m^2 plot was baited with a broadcast application of 6.1 g of bait. This is equivalent to the label rate for Maxforce Complete (1 oz product per 1800 square feet for outdoor broadcast applications). The efficacy of three treatments was evaluated: (i) Maxforce Complete, (ii) Maxforce Complete treated with termite cuticular extract (prepared as earlier), and (iii) untreated control. Each treatment was replicated four times, with two plots at Schenck and two plots at Umstead for each treatment. The efficacy of the treatments was examined on days 1, 3, 7, and 14 using baited note cards as mentioned earlier. All tests were performed in July–September 2022.

2.5 Statistical analysis

For all laboratory and field trials, a one-way repeated measures multivariate analysis of variance test was used to examine the effect of treatment (type of bait additive), time, and the interaction on ant number (for bait attractiveness trial) or ant counts (mortality counts for laboratory test and bait card counts for field test). This was followed by univariate analysis of variance (ANOVA) to examine variation at each time point. Comparisons among treatments or among exposure times consisted of ANOVA tests on mean cumulative percent mortality followed by Tukey's honestly significant difference (HSD) test to test for significant differences among treatment means on each date. All statistical analyses were performed using Statistica 12.6.[37]

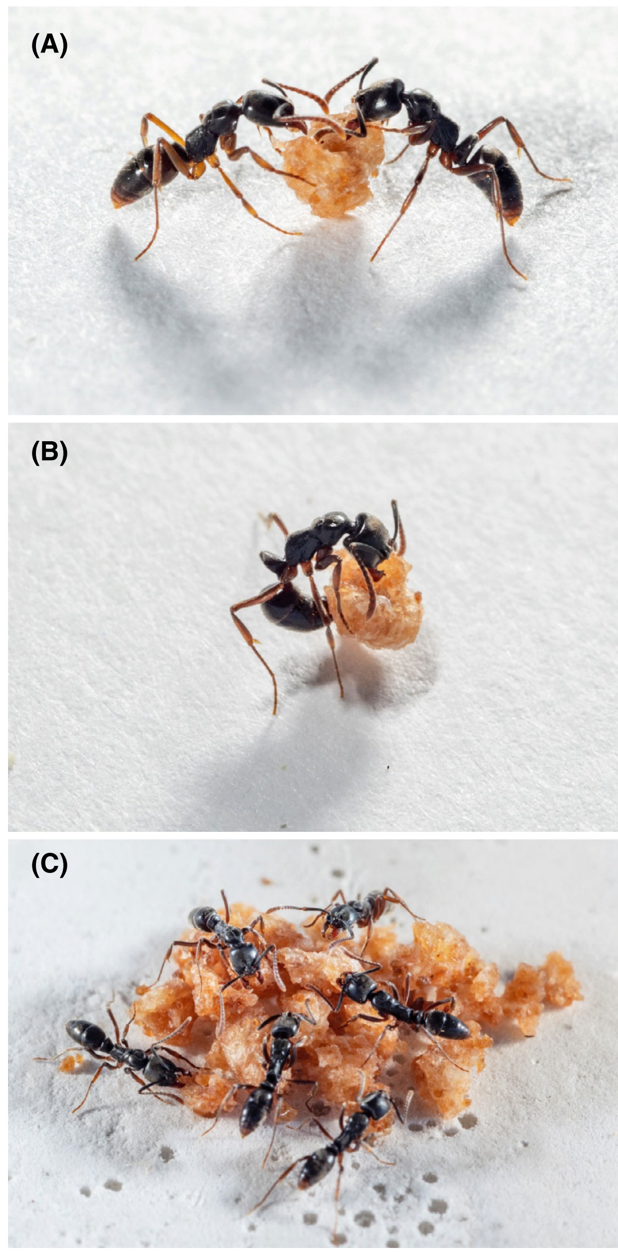

Figure 1. (A) Foraging *Brachyponera chinensis* workers cooperatively transporting a bait granule to the nest. (B) *Brachyponera chinensis* stinging a bait granule treated with termite cuticular extract. (C) Colony of *B. chinensis* assessing bait treated with termite cuticular extract.

Table 2. Mean daily cumulative percent mortality (± standard deviation) in *Brachyponera chinensis* colonies feeding on standard and augmented baits in laboratory assays

	Time (min)							
Treatment	1	2	3	4	5	6	7	8
Bait	5 ± 4 a	11 ± 5 b	31 ± 13 b	48 ± 15 b	65 ± 15 b	77 ± 4	92 ± 6 b	100 ± 0 b
Bait + cuticular extract	9 ± 5 a	16 ± 4 bc	46 ± 9 c	67 ± 11 c	86 ± 10 c	100 ± 0	100 ± 0 b	100 ± 0 b
Bait + pentacosene	4 ± 5 a	12 ± 6 b	42 ± 22 c	54 ± 15 b	66 ± 13 b	84 ± 6	95 ± 5 b	100 ± 0 b
Control	1 ± 1 a	2 ± 2 a	4 ± 5 a	4 ± 5 a	6 ± 5 a	7 ± 5 a	7 ± 5 a	7 ± 5 a

Note: Means within columns followed by the same letter are not significantly different ($P \leq 0.05$) based on Tukey's HSD test.

3 RESULTS

3.1 Evaluation of bait acceptance and efficacy – laboratory study

Results demonstrate that bait acceptance is significantly increased by the addition of termite cuticular extract ($t = -2.39$, df = 1, $P = 0.003$) or pentacosene ($t = -1.10$, df = 1, $P = 0.02$) (Table 1 and Fig. 1(A)–(C)). Foraging activity of Asian needle ants was significantly greater on baits augmented with termite cuticular extract or pentacosene relative to standard bait (Table 1). During the 180 min observation period, a mean total of 23 ± 8 workers were recorded foraging on standard bait. Bait augmented with termite cuticular extract attracted a mean total of 37 ± 11 workers and bait augmented with pentacosene attracted 29 ± 11 workers.

Mortality in laboratory colonies provisioned with standard and augmented baits was relatively quick and all colonies died within 8 days of being provided with the baits (Table 2). Results demonstrate a significant effect of treatment (type of bait additive) ($F = 131.3$, df = 3, $P < 0.0001$), day ($F = 473.9$, df = 7, $P < 0.0001$), and day × treatment interaction ($F = 21.6$, df = 21, $P < 0.0001$). Among the different treatments, significant difference in *B. chinensis* mortality was detected in colonies provided with bait augmented with termite cuticular extract *versus* standard bait ($F = 65.7$, df = 16, $P = 0.001$). In contrast to bait augmented with termite cuticular extract, bait augmented with pentacosene did not appear to improve the rate of *B. chinensis* mortality ($F = 54.2$, df = 16, $P = 0.09$). Mortality in the control treatment did not exceed 7%.

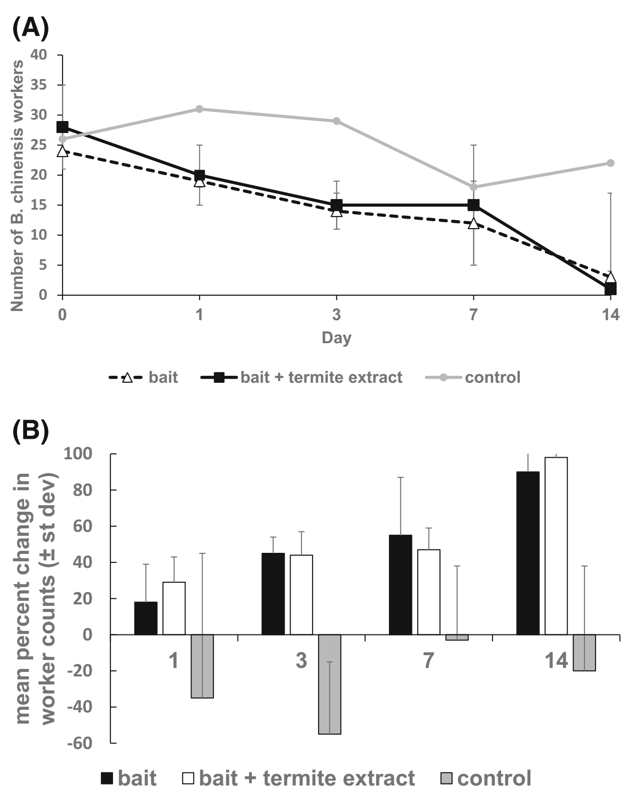

Figure 2. (A) Mean [± standard deviation (st dev)] total number of *B. chinensis* detected in field plots baited with standard and augmented baits. (B) Mean (± st dev) percent mortality in field colonies of *B. chinensis* provided with standard and augmented baits.

3.2 Field study

The application of standard and augmented hydramethylnon bait reduced *B. chinensis* abundance over time relative to the untreated control plots (Fig. 2(A),(B)). At 14 days after the initial treatment, the abundance of *B. chinensis* declined by 90 ± 12% in plots treated with standard bait and 98 ± 3% in plots treated with enhanced bait ($t = 0.78$, df = 1, $P = 0.12$). The number of *B. chinensis* detected over time differed significantly across treatments (time × treatment: $F = 2.23$, df = 8, $P = 0.04$). The results provide evidence that augmented bait is more effective, however, the difference between standard and augmented bait was not statistically significant ($t = -0.31$, df = 1, $P = 0.76$).

4 DISCUSSION

Results of laboratory tests clearly indicate that the addition of termite cuticular extracts increases *B. chinensis* foraging activity on the bait. Furthermore, higher foraging activity leads to significantly faster mortality on augmented *versus* standard bait. The increased rate of mortality might be attributed to a higher number of foragers that are discovering and consuming the bait within a fixed amount of time. There are several potential advantages of the lure-and-kill approach evaluated in the current study. The first advantage is that the addition of termite cuticular extracts might lead to greater bait specificity and more efficient bait retrieval. Olfactometer studies show that *B. chinensis* can detect termite odors from a distance of at least 7 cm and orient towards termite prey.[21] Furthermore, observations from experiments on prey olfactory cues demonstrate that *B. chinensis* track termites in experimental areas, possibly cueing in on the various pheromones produced by the termites.[21] Termite chemical communication is often eavesdropped or mimicked by termitophagous predators and inquilines. For example, the termite-raiding ant *Odontoponera transversa* eavesdrops the trail-following pheromones of fungus-growing termites *Macrotermes yunnanensis* and *Ancistrotermes dimorphus*.[38] The ants use the trail pheromone information as an indication of suitable prey abundance. In field applications, bait granules are typically scattered on the ground and need to be discovered by the ants in a complex, three-dimensional environment. Results of bait attractiveness experiments demonstrate that *B. chinensis* are highly attracted to augmented bait and observations indicate that the ants often sting augmented bait suggesting they are able to detect termite cuticular extracts and may identify augmented bait granules as live termites. The bait stinging behavior is not surprising given that non-animate objects (e.g., glass dummy beads) coated with cuticular extracts have been shown to elicit behavioral responses in social insects.[35,39] A second advantage of the lure-and-kill approach is that augmented bait is highly attractive to *B. chinensis* which may lead to increased bait handing time, increased uptake of the active ingredient, and consequently higher mortality. Observations indicate that *B. chinensis* handle augmented granules in a manner similar to live termites including directional movement toward treated granules, immediate pick up on contact, excitation, stinging, and carrying. The bait granules are impregnated with oil which serves as an attractant and carrier for the active ingredient. Prolonged contact with the granules increases the likelihood for oil transfer from granule to ant and may lead to greater efficacy. Third, the addition of termite cuticular extracts may lead to faster bait discovery. Hydramethylnon, the active ingredient used in the current study, degrades rapidly in sunlight and the timing of applications can influence efficacy.[40] The addition of termite cuticular extracts may increase the likelihood that the ants find the bait before it degrades or is discovered by non-target species. Finally, faster bait discovery and more efficient bait retrieval may offer environmental benefits by reducing the amount of insecticide applied in the environment while providing high efficacy.

Laboratory tests demonstrated that the augmented bait has significantly higher acceptance and is significantly faster-acting relative to standard bait. However, the benefits observed in the laboratory did not immediately translate into improved efficacy under field conditions. The number of ants recorded on the bait cards in the field was similar for standard and enhanced bait. Both baits resulted in > 90% reduction in ant counts in experimental plots based on post-treatment counts at baited cards. However, the enhanced bait treatment was more effective in achieving complete eradication rather than partial control. The standard bait treatment resulted in 100% reduction in ant counts in two out of four plots whereas the enhanced bait treatment resulted in 100% reduction in ant counts in three out of four plots. The reasons for the lack of improved control are unknown, but could be due to various factors including biological and technical variability.

Previous studies evaluated prey-baiting as a potential method for controlling invasive ants including *B. chinensis*[15,16] and *Linepithema humile*.[17] Prey-baiting takes advantage of the predatory feeding habits of many invasive ants and uses live, insecticide-treated prey to deliver the toxicant to the target species. In laboratory tests, *B. chinensis* colonies were offered fipronil-treated termites and the termites were readily consumed by the ants resulting in colony mortality. In field trials, fipronil-treated termites were scattered in natural areas invaded by *B. chinensis*. The treated termites provided rapid control and ant densities declined by 98% within 28 days. Prey-baiting studies demonstrated that insecticide-treated prey are an effective way of delivering toxicants to invasive ants. However, the utility of the prey-baiting approach has never been tested on a large scale to better understand its efficacy at greater temporal and spatial scales and to determine its suitability for area-wide eradications. Another potential drawback is regulatory, legal, and ethical considerations of releasing live termites into natural or urban environments. One of the goals for the current study was to determine if termite cuticular extracts are an effective substitute for live termites. Results of behavioral tests demonstrate that bait augmented with termite cuticular extract is significantly more attractive and significantly faster-acting relative to standard bait and results of the field study demonstrate that augmented bait is highly effective in controlling *B. chinensis*, but not significantly different from standard bait.

One of the goals for the laboratory study was to compare the attractiveness of complete termite cuticular extract which contains over 13 major hydrocarbon components[34,35] to a single, synthetic compound, (*Z*)-9-pentacosene, which is the most abundant cuticular hydrocarbon in *R. flavipes* and accounts for 25% of all cuticular hydrocarbons in worker termites.[34] The objective was to determine if complete cuticular extract and (*Z*)-9-pentacosene are capable of eliciting a similar behavioral response in *B. chinensis*. Bait attractiveness tests demonstrated that bait treated with (*Z*)-9-pentacosene has higher acceptance relative to standard bait, but not as high as bait treated with complete cuticular extract which contains a wide range of volatile and non-volatile pheromones. Additionally, bait efficacy tests demonstrated that the rates of mortality achieved with standard bait *versus* bait treated with (*Z*)-9-pentacosene are similar and significantly slower that bait enhanced with complete cuticular extract. These results demonstrate that (*Z*)-9-pentacosene is capable of eliciting a behavioral response in *B. chinensis* and stimulating feeding behavior. However, (*Z*)-9-pentacosene alone is not as effective as complete cuticular extract and does not appear to provide a substantial improvement for the commercial bait evaluated in the study. From a practical standpoint, incorporating a single, synthetic compound is more realistic and cost-effective than sourcing a complete cuticular extract from live termites. It is possible that a more attractive synthetic blend of cuticular hydrocarbons could be developed by incorporating proper ratios of other major cuticular hydrocarbons including tetracosane, *n*-pentacosene, (*Z*,*Z*)-7,9-pentacosadiene, and 2-methyltetracosane as reported in Howard *et al*.[34] and more recently in Funaro *et al*.[35]

Pheromones can be excellent control agents for pest management due to species-specific effects and low non-target toxicity. However, their use in pest management has been limited mainly to monitoring, mass trapping, and mating disruption, primarily in lepidopteran pests in agricultural environments.[41] In contrast to agricultural systems, the use of pheromones for urban pest management has been limited with some notable exceptions. For example, the sex pheromone of the German cockroach (*Blattella germanica*) has been identified and proven effective in field trapping tests suggesting it may provide a useful tool for cockroach detection, monitoring, and control.[42] The use of pheromones has also been explored for ant management. Ants use a diverse range of pheromones for social communication and colony organization.[43] In particular, trail pheromones of ants play critical roles in exploitation of food resources and colony movement and relocation.[44] The trail pheromone of Argentine ants, (*Z*)-9-hexadecenal has been identified[45,46] and several studies have explored the possibility of using synthetic (*Z*)-9-hexadecenal to develop practical management strategies for Argentine ants. One study demonstrated that the addition of (*Z*)-9-hexadecenal to liquid sucrose bait enhances recruitment and results in significantly higher bait consumption.[47] Other studies have tested the potential of (*Z*)-9-hexadecenal to disrupt Argentine ant trailing and foraging behaviors[48–50] or to attract Argentine ants to areas treated with spray insecticides.[51] Finally, a previous study tested 'pheromone-assisted baiting techniques' for Argentine ants and demonstrated that incorporating (*Z*)-9-hexadecenal into conventional granular and gel baits can significantly improve foraging activity and bait efficacy.[19] Results of the current study demonstrate that termite cuticular extract, which likely includes various termite pheromones, significantly improves bait acceptance when incorporated into a granular bait. The extract-supplemented baiting technique has potential to provide an effective management tool for *B. chinensis* in urban and natural areas.

In summary, the results of this study demonstrate proof-of-concept for extract-supplemented baiting of *B. chinensis*. The baiting technique may provide an effective improvement to current control strategies. Our current knowledge of ant biology and behavior is limiting the ability to effectively and safely manage invasive ants and more research is needed that integrates ant natural history with control strategies and methodologies.[7] Bait acceptance is crucial to the success of toxic baits, yet many baits do a poor job of controlling a wide range of ants. Granular baits have been developed to target fire ants (*Solenopsis* spp.) and other myrmicinae ants. Unfortunately, these baits are not attractive to other groups of ants, particularly species that prefer liquid carbohydrate baits or are not greatly attracted to corn grit or other solids impregnated with oil. The current study demonstrates that compounds present in termite cuticular extracts have the potential to improve baiting programs for Asian needle ants and cuticular extracts of other insects may be effective for developing lure-and-kill approaches for other pest ants.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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