



Vector Control, Pest Management, Resistance, Repellents

Differential toxicological responses of brownbanded and German cockroaches (Blattodea: Ectobiidae) to commercial gel baits

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Subject Editor: Warren Booth

Received on 19 February 2025; revised on 5 April 2025; accepted on 9 May 2025

The brownbanded cockroach, *Supella longipalpa* (F.), is a cosmopolitan pest cockroach that infests indoor environments. Compared to the more prevalent German cockroach, *Blattella germanica* (L.), *S. longipalpa* has higher temperature requirements but can infest a wider range of environments within structures under suitable conditions. Little is known about the toxicity of gel baits against *S. longipalpa* relative to that of *B. germanica*. This study evaluated toxicological responses of brownbanded and the German cockroach to commercial gel baits (Advion Evolution, Maxforce FC Magnum, Maxforce Impact, Alpine, Vendetta Plus, and 1% isocycloseram) using open test arenas and Ebeling choice boxes. Results showed that gel baits were less effective against *S. longipalpa*. *Supella longipalpa* survived 3.3 to 10.2x longer than *B. germanica* when exposed to most bait formulations in open arenas. Gel baits showed lower performance index values against *S. longipalpa* than against *B. germanica* in choice boxes. Based on the low performance index values, it is predicted that Maxforce FC Magnum and Vendetta Plus would be ineffective in treating *S. longipalpa* infestations in the field. Differences in gel bait performance between the 2 species are likely due to the lower palatability of gel baits to *S. longipalpa*, arising from differing nutritional and moisture requirements. Correlation and regression analysis showed a direct relationship between the data obtained from both assays for *S. longipalpa*. While open arena bioassays are useful in comparing the toxicity of different gel baits, choice boxes replicate field conditions more closely and allow a more accurate evaluation of bait performance.

Keywords: fipronil, isocycloseram, dinotefuran, indoxacarb, clothianidin

The brownbanded cockroach, *Supella longipalpa* (Fabricius), is an indoor urban insect pest with a cosmopolitan distribution (Cochran 1999, Nasirian 2016). Alongside the German cockroach *Blattella germanica* (L.), American cockroach *Periplaneta americana* (L.), and oriental cockroach *Blatta orientalis* L., *S. longipalpa* is listed under the “Dirty 22” species, which are considered by the US Food and Drug Administration (FDA) to be the most important vectors of foodborne pathogens (Sulaiman et al. 2011). Specimens of *S. longipalpa* collected from houses and hospitals were found to carry various antibiotic-resistant bacterial pathogens including *Enterobacter* spp., *Klebsiella* spp., *Citrobacter* spp., *Escherichia coli* (Migula), *Salmonella* spp., *Proteus* spp., *Pseudomonas* spp.,

Bacillus spp., and *Staphylococcus aureus* Rosenbach (Vazirianzadeh et al. 2014, Veysi et al. 2023). Additionally, fungi genera such as *Penicillium*, *Aspergillus*, *Rhizopus*, *Cladosporium*, and *Fusarium* were isolated from *S. longipalpa* (Corrêa et al. 2011). Like *B. germanica*, *S. longipalpa* can also potentially produce allergens that trigger asthma (Gore and Schal 2007).

In the continental US, *S. longipalpa* is less common as they require higher temperatures (27 to 33°C) for normal nymphal development and oothecal incubation, while *B. germanica* has more modest temperature requirements (24 to 27°C) (Gould 1940, Gould and Deay 1940, Tsai and Chi 2007). However, under suitable conditions, *S. longipalpa* can infest a wide variety of locations, including living

rooms, bedrooms, offices, pet stores, zoos, and animal-care facilities (Cochran 1999, Brenner and Kramer 2019), while *B. germanica* tends to primarily infest kitchens, restaurants, and other food-preparation facilities (Lee and Wang 2021). Large infestations of *S. longipalpa* have been historically documented in insectaries and research facilities of several universities across the United States (Slater et al. 1980, Slater 1984). In tropical regions such as Southeast Asia, *S. longipalpa* is more frequently encountered than *B. germanica* in residential premises and offices (Lee and Lee 2000, Sriwichai et al. 2002). One of the additional challenges in managing *S. longipalpa* is related to their behavioral tendency to adhere ootheca within furniture such as desks, tables, and beds, as well as on high locations such as shelves and picture frames (Gould and Deay 1940, Benson and Huber 1989). These oviposition habits give *S. longipalpa* their other common name of “furniture cockroach,” and new infestations can often be established through the movement of infested furniture (Gould and Deay 1940, Cochran 1999).

Generally, it is assumed that an insecticide that performs well against *B. germanica* will also be effective against *S. longipalpa* due to their relatively similar body size and habits. Management programs for *B. germanica* rely heavily on the use of toxic baits (Wang et al. 2004, Gondhalekar et al. 2011, Ko et al. 2016, Lee et al. 2022). Although numerous studies on bait performance on *B. germanica* have been reported (Appel et al. 2022, Lee et al. 2022, 2024, Hamilton et al. 2023, McPherson et al. 2023), there is hardly any information on this subject on *S. longipalpa*. The few past studies which investigated bait performance against *S. longipalpa* are outdated now, as they were tested on older bait formulations that are no longer available on the market (Koehler et al. 1991, Savoldelli and Süss 2005, Wang and Bennett 2005, Bayer et al. 2012). It is unknown how the contemporary bait formulations perform against *S. longipalpa*.

Insecticide susceptibility often varies between different species of pest cockroaches (Ebeling et al. 1968, Koehler et al. 1991, Valles et al. 1999, Bayer et al. 2012). Physiological differences may be responsible for the heightened susceptibility of certain cockroach species to a particular insecticide (Ebeling et al. 1968). For instance, differing levels in the activity of enzymes involved in detoxification and biotransformation have been suggested as potential factors (Valles et al. 1999, Bayer et al. 2012). Larger body size can also be associated with higher values of LT_{50} against toxic baits (Koehler et al. 1991). Aside from differences in physiology, behavioral differences may influence insecticide susceptibility. Despite being extremely susceptible to boric acid dust in forced exposure tests, *S. longipalpa* survived comparatively longer in treated choice boxes than the other 3 species of cockroaches tested as they tended to remain on the walls of the dark compartment more frequently (Ebeling et al. 1968). Pest blattid species tended to have a higher preference for gel baits over dog food than pest blattellid species, possibly stemming from a greater need for nutrients from baits due to increased cuticular water permeability and higher metabolism, demonstrating that a combination of both physiological and behavioral factors may influence bait efficacy (Bayer et al. 2012). *Supella longipalpa* and *B. germanica* have different requirements and preferences for the ratio of carbohydrates and protein in their diet, which may result in differing responses toward bait formulations (Cohen et al. 1987, McPherson et al. 2021). These dietary requirements and preferences also vary across different stages of their reproductive cycles, which are vastly different between the 2 species (Hamilton and Schal 1988, Hamilton et al. 1990). Therefore, it is inappropriate to generalize bait performance across different species of pest cockroaches, as doing so may result in control failure and increased allergen exposure.

Unlike in Southeast Asia, field infestations of brownbanded cockroach in California are rare; hence, only laboratory studies could be conducted. This laboratory study evaluated 6 commercial gel bait formulations with different active ingredients and different modes of action on *S. longipalpa* and *B. germanica*. Only insecticide-susceptible strains of *S. longipalpa* and *B. germanica* were used as resistance is currently not known to occur in *S. longipalpa*. The toxicity of the gel baits was evaluated using both open arena bioassays and Ebeling choice box assays (Ebeling et al. 1966). Open arena bioassays and other similar continuous exposure tests are commonly used to evaluate gel baits due to their ease of setup. Choice boxes are more complex but simulate field conditions more closely, and insecticides that perform well in choice box assays are known to have the potential to be effective when used in the field (Rust and Reiersen 1978, Appel 1990, 1992, Rust et al. 1993). We examined the relationship between the results obtained from the 2 assays to determine if data from open arena bioassays can be used to predict choice box results.

Materials and Methods

Insects

The brownbanded and German cockroaches used in the bioassays were from cultures maintained in the laboratory at ambient conditions of 24 ± 2 °C, 30% to 50% relative humidity (RH), 12:12 h L:D photoperiod. For *B. germanica*, the UCR susceptible laboratory strain was used. This strain was established from the Orlando-normal strain more than 40 yr ago and has never been exposed to insecticides. The brownbanded cockroach population was established more than 50 yr ago. All cockroaches were provided with dog food (Purina Dog Chow, Nestlé Purina Petcare, St. Louis, MO), water, and cardboard harborages ad libitum.

Insecticides

Six gel bait formulations were tested: Maxforce FC Magnum (0.05% fipronil, Bayer Environmental Science, Research Triangle Park, NC), Maxforce Impact (1% clothianidin, Bayer Environmental Science, Research Triangle Park, NC), Advion Evolution (0.6% indoxacarb, Syngenta Crop Protection LLC, Greensboro, NC), 1% isocycloseram (Syngenta Crop Protection LLC, Greensboro, NC), Alpine (0.5% dinotefuran, BASF Corporation, Research Triangle Park, NC), and Vendetta Plus (0.05% abamectin + 0.50% pyriproxyfen, MGK Company, MN).

Open Arena Bioassays

Ten adult male cockroaches were acclimatized for 24 h in plastic test arenas (28.7 × 15.5 × 10.9 cm) with dog food, water, and a piece of cardboard harborage. The walls of the arenas were coated with a thin layer of petroleum jelly to prevent cockroaches from escaping, and the bottom of the arenas were lined with construction paper to increase cockroach traction. At the start of each trial, 0.5 g of gel bait applied on a weigh boat was added to the arena. Cockroaches were allowed to feed freely on both dog food and gel bait. Control treatments were not provisioned with gel bait but were otherwise identical. Mortality was recorded every 1 to 2 h for the first 24 h, every 12 h for the next 24 h, and then daily up to 14 d. Cockroaches were considered dead if they were unable to walk or right themselves when probed with forceps. The assays were carried out under ambient conditions (24 ± 2 °C, 30% to 50% RH, 12:12 h L:D photoperiod) and replicated 4 to 8 times for each combination of species and bait formulation.

Ebeling Choice Box Assays

The efficacy and potential field performance of the gel baits were investigated with Ebeling choice boxes (Ebeling et al. 1966). The boxes were constructed from white pine drawer siding (30.5 × 9.5 cm) with a tempered Masonite floor. Boxes were divided into 2 compartments of equal size (light and dark), and the top was covered with plexiglass. An additional Masonite panel was used to cover the dark compartment. A small hole in the top center of the divider separating the 2 compartments allowed cockroaches to move between the 2 sides. The light side was provisioned with dog food and water.

Twenty adult male cockroaches were initially confined to the light side of the choice box by using a cork to plug the hole in the partition. Weigh boats containing 0.5 g of gel bait were placed in the dark side. After the cockroaches were allowed to acclimatize for 5 h in the light side, the cork was removed to allow the cockroaches to access the dark side. Control treatments were not provisioned with gel bait but were otherwise identical. The assays were conducted under a photoperiod of 12:12 h (L:D) at ambient conditions (24 ± 2 °C, 30% to 50% RH), and the number of live and dead cockroaches in both sides of the choice box was recorded for 14 d. Three to 4 replicates were set up for each combination of species and bait formulation.

Performance index (PI) values were calculated to evaluate potential field performance by combining the effects of mortality and repellency (Rust and Reiersen 1978). The formula for the PI is as follows:

$$PI = \left[1 - \left(\frac{\text{Total number alive} + \text{Number alive in light side}}{\text{Total number dead} + \text{Initial total number}} \right) \right] \times 100$$

PI values of 100 indicate complete mortality and no repellency. PI values of 0 indicate no mortality and no repellency. PI values of -100 indicate no mortality and complete repellency.

Statistical Analyses

The survivorship of cockroaches in the open arena bioassays was analyzed using Kaplan–Meier analysis, and the survivorship curves were compared using log-rank tests. Pearson's correlation was calculated to measure the strength of association between PI at 7 d in the choice boxes and data obtained from the open arena bioassays, including mean survival time, along with percentage mortality at 1, 2, 3, 5, and 7 d. In addition, linear regression was performed on the same variables to assess the relationship between the PI in choice boxes and bait performance in open arena bioassays. Control data was excluded from both the correlation and regression analyses. All analyses were performed in SPSS Statistics version 29.0 (IBM Corporation, Armonk, NY).

Results

There was considerable variation in the performance of gel baits against *S. longipalpa* in the open arena bioassays, with significant differences observed between all the gel baits tested aside from Alpine and Maxforce Impact (Fig. 1A, Supplementary Tables S1 and S2). Alpine and Maxforce Impact performed the best against *S. longipalpa* with mean survival times of 0.7 d while Vendetta Plus performed the worst with a mean survival time of 9.2 d (Supplementary Table S1). The mean survival times of *S. longipalpa* exposed to the remaining bait formulations ranged from 1.8 to 5.0 d. Furthermore, Vendetta Plus and Maxforce FC Magnum failed to reach 100% mortality after 14 d (Fig. 1A). In contrast, gel baits performed more consistently against *B. germanica* in the open arena bioassays, with more instances of overlapping 95% CIs between

different formulations (Fig. 1B, Supplementary Table S1). Except for Maxforce Impact, *S. longipalpa* survived 3.3 to 10.2× longer than *B. germanica* when tested on baits. All tested gel bait formulations resulted in 100% mortality by 14 d against *B. germanica*, with mean survival times ranging from 0.1 to 1.8 d.

Similar patterns were observed in the Ebeling choice box assays. The PI of gel baits increased more rapidly when tested against *B. germanica* than against *S. longipalpa* (Fig. 2). Most gel baits attained positive PI values against *B. germanica* by 1 d (Fig. 2B). In comparison, the majority of gel baits only showed positive PI values against *S. longipalpa* by 2 to 3 d (Fig. 2A, Supplementary Table S3). Several gel baits were able to reach the maximum PI values of 100 against *B. germanica*, indicating complete mortality (Fig. 2B, Supplementary Table S4). Conversely, none of the gel baits were able to achieve mean PI values of 100 even by 14 d against *S. longipalpa*. The final mean PI values for most gel baits against *S. longipalpa* ranged from 92.2 to 98.3, while Maxforce FC Magnum and Vendetta Plus displayed particularly low final PI values of 50.4 and 76.2, respectively (Fig. 2A).

The PI in choice boxes for *S. longipalpa* at 7 d was significantly correlated with all the indicator variables obtained from open arena bioassays, except for percentage mortality at 1 d ($r = -0.870$ to 0.860 , $P < 0.05$). Mean survival time showed the strongest association and was the most useful in predicting PI values at 7 d (Fig. 3). The highest R^2 value of 0.757 demonstrated that the regression equation developed from the regression of PI values at 7 d on mean survival time was able to explain 75.7% of the variation between the 2 measures of bait performance ($F_{1,4} = 12.430$, $P = 0.024$). No significant relationship was found between the PI at 7 d for *B. germanica* and any of the indicator variables from the open arena bioassays.

Discussion

Our results show that most tested gel bait formulations exhibited slower kill and may show reduced performance against *S. longipalpa* relative to *B. germanica* in both open arena bioassays and Ebeling choice box assays. While choice box data could overestimate potential field performance, insecticides that performed poorly in choice box assays would invariably display poor field performance (Rust and Reiersen 1978, Rust et al. 1993). Furthermore, if a bait shows poor performance against adult males (which are more susceptible than adult females and late instars), it is unlikely that it will perform well against all stages in the field (Lee et al. 2024). In particular, gel baits such as Maxforce FC Magnum and Vendetta Plus, which had final PI values that were well below 100 even by 14 d post-treatment, are unlikely to provide adequate control of *S. longipalpa* under field conditions (Fig. 2A). In this study, we only compared bait performance between *S. longipalpa* and the laboratory susceptible UCR strain of *B. germanica*. However, the performance of toxic baits against susceptible *B. germanica* strains is unlikely to be reflective of their performance against field strains of *B. germanica*. Previously, we have found that field populations of *B. germanica* demonstrated reduced susceptibility to gel baits due to the widespread presence of insecticide resistance against multiple bait toxicants (Lee et al. 2022). Similar findings have been reported in other studies (Gondhalekar et al. 2011, Ko et al. 2016, Hu et al. 2020). Many gel bait formulations demonstrated lower PI values in choice box assays against resistant strains of *B. germanica*, confirming the decreased field performance of these gel baits (Appel et al. 2022, Kruaysawat et al. 2024).

Either physiological and/or behavioral factors may contribute toward the difference in gel bait susceptibility between *S. longipalpa*

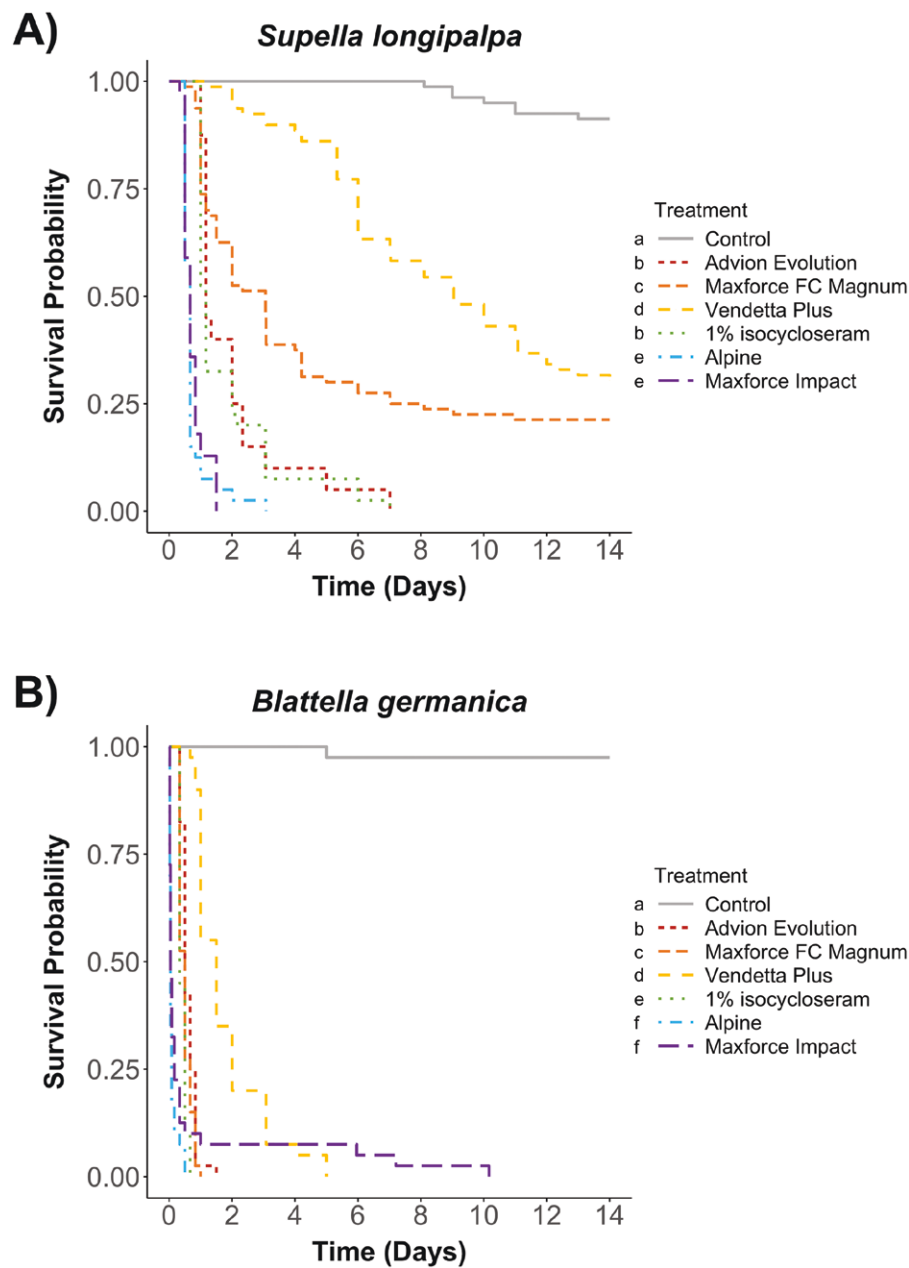


Fig. 1. Survivorship of adult male cockroaches of A) *Supella longipalpa* and B) *Blattella germanica* exposed to gel baits in open arenas. Different letters by the figure legend indicate significant differences between treatments (log-rank test; $\alpha = 0.05$).

and *B. germanica*. Previous studies have reported reduced susceptibility to toxic baits in *S. longipalpa* relative to *B. germanica* (Koehler et al. 1991, Bayer et al. 2012). Bayer et al. (2012) proposed that the reduced toxicity of indoxacarb in *S. longipalpa* could be the result of lower enzyme production, leading to decreased conversion of indoxacarb into the more toxic N-decarbomethoxylated JW062 metabolite. However, we did not observe a similar magnitude of decrease in the performance of Advion Evolution (which contains 0.6% indoxacarb) in our bioassays comparing *S. longipalpa* and *B. germanica*. Moreover, we found that Alpine and Maxforce Impact (both containing neonicotinoids) were the most effective against *S. longipalpa*, which contrasts with the findings of Savoldelli and Süß (2005), where a different neonicotinoid gel bait (Solfac Gel Scarafaggi, 2.15% imidacloprid) was the least effective. This suggests that differences in the toxicity of active ingredients between

the 2 species may not be entirely responsible for the reduced efficacy of gel baits against *S. longipalpa* and that differing responses toward inert ingredients in different bait formulations may play a more significant role. Nalyanya et al. (2001) investigated the attractiveness of multiple bait formulations and found that all tested formulations (powders, solid bait blocks, gel baits, and pastes) were generally less attractive toward *S. longipalpa* than *B. germanica*. Notably, *S. longipalpa* displays more selective feeding preferences than other pest cockroaches, exhibiting significant differences in their preference for cat chow, rat chow, and distiller's grain (Brenner and Patterson 1989). Similar patterns were recorded by Bayer et al. (2012), where *S. longipalpa* exhibited a lower preference for gel baits versus dry dog food. Therefore, the diminished performance of gel baits against *S. longipalpa* may be attributed to reduced bait attractiveness and/or palatability.

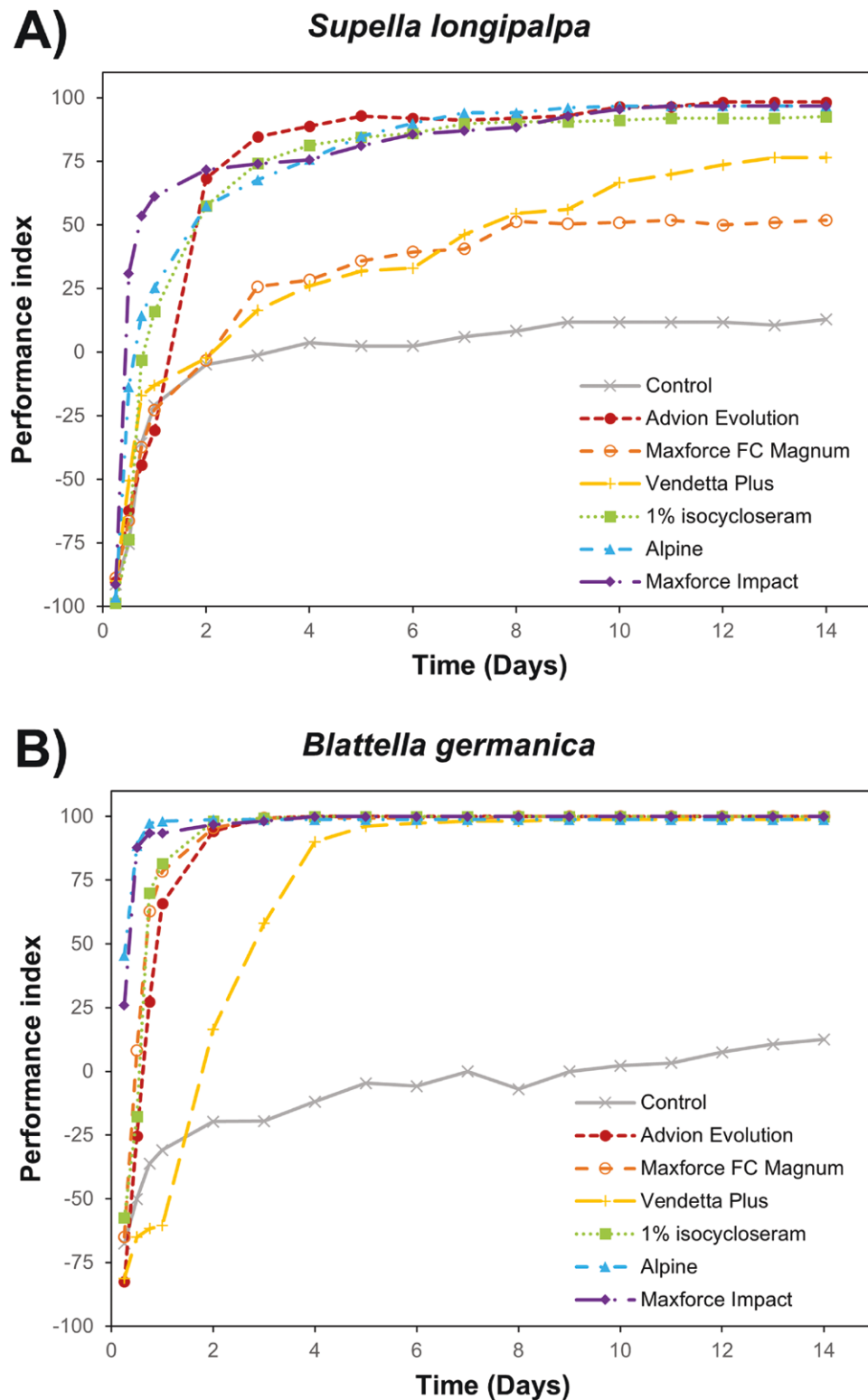


Fig. 2. PI of gel baits against A) *Supella longipalpa* and B) *Blattella germanica* in Ebeling choice boxes.

Differences in the nutritional ecology of *S. longipalpa* and *B. germanica* offer possible explanations regarding the disparity in gel bait efficacy between the 2 species. Firstly, *S. longipalpa* and *B. germanica* differ in their carbohydrate and protein requirements (Cohen et al. 1987, McPherson et al. 2021). When offered diets with varying ratios of carbohydrates (C) and protein (P), *B. germanica*

self-selected a nutrient ratio of 1P:2C to 1P:3C (McPherson et al. 2021). Meanwhile, *S. longipalpa* self-selected a nutrient ratio of approximately 1P:5C (Cohen et al. 1987). Secondly, *S. longipalpa* is better adapted toward drier xeric habitats and food sources with less moisture (Melton 1995). Nymphs of *S. longipalpa* survived significantly longer than nymphs of *B. germanica* when drinking water

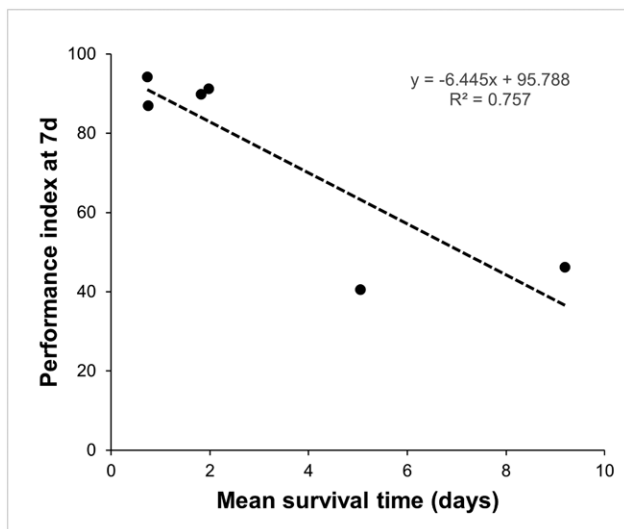


Fig. 3. Linear regression of PI in Ebeling choice boxes at 7 d against mean survival time in open arenas for *Supella longipalpa*.

was absent and appeared more capable of producing and utilizing additional metabolic water from food sources (Melton 1995). While this difference in survival is only applicable to nymphs of both species, adults of *S. longipalpa* may still be less averse to consuming foods with less moisture, resulting in a lower preference for gel baits over dry dog food. Due to the greater importance of *B. germanica* as an urban pest, gel baits may have been optimized to target the nutritional and moisture needs of *B. germanica* (Bayer et al. 2012). Evidently, current gel baits are highly palatable to *B. germanica*, as very high rates of gel bait application could effectively control *B. germanica* populations, even without sanitation and removal of alternative food being necessary (Miller and Smith 2020). On the other hand, *S. longipalpa* may display a lower baseline level of gel bait consumption than *B. germanica* due to a mismatch in preferred nutrient ratios and moisture levels. This means that even higher gel bait application rates may not produce desired levels of control, and instead sanitation may be more important in providing satisfactory control.

Likewise, differences in performance between gel bait formulations could be influenced by the type of active ingredient and the palatability of the bait matrix. Among the tested bait toxicants, dinotefuran was reported to have the fastest speed of action (Hamilton et al. 2023). Clothianidin and fipronil are typically considered to be relatively fast-acting, while indoxacarb and isocycloseram have a moderate speed of action, followed by abamectin which is a slow-acting active ingredient (Stejskal et al. 2004, Hamilton et al. 2023, Saran et al. 2025). The speed of action of these compounds roughly corroborates our bait evaluation results for *B. germanica*. However, the mean survival times of *B. germanica* exposed to Advion Evolution and 1% isocycloseram (0.4 to 0.6 d) were similar to that of Maxforce FC Magnum and Maxforce Impact (0.5 to 0.7 d), suggesting that higher palatability of the former 2 bait formulations may offset the delayed speed of action of their AIs. Advion Evolution was previously reported to be highly palatable, which is also likely the case for the 1% isocycloseram bait (Hamilton et al. 2023). Compared to our results for *B. germanica*, Maxforce Impact performed relatively better while Maxforce FC Magnum performed relatively worse against *S. longipalpa* than the other tested bait formulations. These discrepancies may also reflect

differences in the relative palatability of different bait formulations for *S. longipalpa*.

We found that mean survival times in open arena bioassays for *S. longipalpa* were negatively related to the PI at 7 d in the Ebeling choice box assays (Fig. 3). While a similar relationship was not found for *B. germanica*, this was most likely because all of the PI values were close to or at 100 by 7 d due to the fast kill of *B. germanica* by gel baits (Fig. 2B). Nonetheless, gel baits that produced shorter mean survival times in *B. germanica* also resulted in steeper slopes for PI values. Previously, Appel et al. (2022) reported that choice box data were correlated with resistance ratios of gel baits calculated with the LT_{50} method in continuous exposure tests. Our study confirms the utility of open arena bioassays in estimating the mortality effects of gel baits in choice boxes. That said, choice boxes simulate field conditions more closely than open arena bioassays. While open arena bioassays represent a more straightforward option for evaluating toxicity, choice box assays remain the most accurate and informative method for assessing gel bait performance in the laboratory.

Supplementary material

Supplementary material is available at *Journal of Medical Entomology* online.

Acknowledgments

We would like to thank Ho Eun Park, Monique Arviso, Greg Kund, and Shao-Hung Lee for their technical support and assistance in cockroach colony maintenance. Additionally, we are grateful to Michael Rust and Raj Saran for their constructive criticisms on the manuscript draft. This study was funded by the UCR Urban Entomology Endowed Chair Research Fund.

Author contributions

Jun-Yin Lum (Data curation [lead], Formal analysis [lead], Investigation [lead], Methodology [equal], Software [lead], Validation [lead], Visualization [lead], Writing—original draft [lead]), Rattanan Chungswat (Data curation [supporting], Investigation [supporting], Visualization [supporting], Writing—review & editing [supporting]), Emily Ta (Data curation [supporting], Investigation [supporting], Writing—review & editing [supporting]), Dong-Hwan Choe (Project administration [supporting], Supervision [supporting], Writing—review & editing [supporting]), and Chow-Yang Lee (Conceptualization [lead], Funding acquisition [lead], Methodology [supporting], Project administration [lead], Resources [lead], Supervision [lead], Writing—original draft [supporting], Writing—review & editing [equal])

Conflicts of interest. The authors declare no conflict of interest.

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