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PERFORMANCE OF COMMERCIAL COCKROACH GEL BAITS AGAINST FIELD POPULATIONS OF THE GERMAN COCKROACH, *BLATTELLA GERMANICA*, FROM SINGAPORE

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Abstract Insecticide resistance in the German cockroach, *Blattella germanica* (L.), is a significant challenge affecting pest management professionals worldwide. The use of gel baits against German cockroaches has become a popular option in Asia. However, recently, there were anecdotal reports that the field performance of some cockroach gel baits has declined. In this study, we evaluated the performance of four commercial gel baits containing 0.01% fipronil (Maxforce® FC Professional Insect Control Roach Killer Bait Gel), 2.15% hydramethylnon (Maxforce® Professional Insect Control Roach Killer Bait Gel), 2.15% imidacloprid (Premise® Cockroach Bait), and 0.60% indoxacarb (Advion® Cockroach Gel Bait) against 22 field-collected populations of *B. germanica* from Singapore, in the presence of food and water for up to 14 d. Results showed that with exception to the indoxacarb baits (100% mortality against all stages of all strains), all tested baits exhibited varying effectiveness against the insecticide-resistant strains. The efficacy of all baits against adult males was encouraging (fipronil: 77.5 – 100%, hydramethylnon: 92.5 – 100%, imidacloprid: 82.5 – 100%, and indoxacarb: 100%). When tested against the adult females and mid-instars of the field strains, fipronil caused 77.5–100% and 35.0–95.0% mortality, respectively. The hydramethylnon bait's effectiveness was moderate to high against adult females (42.5–100%) and mid-instars (40.0–97.5%), whereas the imidacloprid bait showed poor to high performance against mid-instars (10.0–82.5%) and moderate to high performance against adult females (52.5–95.0%).

Key words Indoxacarb, fipronil, hydramethylnon, imidacloprid, insecticide resistance

INTRODUCTION

The control of the German cockroach, *Blattella germanica* (L.), has relied heavily on the use of insecticides (Lee and Ng, 2009). Heavy reliance and frequent use of insecticides have led to the development of insecticide resistance in this species (Cochran, 1996; Lee and Lee, 2004; Chai and Lee, 2010; Fardisi et al., 2019). Cockroach bait is an effective option for managing field populations of the German cockroach. Many bait toxicants had been evaluated, including hydramethylnon (Appel, 1990; 1992), abamectin (Ogg and Gold, 1993; Appel and Benson, 1995), fipronil (Miller and Peters, 1999), indoxacarb (Appel, 2003), and imidacloprid (Appel and Tanley, 2000). Baits are safe because they contain a relatively small amount of insecticide toxicant and are environmentally friendly, odorless, and long-lasting. In addition, toxicants may be transferred to cockroaches that did not come into contact with the baits through mediation by poisoned cockroaches, either via coprophagy (Silverman et al. 1991), necrophagy (Gahlhoff et al., 1999), emetophagy (Buczkowski and Schal, 2001), trampling, or social interactions (Durier and Rivault, 2000).

Cockroach bait was previously reported to be an effective option to manage insecticide-resistant German cockroaches. Lee (1998) reduced the number of insecticide-resistant German cockroaches by > 90% within four weeks post-treatment using hydramethylnon baits. Lee (2002) reported that both fipronil and hydramethylnon baits reduced by > 80% the number of insecticide-resistant German cockroaches in hotels and restaurants within a week of baiting.

There were anecdotal reports from pest management professionals in Singapore that the field performance of some gel baits against *B. germanica* has declined. We investigated the laboratory performance of four commercial cockroach baits (containing fipronil, hydramethylnon, imidacloprid, and indoxacarb) against 22 field-collected strains of the German cockroach from Singapore, and found variations in the effectiveness of these baits against these tested strains.

MATERIALS AND METHODS

Insects. We used 22 field strains of *B. germanica* from Singapore in this study, and their insecticide resistance profiles are shown in Table 1. An insecticide-susceptible strain (EHI) was used as a standard for comparison. The cockroaches were reared in polyethylene containers (38 x 22 x 27 cm) under laboratory conditions of 26 ± 2 °C, 50 ± 10% relative humidity, and a 12:12 photoperiod. Food and water were provided *ad libitum*.

Baits. Four commercial cockroach baits were evaluated: Maxforce FC Professional Insect Control Roach Killer Bait Gel (containing 0.01% fipronil) [Bayer Environmental Science, Montvale, NJ, USA]; Maxforce Professional Insect Control Roach Killer Bait Gel (containing 2.15% hydramethylnon) [Bayer Environmental Science, Montvale, NJ, USA]; Premise Cockroach Bait (containing 2.15% imidacloprid) [Bayer Environmental Science, Kuala Lumpur, Malaysia]; and Advion Cockroach Gel Bait (containing 0.6% indoxacarb) [DuPont Professional Products, USA, Wilmington, DE, USA).

Test method. Ten adult males (1–3 w old), ten non-gravid adult females (1–3 w old), and 20 mid-instars were acclimatized in test arena (48.5 x 37.0 x 8.0 cm) for 24 h. The inner surfaces of the test arena were coated with fluon to prevent the cockroaches from escaping. Each tray contained a piece of folded corrugated cardboard as a harborage (22.0 x 5.0 cm), a water vial plugged with a moistened cotton ball, and a Petri dish of dried dog food (Trusty Dog Chicken Purina® PetCare, KLN Enterprises, Inc, Perham, MN, USA). Approximately 0.3 g of gel bait was introduced into a bait tray, which was placed at the end of the test arena opposite that of the food. Bait was replenished when it was entirely consumed by the test insects. Mortality was assessed daily, and dead insects were removed from the test arena. The experiment was replicated 4X and terminated after 14-d post-treatment, or earlier if all insects were killed. For control sets, cockroaches were evaluated in the absence of the bait. Test arenas were maintained at 26–28 °C, 54% RH, and a 12-hour photoperiod.

Data analysis. Mortality data were pooled and subjected to probit analysis using the Polo-Plus software (Robertson et al., 2017). The resistance ratio at LT_{50} (RR_{50}) was calculated by dividing LT_{50} values of the field strains with the corresponding lethal time of EHI susceptible strain. The relationship between fipronil resistance ratio (topical bioassay) and fipronil bait RR_{50} for adult males, imidacloprid resistance ratio (topical bioassay) and imidacloprid bait RR_{50} for adult males, and indoxacarb resistance ratio (topical bioassay) and indoxacarb bait RR_{50} for adult males were determined using Pearson correlation test (StatPlus Version 6.2, AnalystSoft, 2017).

RESULTS AND DISCUSSION

All strains tested were susceptible to indoxacarb baits. Complete mortality of all stages of test insects was achieved within nine days of bait exposure (Table 2). Despite the mid-instars of some strains (e.g., Bukit Merah Central and Ang Mo Kio) showing RR_{50} of > 2, total mortality was achieved within nine days for all stages of all strains. The field strains fed almost immediately on indoxacarb bait upon introduction, indicating the high bait palatability. Indoxacarb bait also could be effectively transferred from bait-fed cockroaches to other conspecifics via necrophagy, emetophagy, and contact with or ingestion of contaminated excretions from the donors especially the first instars (Buczkowski et al., 2008).

Hydramethylnon bait was effective against the adult males, with > 90% mortality at 14 d post-treatment (Table 2). Complete death was achieved for adult males of the Tiong Baru Road, Bt Merah Central, Jalan Victoria, Victoria Street, Ang Mo Kio, Jurong, Serangoon Central, Geylang, and Ghimmoh Road strains. Mortality of $\geq$ 75% occurred in the majority of the female populations, but this was only true for instars of four strains. Poor bait performance was recorded in the females and nymphs of strains from Thomson Plaza, Tiong Baru Road, and Cavenagh Road with the highest RR_{50} > 4 in the nymphs from Thomson Plaza. Because we did not test hydramethylnon resistance using topical bioassay, we are unable to verify whether physiological resistance to hydramethylnon (Ko et al., 2016) was present in these strains.

The performance of the imidacloprid bait varied considerably among the tested strains (Table 2). Although adult males were generally more susceptible, adult females of Joo Chiat Road, Biopolis Street, Jalan Membina, Victoria Street, and Ghimmoh Road strains showed greater susceptibility towards imidacloprid bait than the males. This bait showed poor performance (< 50% mortality) against the mid-instars in > 50% of the strains, with the B1 Tampines Central strain being the most resistant (only 10% mortality). In most instances, the tested cockroaches showed poisoning symptoms within an hour of bait exposure, but they recovered 24 hours later. This was very pronounced, especially for the mid-instars.

Table 1. Insecticide resistance status of German cockroaches from Singapore (after Chai & Lee, 2010)

Strain	Resistance ratio[1]						
	Deltamethrin	β-cyfluthrin	Propoxur	Chlorpyrifos	Fipronil	Imidacloprid	Indoxacarb
Tampines Central	52.0	28.0	11.4	2.4	1.0	1.1	2.5
Thomson Plaza	94.5	18.0	7.8	1.7	1.0	1.5	1.4
Joo Chiat Road	65.0	55.5	7.3	6.4	1.0	1.2	1.8
Biopolis Street	86.5	32.5	4.2	2.6	1.0	1.5	2.6
Tiong Baru Road	21.5	17.5	5.4	4.7	1.0	1.4	2.1
B1 Tampines Central	319.0	24.0	7.5	6.2	3.0	1.2	2.4
Bt. Timah Road	109.5	94.5	9.5	3.1	1.0	1.6	2.4
Bt. Merah Central	62.0	39.5	6.8	1.5	1.0	1.1	2.1
Beach Road	87.5	50.5	21.5	3.1	1.0	1.1	2.8
Boat Quay	313.5	89.5	8.5	22.8	1.0	2.4	2.9
Jalan Membina	111.5	30.0	3.9	6.4	1.0	0.8	2.9
Victoria Street	468.0	71.5	6.9	6.9	2.0	1.8	1.8
Ang Mo Kio	127.0	42.5	5.7	1.8	1.0	1.4	2.8
Jurong	128.5	49.5	14.5	4.5	2.0	1.2	2.1
Kallang Sector Road	193.0	56.5	12.8	4.5	1.0	1.0	2.7
Serangoon Central	55.0	43.0	4.1	1.8	1.0	1.2	1.9
Cavenagh Road	182.5	76.5	13.1	11.9	8.0	3.2	5.3
Jelebu Road	26.5	19.0	5.6	2.2	1.0	2.0	1.7
Bedok North	4.5	3.0	5.0	2.0	1.0	0.8	2.0
Rivervale Crescent	12.0	5.0	5.3	3.0	1.0	1.0	1.9
Geylang	39.5	12.5	5.8	2.3	1.0	1.4	1.9
Ghimmoh Road	37.0	47.0	18.8	3.8	10.0	3.8	1.9

[1] Classification of resistance status based on Lee and Lee (2004): ≤ 1 = no resistance; > 1 to ≤ 5 = low resistance; > 5 to ≤ 10 = moderate resistance; > 10 to ≤ 50 = high resistance

Table 2: Performance of commercial gel baits against 22 field-collected strains of *B. germanica* from Singapore, based on % mortality at 14-d post-treatment, and resistance ratio.

Strain	% mortality (range) and RR_{50} (range)							
	fipronil % mortality	fipronil RR_{50}	hydram. % mortality	hydram. RR_{50}	Imidacl. % mortality	Imidacl. RR_{50}	Indoxacarb % mortality	Indoxacarb RR_{50}
Tampines Central	56.3–100	1.35–3.42	56.3–97.5	1.26–1.86	38.8–95.0	3.62–9.03	100	1.37–1.65
Thomson Plaza	46.3–90.0	3.29–4.83	37.5–95.0	1.47–4.75	36.3–92.5	3.62–9.30	100	1.07–1.84
Joo Chiat Road	70.0–95.0	1.63–2.26	48.8–92.5	1.59–2.56	83.8–100	1.18–2.93	100	1.13–1.62
Biopolis Street	66.3–92.5	2.35–3.90	60.0–95.0	1.88–1.99	77.5–100	0.40–1.89	100	1.25–1.80
Tiong Baru Road	55.0–90.0	3.13–4.91	42.5–100	1.25–3.53	33.8–100	6.10–12.25	100	1.38–1.72
B1 Tampines Central	52.5–97.5	3.45–8.61	40.0–95.0	1.33–3.01	10.0–97.5	6.93–>40	100	0.93–1.45
Bt. Timah Road	68.8–87.5	2.27–3.58	67.5–97.5	1.22–1.55	25.0–100	4.67–26.18	100	1.36–2.30
Bt. Merah Central	53.8–97.5	3.02–3.38	72.5–100	0.90–1.42	17.5–100	5.81–34.96	100	0.96–2.68
Beach Road	82.5–97.5	2.50–3.93	52.5–97.5	1.11–2.07	17.5–100	8.19–10.69	100	1.45–1.83
Boat Quay	62.5–100	2.58–5.45	68.8–97.5	1.03–1.39	18.8–82.5	10.06–10.69	100	1.04–2.41
Jalan Membina	93.8–100	1.26–4.10	75.0–100	0.94–1.45	60.0–100	2.87–9.67	100	1.16–1.59
Victoria Street	48.8–92.5	3.91–5.20	70.0–100	0.92–1.60	62.5–97.5	1.39–3.71	100	0.89–1.93
Ang Mo Kio	55.0–92.5	3.89–5.79	63.8–100	0.83–1.42	38.8–100	3.02–14.07	100	1.15–2.50
Jurong	45.0–87.5	3.99–9.03	77.5–100	1.26–1.36	58.8–100	2.12–4.30	100	0.78–1.95
Kallang Sector Road	30.0–90.0	4.02–9.57	82.5–97.5	1.03–1.32	30.0–95.0	3.81–6.76	100	1.22–2.18
Serangoon Central	28.8–90.0	4.00–7.44	68.8–100	0.98–1.42	20.0–100	4.02–14.12	100	1.40–1.93
Cavenagh Road	18.8–87.5	6.79–22.1	50.0–95.0	1.23–3.39	38.8–85.0	9.89–16.67	100	1.95–2.31
Jelebu Road	53.8–95.0	3.31–5.43	47.5–95.0	1.08–2.29	58.8–100	4.24–10.25	100	1.42–1.71
Bedok North	73.8–100	1.62–3.72	83.8–100	1.04–1.40	57.5–100	2.62–3.85	100	1.11–1.47
Rivervale Crescent	77.5–95.0	0.90–3.48	97.5–100	0.83–1.46	82.5–100	0.98–1.76	100	1.36–1.64
Geylang	82.5–100	1.67–5.50	70.0–100	1.22–1.34	67.5–97.5	2.48–4.07	100	1.05–1.37
Ghimmoh Road	42.5–80.0	1.75–14.1	72.5–100	0.81–1.44	45.0–92.5	5.37–7.48	100	1.15–1.42

When tested with fipronil bait, complete mortality of adult males only was observed in the Tampines Central, Jalan Membina, Boat Quay, and Geylang strains (Table 2). All strains showed mortality of adult male of > 80%, except the Ghimmoh Road strain, which exhibited 14X resistance to fipronil bait when compared to the EHI susceptible strain. This observation was not surprising because the Ghimmoh Road strain was found to be 10.0X resistant to fipronil in an earlier topical bioassay test (Table 1). Mortalities for females and nymphs were lower than that of the males.

The relationship between fipronil resistance ratio (topical bioassay) and fipronil bait RR_{50}, and indoxacarb resistance ratio (topical bioassay) and indoxacarb bait RR_{50} were positively correlated ($P < 0.001$, $r = 0.8365$; $P < 0.01$, $r = 0.6251$, respectively). We deduce that bait aversion towards both baits may be absent or have a minor role since bait performance was significantly correlated with insecticide susceptibility of the toxicant. On the other hand, no correlation was found between imidacloprid resistance ratio (topical bioassay) and imidacloprid bait RR_{50} ($P > 0.05$, $r = 0.3149$). Imidacloprid bait performance was moderate to poor against some of the field strains of German cockroach tested, even though they showed no or low imidacloprid resistance in topical bioassays, suggesting bait palatability. However, whether this was due to bait aversion (Wang et al., 2004) or glucose aversion (Silverman, 1995, Lee and Soo, 2002, Wada-Katsumata et al., 2013) remains unknown and warrants further investigation.

Insecticide resistance in the German cockroach had been affecting the pest management industry worldwide. Since the introduction of cockroach bait, low to moderate levels of physiological resistance of *B. germanica* to insecticide toxicants used in baits such as abamectin (Wang et al., 2004), imidacloprid (Wei et al., 2001), indoxacarb (Chai and Lee, 2010, Gondhalekar et al., 2011) and fipronil (Wei et al., 2001; Wang et al., 2004; Kristensen et al., 2005; Gondhalekar et al., 2011; Rahayu et al., 2012; Ang et al., 2013) have been reported in laboratory bioassays. However, to date, there has never been any single published literature on field control failure due to the physiological resistance of bait toxicants. This is likely due to the fact that cockroaches are feeding on a highly palatable bait, hence typically, more amounts of toxicant will be ingested than that the actual amount that is required to cause a lethal response (Holbrook et al., 2003; Gondhalekar et al., 2011; Gondhalekar and Scharf, 2012). Bayer et al. (2012) reported that *B. germanica* consumed 150 –>1300X and 218–441X the LD_{50} of fipronil and indoxacarb, respectively, after 24 h of exposure to the gel baits. Gondhalekar et al. (2011) found that a field strain of *B. germanica* was 36X more resistant to fipronil compared to a laboratory susceptible strain when the insecticide was applied topically, but only 2–3X resistance when they were fed 0.01% fipronil bait. Ang et al. (2013) reported a quick increase in fipronil and indoxacarb resistance levels when field-collected *B. germanica* strains were selected with 0.05% fipronil and 0.6% indoxacarb baits for five generations. Despite that, the F5 insects only showed low resistance to gel baits with 100% mortality at 14-day post-treatment.

In summary, we found variation in the effectiveness of commercial baits tested against 22 field strains of *B. germanica* collected from Singapore. The indoxacarb bait showed excellent performance against all field strains, with 100% mortality of all stages of test insects within the evaluation period. The performance of fipronil, imidacloprid and hydramethylnon against different sexes/stages, However were varied, ranging from low to excellent. It is imperative to note that the results obtained from this laboratory study only suggest the potential development of insecticide resistance in the field strains and not an indication of field control failure. The field strains that were tested were based on progenies of field collected samples that were bred in the laboratory conditions for several generations. Only when control failure is experienced in the field can such a conclusion of bait toxicant resistance in the field be drawn.

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