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Research article

Efficacy and toxicity of cockroach gel bait (imidacloprid 2.5% and fipronil 0.05%) against American cockroach infestation in sewer system

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ABSTRACT

Background: The American cockroach, *Periplaneta americana*, is the most prevalent domiciliary and invasive urban pest in the sewer and waste water system. It poses a substantial threat to human public health and home allergens. This study was conducted at Universiti Sains Malaysia main campus to highlight and provide information on the control and management of American cockroach infestations in sewage systems by comparing the efficiency of fipronil 0.05% gel bait with imidacloprid 2.5% gel bait. A total number of adult and nymph stages of trapped American cockroaches was recorded using glass jar traps at eight sampling sites. Gel baits were placed beneath the lids of each manhole shaft along the inner wall perimeter.

Results: The use of fipronil and imidacloprid gel baits in the sewer system resulted in a significant difference ($P = 0.013$). Imidacloprid 2.5% gel bait, compared to fipronil 0.05% gel bait, is the most effective treatment technique for reducing American cockroaches' population in sewer systems, with a high reduction percentage mean for both adult (91.17%) and nymph (85.50%) stages.

Conclusion: As a conclusion, imidacloprid gel bait can effectively control cockroaches in sewer systems up to eight weeks.

1. Introduction

The Blattidae family includes the American cockroach, *Periplaneta americana* (Linnaeus, 1785) a primary pest in urban areas. *P. americana* not only degrades food, but it also spreads illnesses, causes mental distress, and triggers allergic reactions. Many pathogenic species have been infected by cockroaches as a potential mechanical vector of human sickness, including poliomyelitis viruses, bacteria, fungi, protozoa, and helminths [1]. *Periplaneta americana* is the most prevalent domiciliary pest cockroach in Southeast Asia and can reproduce in large numbers, particularly in outdoor areas such as sewers and garbage chutes, where the conditions are favourable for its growth [2].

Generally cockroaches prefer dark and moist surroundings, including any source of water or humidity same goes to *P. americana*, the species have evolved in proximity to human habitations [3]. According to Zahraei-Ramazani (2018), American cockroaches

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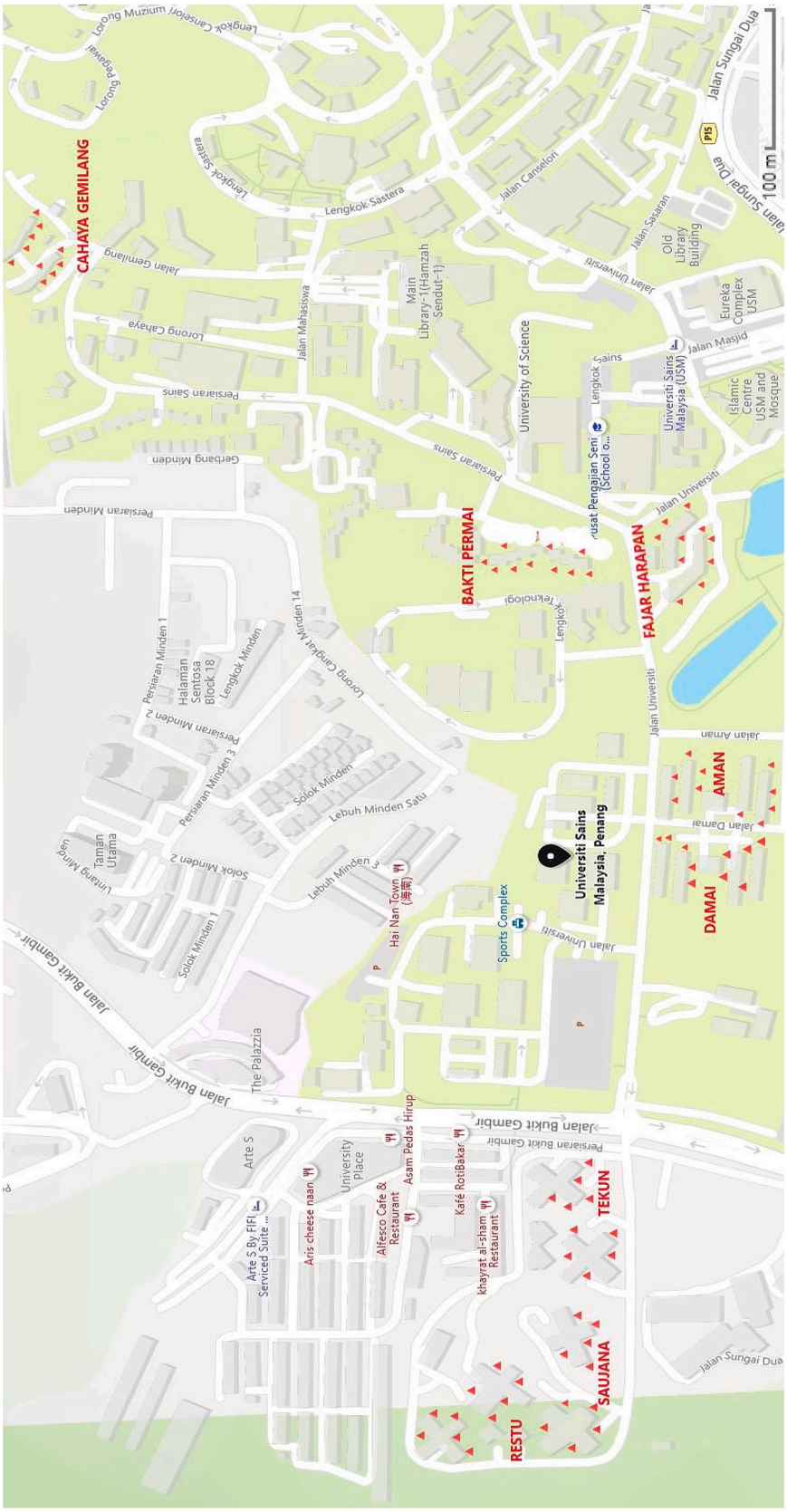

Fig. 1. Shows schematic view of manhole shaft at sampling site in Universiti Sains Malaysia, main campus sewer system.

prevalent in sewers of semi-arid climates like Iran and southern US [4] but this species also located in tropical and subtropical climates country same goes to Malaysia climates in this study. Another similar finding established that it is usually found in urban regions with sewage pipelines connected to human residences, which are excellent for reproduction, development, and spread of this species [5,23].

The level of infestation of American cockroaches locally at a medium level was recorded and may increase in the future [1]. They inhabit man-made structures through crevices, drains, pipes, and basements, becoming the second most familiar domiciliary pest. In addition, the hygiene standard of construction affects their infestation. Poor waste management systems contribute to the exponential growth of American cockroaches in society since they are often considered to be carriers of infectious diseases such as salmonellosis, dysentery, gastroenteritis, and typhoid linked to food production [7].

Therefore, 20% of the total revenue of the pest management industry is contributed by cockroach management in Malaysia. Periodic monitoring and inspection of the premises are needed to control the American cockroach infestation [2]. According to Rentokil's annual report for 2018 in North America, 40,000 pest control companies reported an annual market value of US $18 billion, rising from 4% to 6% in 2023. The complete sum contributed by cockroach management services suggested an increased degree of the American cockroach infestation. Integrated Pest Management (IPM), a holistic approach to control infestation, has been implemented. It aims to reduce pest population infestation below the level of economic harm to a secure and viable long-term rate while considering the management system cultural, physical, biological, and chemical controls. Traditional pyrethroids and carbamates are ineffective in control management strategies [8], so neo-neonicotinoids and phenyl-pyrazoles have been used instead.

Exposure of different life stages of *P. americana* to the pesticide yields different reactions. Adult males were less sensitive to pesticides than adult females, while nymphs were the most vulnerable during treatment. All cockroaches at every stage were killed in early poisoning tests after ten days [9]. Since adult females and larger nymphs have higher body mass proportions than gravid females and adult males, each cockroach stage indicated varying levels of toxicity. Besides, coprophagy (faeces intake) [10], can be possible contributing factor for distribution of toxicity residue among population.

Exposing cockroaches to a lethal dose of gel baits caused them to infect their colonies upon returning to their nest. Since total death takes time, this predisposition reduces colonies over time in a long-term control management method. Both imidacloprid and fipronil had a reduction rate of >90% [11], similar to previous study that found both types of treatments also caused >90% of death in first month application in sewer system then reduced within time frame [12]. Therefore, large bait reservoirs and improve bait design might increase the efficacy and also can reduce frequency of maintenance require for the treatment stations [13]. The efficacy of the gel would significantly improve as a result of this innovation.

The purpose of this study is to determine the effect and efficacy of chemical treatment products, Blattathor Altra cockroach Gel Bait (fipronil, 0.05%) and Premise® Cockroach Bait (imidacloprid, 2.5%) in the sewer system.

2. Materials and methods

2.1. Study site

The study sites were conducted in the main campus, Universiti Sains Malaysia, Penang, on the northwestern coast of Peninsular Malaysia (5°21′N, 100°18′E) (Fig. 1, Table 1). Penang has a tropical climate with high temperatures and rainfall throughout the year. The mean temperature during the day ranges from 30.4 – 33 °C to 23.3–25 °C during the night. The average annual precipitation is 2407.6 mm per year and 200.6 mm per month, with rainy weather occurring more regularly during the southwestern monsoon from April to September. The population of cockroaches increase in hot and humid places, particularly with the availability of food resources.

2.2. Allocation of the sewer system

Each of these eight sites selected ten man hole shaft were selected to install glass jar traps, totalling eighty (80) traps. Three sites were treated with fipronil (Aman, Damai, and Harapan), another three with imidacloprid (Saujana, Restu, and Tekun), and another two sites as control (Bakti Permai and Cahaya Gemilang). The number of trapped cockroaches in glass jar trap at each shaft were evaluated during pre-treatment and post-treatment. The unsealed-type shaft covers of the targeted sewer allowed for monitoring and observation. Reduction in number of American cockroach population in the sewer system were recorded for 6 weeks. Eventually, the square-shaped metal shaft cover was removed to reach the sewage manholes using the flattened end of the crowbar (45 cm long) placed

Table 1
Allocation of treatments in the Universiti Sains Malaysia sewer system.

Site	Dormitory	Treatment
1	Desasiswa Aman (K01–K04) 5.3548° N, 100.2970° E	Blattathor Altra cockroach Gel Bait (fipronil 0.05%)
2	Desasiswa Damai (K05–K08) 5.35515°N, 100.29693°E	Blattathor Altra cockroach Gel Bait (fipronil 0.05%)
3	Desasiswa Harapan (F25, F26) 5.3548°N, 100.3000°E	Blattathor Altra cockroach Gel Bait (fipronil 0.05%)
4	Desasiswa Bakti Permai (H06, H07)5.3585°N, 100.3007°E	Control
5	Desasiswa Saujana (M03, M04) 5.3564°N, 100.2894°E	Premise® Cockroach Bait (imidacloprid 2.5%)
6	Desasiswa Restu (M01, M02) 5.35798°N, 100.28893°E	Premise® Cockroach Bait (imidacloprid 2.5%)
7	Desasiswa Tekun (M05, M06) 5.35564°N, 100.29119°E	Premise® Cockroach Bait (imidacloprid 2.5%)
8	Desasiswa Cahaya Gemilang (H38, H39)5.3604°N, 100.3035°E	Control

a)

b)

Fig. 2. (a) and (b) placement of glass jar traps in the shaft.

beside the cover.

2.2.1. Sampling technique

Glass jar traps consist of four slices of beer-soaked bread coated with petroleum jelly inside perimeter of glass jar to prevent cockroaches escaped. One glass jar trap were installed on each shaft. The glass jar trap with size of 15 cm × 10 cm placed upward with the help of a wire attached to the body of the glass jar. Additionally, masking tape covered the newspaper on the outer layer of the glass container to maximise the effectiveness of the traps. A glass jar trap was placed at the bottom half of each manhole (Fig. 2a and b).

2.3. Application of gel Bait (insecticide)

To test the application of fipronil and imidacloprid gel bait to the sewer system, Blattathor Altra cockroach Gel Bait (fipronil 0.05%) manufactured by Ensystex (M) Sdn. Bhd. and Premise® Cockroach Bait (imidacloprid 2.5%) manufactured by Bayer Co. Malaysia Sdn. Bhd. were used as treatments (Fig. 3a and b). Fipronil treated sewer (Aman, Damai, and Harapan) and one control (Bakti Permai), while imidacloprid treated another sites (Tekun, Restu, and Saujana) and one control site (Cahaya Gemilang) (Fig. 1). 30 g of gel baits were applied near the cover of each shaft at the perimeter of the interior wall. The first day of treatment started as the "0" day by adding the gel bait to the shaft before eventually hanging the glass jar traps close to the walls. The first number of trapped cockroaches was recorded as before treatment. Post-treatment data were recorded on days 7, 14, 21, 28, and 45.

2.4. Statistical analyses

The product efficacy was determined based on the number of trapped American cockroaches in glass jar traps for up weeks following treatment. All American cockroaches were grouped for each treatment. SPSS software analyzed the data for the given treatment and repeated tests, while one-way ANOVA assessed various control methods for *P. americana* in the sewer system.

3. Result

3.1. Total trapped cockroache in each site

The study evaluates the toxicity of Blattathor Altra cockroach Gel Bait (fipronil 0.05%) and Premise® Cockroach Bait (imidacloprid 2.5%) by applying them to different sites as a replicate. The number of trapped cockroaches in glass jar traps were subjected to one-way ANOVA as in Table 2 and tabulated based on different treatments, sites, and sampling weeks.

3.2. Percentage reduction of both treatment fipronil and imidacloprid

The cockroach infestation in all sites ranged from medium to high, primarily of *P. americana*. Table 2 presents the pre and post-treatment visual counts of cockroaches in treatment and control sites. A physical assessment method of counting one by one number of trapped cockroaches in glass jar traps becomes the pre-treatment and post-treatment sampling technique. Table 3 shows the cockroach infestation reduction percentage for both treatments, fipronil and imidacloprid, for adult and nymph American cockroaches from week one until week six.

Fig. 4 shows 90% ± 5.0 and 95% ± 3.5% of reductions in adult and nymph from fipronil treatment, respectively, while imidacloprid treatment also records the highest reductions, 94% ± 1.9 and 93% ± 2.3 for both adult and nymph, respectively, in week 2. Fipronil-treated sites observed a lower reduction percentage for adults (78% ± 1.8) in the third week, while nymphs recorded 63% ±

Fig. 3. (a) Gel bait application around perimeter of sewer shaft (b) Gel bait after installation.

Table 2
Population density of *P. americana* before and after application of gel bait insecticide formulation.

Treatment		Replicate		Time Interval											
		Pre-treatment		Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
		Adult	Nymph	Adult	Nymph	Adult	Nymph	Adult	Nymph	Adult	Nymph	Adult	Nymph	Adult	Nymph
	Aman	67	198	96	58	2	1	14	8	61	25	26	16	26	22
	Damai	66	154	11	27	2	11	12	21	23	34	33	34	49	83
Harapan	70	86	26	46	17	12	18	14	23	9	27	13	31	56	
	Tekun	132	107	9	8	7	16	6	16	10	15	15	21	14	51
	Restu	49	102	4	7	6	3	4	7	6	4	3	5	16	28
	Saujana	65	50	6	10	1	0	5	5	2	4	10	8	6	17

Table 3
Field evaluation of fipronil and imidacloprid of reduction percentage based on American cockroach's life stages.

Treatment	Percentage Reduction (%)						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Mean/sd
Adult	35 ± 26.2	90 ± 5.0	78 ± 1.8	62 ± 12.7	58 ± 2.2	48 ± 7.0	59.33/5.981
Nymph	70 ± 9.0	95 ± 3.5	90 ± 3.8	84 ± 7.3	86 ± 6.6	63 ± 17.6	79.33/5.672
Adult	92 ± 1.5	94 ± 1.9	94 ± 0.6	93 ± 2.3	89 ± 3.5	85 ± 3.1	91.17/6.672
Nymph	90 ± 0.9	93 ± 4.9	89 ± 3.4	91 ± 3.7	87 ± 4.9	63 ± 10.0	85.50/6.178

17.6 during week 6. Besides, imidacloprid-treated sites recorded the lowest reductions (85% ± 3.6 and 63% ± 10.0, respectively) for both adults and nymphs by the end of the sixth-week post-treatment. Cockroach population increases by the third week since the reduction percentage decreases to 78% ± 1.8 and 90% ± 3.8 for both adults and nymphs, respectively, for fipronil-treated sites. The increase of cockroach density in imidacloprid-treated sites began in the fifth week, recording a reduced percentage at 89% ± 3.5 and 87% ± 4.9 and continued to decline by the end post-treatment week.

3.3. Mean number of American cockroaches trapped before and after fipronil and imidacloprid gel bait treatment

The number of trapped cockroaches is subjected to a one-way ANOVA, presented in Table 4. Data recorded groups of treatments, fipronil and imidacloprid, measured by the total number trapped cockroaches in the sixth-week post-treatment. The mean comparison in Table 4 recorded two different groups of treatments' performances by the value of means and standard error.

There are numerous trapped cockroaches for the fipronil product (Blattathor Altra Cockroach Gel Bait). For week 1, Aman recorded the highest number of trapped cockroaches rather than replicating Damai and Fajar Harapan, followed by no significant difference between replicates. Aman recorded a rapid descent during week 2, followed by a slight increase until week 4 before it recorded another reduction for weeks 5 and 6.

There was a significant difference between weeks 1 and 2, and weeks 1 and 3. Damai replicates recorded a high reduction between weeks 1 and 2 but slightly increased until week 6, followed by a significant difference between weeks 1 and 6. Fajar Harapan replicates the recorded reduction between weeks 1 and 2. The number of trapped cockroaches ascended until week 6, although there was no significance difference between weeks. Thus, for fipronil treatment, Aman registered the highest number of trapped cockroaches among those sets of replicates from weeks 1–6.

Table 4 shows that trapped cockroaches in an imidacloprid product (Premise® Cockroach Bait) have a high mean value for both adult (91.19%) and nymph (85.5%) stages, ranging from 0.5 ± 0.5 to 32.5 ± 18.5. In week 1, Tekun recorded the most trapped cockroaches rather than replicating Restu and Saujana, followed by no significant differences between replicates and weeks. Restu

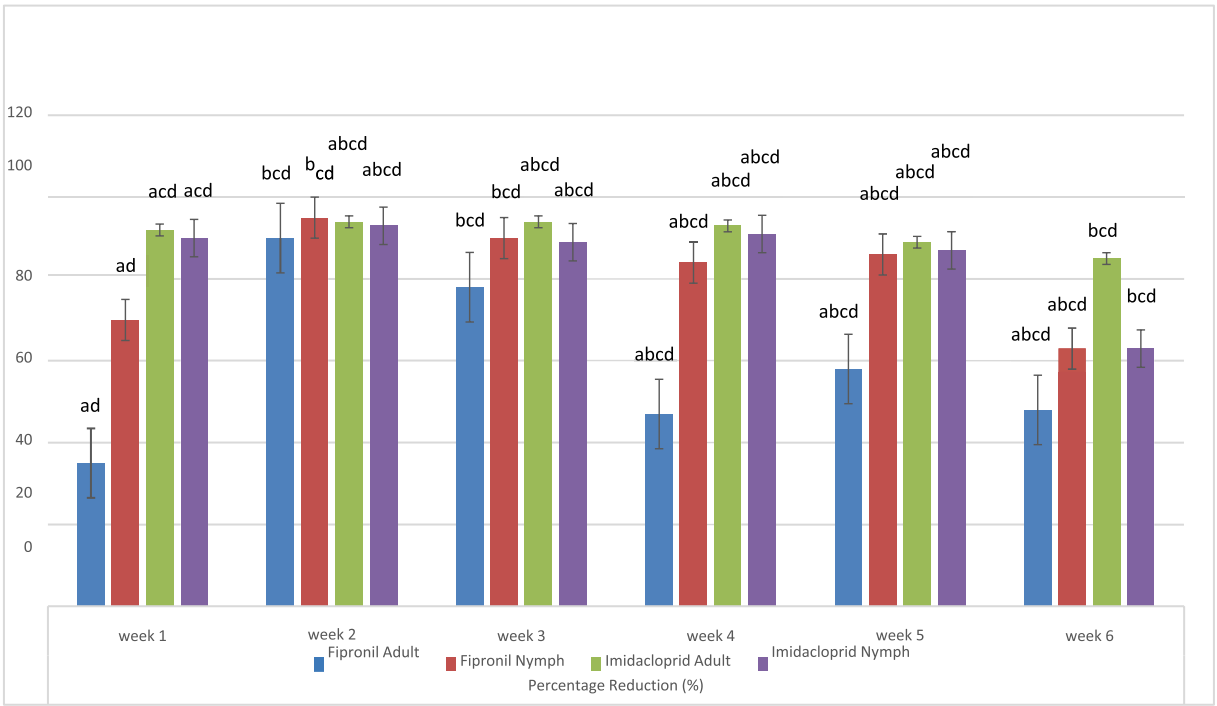

Fig. 4. The reduction (percentage) in cockroach infestation after treatment with fipronil and imidacloprid.

Table 4
Mean comparison density of cockroaches exposed to different treatment, Blattathor Altra cockroach Gel Bait (fipronil 0.05%), Premise® Cockroach Bait (imidacloprid 2.5%).

Treatment	Replicate	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
	Aman	77.0 ± 19.0ad	1.50 ± 0.5bcd	11.0 ± 3.0bcd	43.0 ± 18.0abcd	21.0 ± 5.0abcd	24.0 ± 2.0abcd
	Damai	19.0 ± 8.0 acd	1.50 ± 0.5abcd	16.5 ± 4.5abcd	28.5 ± 5.5abcd	33.5 ± 0.5abcd	66.0 ± 17.0bcd
	FajarH	36.0 ± 10.0abcd	14.5 ± 2.5abcd	16.0 ± 2.0abcd	16.0 ± 7.0abcd	20.0 ± 7.0abcd	43.5 ± 17.7abcd
	Tekun	8.5 ± 0.5abcd	11.5 ± 4.5abcd	11.0 ± 5.0abcd	12.5 ± 2.5abcd	18.0 ± 3.0abcd	32.5 ± 18.5abcd
	Restu	5.5 ± 1.5 acd	4.5 ± 1.5abcd	5.5 ± 1.5abcd	5.0 ± 1.4abcd	5.0 ± 1.4abcd	22.0 ± 6.0bcd
	Saujana	8.0 ± 2.0abcd	0.5 ± 0.5abcd	5.0 ± 0.0abcd	7.0 ± 1.0abcd	9.0 ± 1.0abcd	11.5 ± 5.5abcd

recorded a slight increase from weeks 2–6, followed by a considerable difference between weeks 1 and 6. Saujana recorded a drastic reduction between weeks 1 and 2 (8.0 ± 2.0 to 0.5 ± 0.5), followed by a slight increase from weeks 3–6 (5.0 ± 0.0 to 11.5 ± 5.5). Thus, for imidacloprid treatment, Tekun registered the most trapped cockroaches among those sets of replicates from weeks 1–6.

In general, the number of trapped cockroaches is proportional to the time for fipronil and imidacloprid treatments. However, imidacloprid has a higher reduction percentage between 90% and 95%, with a total mean of 91.17% for adults and 85.5% for nymphs at similar fipronil gel bait. This result indicates that Premise® Cockroach Bait (imidacloprid) is more effective in controlling American cockroach infestations in sewer systems Nonetheless, reapplication of gel bait after one month from the first application is necessary for a long-term effect.

4. Discussion

Based on different treatments, namely fipronil (Blattathor Altra Cockroach Gel Bait) and imidacloprid (Premise® Cockroach Bait), from several sites and weeks after treatment, American cockroaches (*P. americana*) demonstrate a distinct percentage reduction effect. The results establish that the latter performs better in the field. The total mean reduction percentage for imidacloprid is 91.17% for the adult stage and 85.50% for the nymph stage. Fipronil is less effective in 59.33% of reductions in adult stages and 79.33% of reductions in nymph stages. There is a significant difference between the treatments used. Fig. 4 shows the progress of percentage reductions for both nymphs and adults' life phases. The latter has a higher percentage when treated with imidacloprid. High nymph trap counts before treatment (59% of cockroach trap counts) and poor baits applied result in modest reduction, particularly for nymphs, after six weeks. In addition, a high nymph population indicates strong reproduction rates. They travel faster around active areas (nests), but in this case, the application baits are placed just beneath the manhole cover while the nest position is unknown. According to a previous study Shahraki et al. (2013), adult cockroaches are more resistant to desiccation and migrate long distances to feed [1]. Therefore, adult stages have a higher reduction percentage than nymphs.

Davari et al. (2018) claimed baits are efficient against cockroaches in sewer systems, especially American cockroaches [14]. Neonicotinyl baits (imidacloprid) can control *P. americana* effectively and reasonably well in sewer systems. A Maxforce FC Roach Killer (fipronil 0.05%) and Pre-Empt IMAGEL (imidacloprid) gel baits provide more than a 90% reduction in control for six months [15]. Another similar study has applied both Blattathor Altra cockroach Gel Bait (fipronil 0.05%) and Premise® Cockroach Bait (imidacloprid 2.5%), along with adequate sewer conditions such as humidity, temperature, and plenty of water and food [16]. Moreover, an ecological element might influence gel bait performance. Each gel bait product had a different performance rate. Due to high humidity and temperature in the sewer system, Blattathor Altra Cockroach Gel Bait (fipronil 0.05%) degraded quickly. During week 3 of post-treatment, the layer of gel baits had already melted and washed away, but Premise® Cockroach Bait (imidacloprid 2.5%) showed a long-lasting persistence since the gel baits were able to retain and were visible on the wall of the manhole during week 5. As a result, compared to Blattathor Altra Cockroach Gel Bait, Premise® Cockroach Bait has a higher level of sewer system persistence.

Laboratory strain *P. americana* prefers toxic baits above any other food source [17]. However, Varadinova et al. (2015) found that field strain *P. americana* prefers food sources other than toxic baits [18]. Natural foods are the preferred abode of American cockroaches. As a result, cockroaches are not entirely drawn to the gel baits when other foods are present in the harbourages. Therefore, reducing the availability of other food sources is critical before applying gel baits around their harbourages to increase product efficacy.

Apart from the excellent performance of gel baits linked to moisture, products that can sustain a high moisture level in the gel bait contribute to high palatability and efficacy [19]. This investigation also determined that Premise® Cockroach Bait has higher palatability than Blattathor Altra Cockroach Gel Bait.

The susceptibility or resistance of American cockroaches to insecticides has not been thoroughly investigated. However, there is limited research on pesticide formulations in sewer systems [11,20]. *Periplaneta americana* has a susceptibility order of lambda-cyhalothrin > permethrin > deltamethrin > cyfluthrin > alpha-cypermethrin [16], based on lethal concentrations recorded in prior studies. In this study, the *P. americana* population in the sewer system of Universiti Sains Malaysia's main campus is susceptible to Premise® Cockroach Bait (imidacloprid 2.5%), with a mean reduction value of 91.17% and 85.50% for adult and nymph stages, respectively. Lambda-cyhalothrin is the most effective, while alpha-cypermethrin is the least effective against American cockroaches. Blattathor Altra cockroach Gel Bait (fipronil 0.05%) has a success rate of 59.33% and 79.33% for adult and nymph stages, respectively. Imidacloprid (2.0-fold), deltamethrin (3.9-fold), and fipronil (3.9-fold) have modest resistance to *P. americana*, namely 90%–100%

high resistance, 50%–80% modest resistance, and the remaining is low resistance, which is comparable to a previous finding [8].

To efficiently control American cockroaches infestation in the Universiti Sains Malaysia campus, a long-term cockroach control approaches that consider the passage of American cockroaches from their source niches in the sewer system are required. The most significant niches can be easily defined, which is a strategy for reducing populations of American cockroaches where they breed before reaching a nearby structure. Table 4 shows the weekly percentage reduction of American cockroaches. Pesticide usage in the home decreases due to identifying and treating outdoor sources, a rising public health concern, particularly for residents of metropolitan areas [21]. Furthermore, many American cockroaches found in each of the targeted manholes in Table 2 simplify that sewage system treatment may be beneficial in all locations where American cockroaches are present. Using insecticidal baits to control American cockroaches in sewers with reproducing populations that would migrate indoors could be a more effective method. Imidacloprid is the first active component from the chloronicotinyl class of chemicals employed in cockroach gel bait compositions [22]. The route of pesticide transmission via gel bait formulations is oral. Hence, the critical factor with a gel is its sufficient consumption by the cockroach to achieve oral efficacy.

During week 5, imidacloprid-treated sites drop 89% and 87% for adult and nymph stages, respectively. However, fipronil-treated sites significantly reduced 78% for adult stages in week 3 and 84% for nymph stages in week 4. Due to the long-lasting residue of gel bait on the cockroach population, imidacloprid has a better performance than fipronil. Coprophagy (faecal consumption), necrophagy (dead cockroach ingestion), and mitophagy (dying cockroach excrement ingestion) proceed via toxicity, in addition to pesticide distribution within the cockroach population via American cockroach behaviour [10]. Furthermore, cockroaches exposed to a lethal imidacloprid dose might infect their colonies inside the same harbour when returning to the nest via chemical contact, contributing to a considerable reduction between weeks. As a result, imidacloprid has superior performance to fipronil in the field. The total mean reduction percentage for imidacloprid is 91.17% and 85.50% for adult and nymph stages, respectively, while fipronil is effective in 59.33% and 79.33% of adult and nymph stages, respectively. There is a significant difference between the two treatments used. Therefore, imidacloprid gel is effective in controlling cockroaches in sewer systems. It is more convenient to treat places and requires a straightforward application (quite stable for various situations) with minimal disruption to the home or business. Since there has been no medical report on this treatment in previous years, imidacloprid cockroach gel bait is highly effective and safe for consumers and the surrounding environment.

Imidacloprid has a total mean reduction of 91.17% in the adult stage and 85.50% in the nymph stage. Meanwhile, fipronil is efficacious in 59.33% of adults and 79.33% of nymph stages. There is a substantial difference between the two treatments utilised. As a result, imidacloprid gel can effectively control cockroaches in sewage systems. It can conveniently treat treated areas and is simple to administer (relatively constant in several circumstances) with minimum interruption to the house or company. Imidacloprid cockroach gel bait treatment is very successful and safe for consumers and the environment, although without any medical reports.

Author contribution statement

NNAB and AHAM conceived and designed the experiments NNAB and AHAM contributed to the proof-of-concept experiments and initial development. AHAM contributed reagents and materials. NNAB performed the experiments. NNAB and AHAM analyzed and interpreted the data. NNAB and AHAM wrote and drafted the manuscript. NNAB and AHAM authors edited the manuscript. NNAB and AHAM reviewed and edited the manuscript. NNAB and AHAM final approval of the version submitted.

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Declaration of competing interest

The authors declare that there are no conflicts of interest.

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