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The effectiveness of commercial gel baits against German cockroach *Blattella germanica* (Linnaeus, 1767) in Indonesia

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Abstract: Gel baits product sold commercially to the public has long been used to control German cockroach populations in urban areas. The effectiveness and resistance level of gel bait products need to be known for the successful control of German cockroaches in the field. However, there have been no reports of resistance in Indonesia. This study used toxicity tests of six gel bait products (MF, CBG, SPB, OTG, BTX, and UBA) against two populations of adult male German cockroaches (VCRU-WHO and RKMN-BKT). Fipronil, boric acid and emamectin benzoate containing gel baits were effective to knock down and kill the German cockroaches. In contrast, gel bait with imidacloprid as an active ingredient was only useful to knock down the German cockroaches. Commercial gel bait product in Indonesia are still useful in controlling German cockroaches' populations with a time of effectiveness to cause mortality between three to four weeks after being exposed in the field and the level of cockroach resistance to gel bait are susceptible until low resistance.

Keywords: toxicity, efficacy, commercial insecticides, resistance, persistence, urban pest

Introduction

The German cockroach, *Blattella germanica* (Linnaeus, 1767) is an urban pest (Dingha *et al*., 2013), distributed in various countries including Indonesia (Rahayu *et al*., 2012; 2016). It is the most important insect pest in hospital environments. It is vector for several diseases and contaminations of 25 fungi species (Nasirian, 2017) and 61 bacteria species (Nasirian, 2019). German cockroach has been shown to be resistant to commercial spray insecticides (Rahayu *et al*., 2016). Gel baits are an alternative insecticide tool to control German cockroaches and many commercial gel baits were available for sale to the public until now. To control German cockroaches using gel baits method can be applied any time. In contrast, the spray method was only used at a specific time and left an insecticide residue on the environment.

Gel baits significantly reduced the population of German cockroaches compared to the spray method (Shahraki *et al.,* 2013). It is easier for German cockroaches to consume gel baits, they are more toxic, and more effective than the solid bait (Appel, 2004). Widely used active ingredients in gel baits are fipronil, hydramethylnon, abamectin, and imidacloprid (Miller & Mc Coy, 2005).

Previous studies have shown different levels of effectiveness of gel baits in controlling German cockroaches in the field. Dangsheng (2005) reports that gel baits with the active ingredient hydramethylnon were less effective than fipronil in controlling German cockroaches. Nalyanya *et al*. (2009) also reported different attractiveness of gel baits with active ingredients abamectin and hydramethylnon to German cockroaches. The efficacy of gel baits to control German cockroaches in Indonesia have not been

reported previously. Therefore, this study aimed to monitor the effectiveness of commercial gel baits and its resistance level to German cockroach population to be a recommendation for the public in choosing the right active ingredient of gel bait products in controlling the German cockroach population in Indonesia.

Materials and Methods

Provision of German cockroach populations. The cockroach used in this study was adult male German cockroach from two populations (VCRU-WHO as a standard population and RMKN-BKT as a field population). Cockroach populations were reared in the laboratory, food and drink gave ad libitum (Rahayu *et al.,* 2018). Cockroaches used for treatment have an age range from 2 to 3 months.

Provision of gel baits. The gel bait tested in this study were commercial products were MF (fipronil 0.05%), BTX (imidacloprid 2.15%), UBA (fipronil 0.05%), OTG (emamectin benzoate 0.1%), CBG (fipronil 0.05%), and SPB (0.01% boric acid).

Toxicity test of gel baits. The toxicity test of gel bait was carried out in a test box (one-liter volume of a plastic container). Adult male cockroaches as many as ten individuals, water, and 0.5 gram of gel bait were put into the test box. The toxicity test was replicated three times. Observation of mortality time and effectiveness criteria of gel bait refers to the standard of DPP (2004).

Persistency test of gel baits. The persistency test uses the remaining gel bait that has been using in a previous toxicity test, or that has been exposed to air before. The same gel bait was retested every week for up to five weeks or until the bait was no longer able to kill the German cockroaches. Persistency test using new cockroaches every week. If any cockroaches die during observation, they will be removed from the test box. The persistence test aimed to see the effectiveness of the gel bait used since it was first exposed to the air and was replicated until three times. The persistency test methods followed identical methods to the toxicity test (DPP, 2004).

Data analysis. The number of German cockroach knockdown and mortality was analyzed by probit analysis using the Minitab 18 software to obtain the Knockdown Time 50% (KT_{50}) and the Lethal Time 50% (LT_{50}). Gel baits were considered effective if KT_{50} and LT_{50} were reached before 72 hours of observation (DPP, 2004). The resistance ratio (RR_{50}) was a comparison between lethal time (LT_{50}) of field collected and standard German cockroach populations. Resistance level refers to Rahayu *et al*. (2016) modified from Lee & Lee (2004) with criteria of $RR_{50}\leq1$: susceptible, $1<RR_{50}\leq5$: low resistance, $5<RR_{50}\leq10$: moderate resistance, $10<RR_{50}\leq50$: high resistance,$50<RR_{50}\leq1000$: very high resistance, $RR_{50}>1000$: extremely high resistance.

Results

Toxicity test of gel bait. All gel baits used in this study were effective in controlling the population of German cockroaches (Table 1). The gel bait is related to how quickly it paralyzed and killed the cockroaches. The difference in efficacy is also affected by the active ingredients in the gel bait and exposure duration.

All gel baits tested to German cockroach populations were effective according to the Knockdown Time (KT_{50}). Paralysis is a condition when a cockroach's body is turned upside down and unable to move from one point to another, but its legs still move when touched. According to the lethal time (LT_{50}), there was one product of gel bait that was not effective in killing both German cockroach populations (Table 2). The gel bait product was BTX with active ingredients was imidacloprid.

Gel baits resistance level. The field population of German cockroach (RMKN-BKT) was still susceptible to MF and UBA gel baits

Table 1. Effectiveness criteria of all gel baits and Knockdown Time (LT_{50}) of German cockroach populations (VCRU-WHO and RMKN-BKT); KT50 - the time needed to knock down 50% of the German cockroach population, * Effective if KT50 was reached at 72 hours (DPP 2004).

Population	Gel bait product	Active ingredient	KT_{50} (hours)	Slope ± SE	Criteria*
VCRU-WHO	MF	Fipronil	3.50	2.33 ± 0.09	Effective
	BTX	Imidacloprid	13.00	0.36 ± 0.08	Effective
	UBA	Fipronil	5.93	3.07 ± 0.09	Effective
	CBG	Fipronil	3.09	0.55 ± 0.05	Effective
	SPB	Boric acid	3.43	0.62 ± 0.06	Effective
	OTG	Emamectin benzoate	22.28	2.42 ± 0.40	Effective
RMKN-BKT	MF	Fipronil	5.01	2.99 ± 0.09	Effective
	BTX	Imidacloprid	14.17	0.24 ± 0.03	Effective
	UBA	Fipronil	6.47	7.90 ± 0.09	Effective
	CBG	Fipronil	5.65	0.59 ± 0.08	Effective
	SPB	Boric acid	4.82	0.68 ± 0.07	Effective
	OTG	Emamectin benzoate	23.29	0.10 ± 0.01	Effective

Table 2. Effectiveness criteria of all gel baits and Lethal Time (LT_{50}) of German cockroach populations (VCRU-WHO and RMKN-BKT). LT_{50}: the time needed to kill 50% of the German cockroach population. Criteria*: Effective if LT_{50} was reached at 72 hours (DPP 2004).

Population	Gel bait product	Active ingredient	LT_{50} (hours)	Slope ± SE	Criteria*
VCRU-WHO	MF	Fipronil	26.47	7.58 ± 0.07	Effective
	BTX	Imidacloprid	76.56	2.99 ± 0.10	Ineffective
	UBA	Fipronil	36.00	18.28 ± 0.00	Effective
	CBG	Fipronil	14.96	0.67 ± 72.21	Effective
	SPB	Boric acid	14.95	0.67 ± 72.21	Effective
	OTG	Emamectin benzoate	25.63	0.09 ± 0.01	Effective
RMKN-BKT	MF	Fipronil	24.76	6.57 ± 0.07	Effective
	BTX	Imidacloprid	83.26	0.73 ± 0.12	Ineffective
	UBA	Fipronil	36.00	18.28 ± 0.00	Effective
	CBG	Fipronil	23.42	0.35 ± 52.22	Effective
	SPB	Boric acid	25.63	0.09 ± 0.01	Effective
	OTG	Emamectin benzoate	33.27	0.07 ± 0.01	Effective

with fipronil active ingredients and low resistance to other bait products (Table 3). Most cockroaches were still susceptible to gel bait containing the active ingredient fipronil, whereas gel bait containing other active ingredients had low resistance.

Gel bait persistence test. The same gel bait which was tested in the toxicity test was effective in controlling the population of German cockroaches for up to five weeks in the persistence test (Table 4).The persistence of the MF gel bait was only three weeks. The MF bait became moldy at the four and five weeks of observations so that cockroaches can eat nothing else. Gel bait with the active ingredient emamectin benzoate had decreased effectiveness at five weeks of observation. The emamectin benzoate bait was not effective in controlling the RMKN-BKT population of German cockroach because it only kills 40% of the population at the 72 hours observation.

Discussion

All gel bait products tested to German cockroach populations were effective. The gel baits with active ingredients of fipronil (CBG product) were most effective in killing field population of German cockroaches faster 1.09–3.55 times than other gel bait products (MF, UBA, SPB, OTG products). Fipronil contained in gel bait products can be used as an alternative method for controlling German cockroach populations that have been resistant to spray insecticides. Nasirian (2008) reported the fipronil gel bait is more effective than spray insecticides in controlling German

Table 3. The resistance level of the German cockroach field population (RMKN-BKT) to tested commercial gel baits; * RR_{50}: Resistance ratio (lethal time of field population (LT_{50})/ lethal time of standard population (LT_{50}), ** resistance levels based on Rahayu *et al*. (2016).

Gel bait	Active ingredients	RR_{50} (fold)*	Resistance level**
MF	Fipronil	0.94	Susceptible
BTX	Imidacloprid	1.09	Low resistance
UBA	Fipronil	1.00	Susceptible
CBG	Fipronil	1.57	Low resistance
SPB	Boric acid	1.71	Low resistance
OTG	Emamectin benzoate	1.30	Low resistance

Table 4. The mortality of German cockroach after being treated with gel bait observed at 72 hours each week for up to five weeks of observation.

Gel bait product	Population	Mortality (%)				
		Week I	Week II	Week III	Week IV	Week V
Control	VCRU-WHO	0	0	0	0	0
	RMKN-BKT	0	0	0	0	0
MF (Fipronil)	VCRU-WHO	100	100	100	0	0
	RMKN-BKT	100	96	98	0	0
UBA (Fipronil)	VCRU-WHO	100	100	100	100	100
	RMKN-BKT	100	100	100	100	100
CBG (Fipronil)	VCRU-WHO	100	100	100	100	100
	RMKN-BKT	100	100	100	100	100
SPB (Boric acid)	VCRU-WHO	100	100	100	100	100
	RMKN-BKT	100	100	100	100	100
OTG (E. benzoate)	VCRU-WHO	100	100	100	100	90
	RMKN-BKT	100	100	100	100	40

cockroach populations. Rahayu *et al*. (2016) also reported that several strains of German cockroaches collected in Indonesia were resistant to commercial spray insecticides.

There was a difference in effectiveness between gel bait products even though it has same fipronil active ingredient, such as UBA product, it was not as good as CBG product. UBA gel bait products kills just 50% of the population of cockroaches (LT_{50}) after 36 hours or longer than other products with same active ingredients (CBG and MF gel baits). CBG and MF gel bait were able to kill German cockroaches in a time range of 14–26 hours. We assumed the differences in results is influenced by the composition of formulations, such as attractant types and other complementary compositions in gel bait products. The attractant substance of the SPB gel bait might be weak in attracting German cockroaches, then the amount of bait eaten was less and also causes less mortality. Putra (2018) reported that attractant substances in gel bait formulations affect the frequency of presence and the amount of bait eaten by German cockroaches. The effectiveness of gel bait is not only influenced by the active ingredients but also by the attractant substances in the formulation of gel bait products. Nalyanya *et al*. (2001) also reported that the attractiveness of gel baits was not only influenced by substances in the formulation but also is influenced by the age of the bait.

Gel bait with fipronil active ingredient was more effective than gel bait with other active ingredients because it was a new insecticide used publicly in Indonesia. Rahayu *et al*. (2012) reported that fipronil was classified as a new insecticide to control cockroach pests in Indonesia, and the level of resistance was still lower in German cockroaches than other commercial synthetic insecticides like permethrin. Fipronil was also a solution to overcome the problem of insecticide resistance in various insect species with a low level of toxicity to humans and other mammals (Bloomquist, 2009).

SPB gel bait with boric acid as an active

ingredient in its formulation became the fast insecticide to paralyzed field German cockroach population but not cause mortality as fast as fipronil gel bait. Boric acid worked as a stomach toxicant that could affect metabolism and destroy the epithelium in the foregut of insects (EPA, 1993). If boric acid were combined with other gel bait formulation and eaten by insects, it would damage the digestive system. Lank & Wahl (2014) also reported that boric acid was toxic to insects, but can also damage the human digestive system, humans who are exposed to boric acid continuously will cause gastroenteritis.

German cockroach was still susceptible to MF and UBA gel baits with resistance ratios of 0.94 and 1.00 times, while other gel baits low resistance with resistance ratios of 1.09 to 1.71 times. German cockroach resistance level was still low against gel bait because the method of controlling cockroaches using gel baits was still relatively new and was rarely used by people in Indonesia compared to spray insecticides. Rahayu *et al*. (2016) reported that some German cockroach populations in Indonesia have been low to high resistance to commercial spray insecticide products with a resistance ratio range of 1.18 to 29.74 times. The resistance level of German cockroach was low and they were still susceptible to gel baits, which makes gel bait an alternative method to control German cockroaches instead of using commercial spray insecticides. However, the frequency of using gel baits in the field should be a public concern because German cockroaches can not only develop physiological resistance but can also develop behavioral resistance. Wang *et al*. (2004) reported that German cockroaches were able to develop behavioral resistance to the gel bait formulation.

The persistence of all gel baits lasted only three until five weeks. Then the gel bait has decay and deformation; the surface of the bait has dried, became shiny and slippery. After deformation, the gel bait was difficult to be consumed by the cockroaches. Therefore, emamectin benzoate gel bait was highly preferred by cockroaches at the beginning of the first week of treatment because it has a better texture than other baits but the bait had dried by the second week.

Nalyanya *et al*. (2001) tested several gel bait formulations and found that bait attractiveness is influenced by bait age. Gel bait attractiveness decreases after a week in laboratory and field tests because influenced by gel bait formulation. Therefore, choosing the right gel bait formulation is highly recommended for pest control operators. Attractive gel bait on German cockroaches will also be attractive to brown-banded cockroaches. Putra (2018) also reported that German cockroaches like gel bait that has a chewy texture and contains much water. The presence of mold on the gel bait will reduce the quality of the bait and reduce the aroma of the bait, which attracts the cockroaches. Mold can also reduce the nutrient content such as carbohydrate in the bait that was needed by cockroaches as an energy source.

The use of gel bait for pest control operators is an alternative way to replace the spray method. The development of an integrated pest management framework for controlling German cockroaches using gel bait is needed. Gel bait can be used in the field for several weeks without losing its effectiveness. German cockroaches are also still susceptible and have a low resistance to German cockroaches depending on the active ingredients. Another benefit is that the gel bait leaves no insecticide residue in the field.

Conclusion

Five of the six commercial gel bait products are still effective for controlling German cockroaches in standard and field populations. The persistence of four of five gel bait products is five weeks. The level of resistance of German cockroaches to gel baits is still susceptible and low resistance. Gel bait with active ingredients of fipronil and boric acid can be an alternative

insecticide to control the population of German cockroaches in Indonesia.

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