Efficacy of three insecticides against German cockroach, *Blattella germanica*

Esayas Kinfe*, Yonas Wuletaw, Fitsum Tesfaye, Sintayehu Abate and Yebeltal Asefa

Ethiopian Public Health Institute

Corresponding author: esayasknf82@gmail.com *Cell phone: +251911716218*

Abstract

Background: Arthropod adaptability joined with ecological and climate change combined with frequent air travel, ensures that vector-borne diseases continue to be a problem for humankind. Cockroaches are among the most important residential, commercial, institutional, and industrial pests today all over the world including Ethiopia.

Methods: Efficacy of fipronil gel, boric acid and hydramethylnon baits were evaluated against German cockroach, *Blattella germanica,* in the Ethiopian Public Health Institute's laboratory.

Result: Fipronil gel bait was significantly more toxic and caused fast action with higher mortality of *Blattella germanica* than boric acid and hydramethylnon baits. The overall mortality of *B. germanica* due to exposure to fipronil, hydramethylnon and boric acid at the end of the experimental 14 days test were 96.5, 93.4 and 84.6 %, respectively. Although all the baits were toxic to adult males and females of *B. germanica* at all rates, the result of oral toxicity against this species varied by developmental stage. To this effect, fipronil caused higher nymphal death than the two baits. The median lethal time (LT50s) were 0.8, 2.4, and 7.6 days for fipronil, hydramethylnon and boric acid baits, respectively. In terms of attraction, *B. germanica was* more attracted to fipronil than hydramethylnon and boric acid baits.

Conclusion It was observed that fipronil is the most effective insecticide against *B. germanica* than boric acid and hydramethylnon.

Keywords: Cockroach, Fipronil, Hydramethylnon, Boric acid, lethal time, Toxicity, Ethiopia

Introduction

Insects high adaptability nature, combined with ecological and environmental change and frequent air travel of the international community for various reasons, ensure that vector-borne diseases will continue to be a major public health problem for humankind. Cockroaches are among the most important residential, commercial, institutional, and industrial pests today all over the world including Ethiopia. Cockroaches are disgusting and unpleasant to most people simply by their presence around dwellings. Quite a lot of, approximately 3,500 species in the world have become adapted to living in human habitations. They can remain active throughout the year in all seasons; consume any animal food or beverage, as well as dead animal and plant materials such as leather, glue, hair, wallpaper, fabrics, and the starch in book bindings. Although, opinions differ regarding the role of cockroaches in disease transmission, some health officials/workers perceive cockroaches have no association with disease transmission, rather, they think as they are merely nuisance pests. However, many human disease-causing organisms have been found on the legs, other body parts, or fecal pellets of cockroaches (Reierson 1995. Frishman, 1982; Roth and Willis 1957).

Because of their dirty habits of feeding indiscriminately on both excreta and foods, as well as their practice of excreting and regurgitating their partially digested meals over food make their presence in houses, hotels, guesthouses, supermarkets, stores, they have for a longtime been regarded as highly undesirable or nuisance. However they have been suspected as aiding the transmission of various illnesses. Currently, cockroaches are known to carry pathogenic organisms such as poliomyelitis, protozoa such as *Entamoeba histolytica* and bacteria such as *Escherichia coli*, *Staphiloccocus aureus, Shigella spp.* and *Salmonella spp.* These pathogens have been identified from specimens collected from their gut and fecal pellets. Several researchers have obtained data that indicate they are most commonly implicated in the transmission of *Salmonella* (Rueger and Olson 1969). In line with this, cockroaches affect human health physically, for instance they bite softly and gnawing the fingernails of sleeping children; they may enter human ear canals; they contaminate food, imparting an unpleasant odor and taste. Besides, cockroach filth and cast skins contain a number of allergens to which sensitive people may exhibit allergic responses. Moreover, killing cockroaches may not eliminate antigen from the dwelling, since the shelf life of cockroach allergen is several years.

Some people living in dwellings with a large population of cockroaches make them sensitive to their allergens, which are associated with asthma, for instance Litonjua and his colleagues (2001) indicated that young children in families with a history of asthma reported to suffer from recurrent wheezing problem. Besides, Asthma-related health problems are most severe among children in city areas. In a study that involved 476 asthmatic inner-city children, 50.2%

of the children's bedrooms had high levels of cockroach allergen in dust. This study also found that children who were both allergic to cockroach allergen and exposed to high levels of this allergen had 0.37 hospitalizations a year, as compared with 0.11 for other children (Rosenstreich et al. 1997). In New York, those living in apartments consider that cockroaches as a health hazard that has led to most (90%) of the pesticides applied aimed at cockroaches control (Whyatt et al. 2002). Disease transmission or allergic reactions due to them incontestably prevented by controlling cockroaches in the residential, institutional, commercial and industrial environments. The best approach to cockroach control involves good sanitation, protecting against new entry and a combination of less toxic pesticides application as well as using growth inhibitors that are more safe than other control measures (DeMark 1988). Although there are different types of trap designs that vary in their effectiveness, sticky traps are generally used (Stejskal et al. 2004). Kim and co-authors (1995) reported that the densities of German cockroaches in Suwon, Kyonggido in September-October were 4.9/trap/day in Chinese restaurants, 0.5/trap/day in Korean restaurants, 1.1/trap/day in apartments, 1.3/trap/day in tea-rooms, 0.4/trap/day in resident houses, 0.02/ trap/day in hospitals, and 0.1/trap/day in hotel rooms. German cockroach densities in Seoul in October 1976 were 7.0/trap/day in apartments, 6.8/ trap/day in tea rooms and 9.7/trap/day in restaurants (Ree et al. 1976), and 9.7/trap/day in lab animal rooms and 4.5/trap/day in apartments in 1994 (Ree et al. 1995).

In recent times, poisonous bait application has been the most widely employed method for cockroach control and the incorporation of this practice into integrated pest management programs has been stressed. The usage of poisonous baiting in the control of cockroaches has a long and varied history, for example, toxic baits containing phosphorous, boric acid, and other compounds were most effective against *Periplaneta spp.* such as the American cockroach, *P. americana* and other large peridomestic cockroach species (Cheng and Campbell 1940; Lofgren and Burden 1958). On the other hand, the more prevalent German cockroach, *Blattella germanica* was not successfully controlled with these products (Valles et al. 1996; Koehler et al. 1993. Frishman 1982). Varying intensities of control in the use of baits in the control of *B. germanica* and *P. americana* have been reported with chlorpyrifos, sulfluramid, abamectin, boric acid, hydramethylnon, and other baits (Hagenbuch et al. 1988; Appel 1990 1992; Reid et al. 1990; Brenner and Pierce 1991; Koehler et al. 1991; Appel and Benson 1995; Kaakeh and Bennett 1996; Kaku and Matsumura 1994). Using baits results less environmental contamination and greater ease of application than other insecticide products (Rust 1986). However, effective bait formulations must be palatable and non-repellent, readily available, and toxic in the amounts consumed (Appel 1990).

Furthermore, the usage of baits is now recommended instead of sprays to control cockroaches, since this method avoids any food preparing surfaces and reduce risk of unexpected ingestion by domestic animals and children. Baits can be placed in areas under sinks, behind or along pipes and on top of cupboards inaccessible to children. Some baits are formulated as a gel, in which an insecticide, fipronil, is mixed with one or more attractants. The speed of action depends on the insecticide used. Some insecticides can achieve a rapid kill or may have slow action (Stejskal et al. 2004). Slow action allows cockroaches that have eaten bait to go back to their hiding places where other cockroaches exist. When those cockroaches who took baits die, the live ones consume the dead body and succumb to similar fate. Such baits are more effective against the early instars nymphs. Hydramethylnon in a bait that was evaluated in infested cafeterias in Thailand reduced the number caught in traps by more than 90% in a week and remained effective for up to 3 months post-treatment (Sitthicharoenchai et al. 2006). Recently, poison bait application has been most widely employed for cockroach control and the incorporation of this practice into integrated pest management programs has been emphasized.

Lee (2002) compared control effects of fipronil bait to hydramythylnon and chloropyrifos baits in laboratory, and 100% mortality of German cockroaches was observed in five days. In line with this, several field trials have been conducted to evaluate hydramethylnon baits against German cockroaches, and these showed a 100% reduction rate in laboratory animal rooms (MacDonald et al. 1987), 94% in apartments (Patterson and Koehter 1989), 84.4% in private premises, 99.2% in laboratory animal rooms, and 88.8% in apartments (Ree et al. 1995), whereas a field trial with fipronil bait showed 93.1% of reduction rate. These different control effects were probably resulted from different environmental factors, rather than insecticide itself. Generally, less furniture and food are associated with better control effects when poison baits are implemented. The objectives of the present study were therefore to determine the oral toxicity of fipronil, boric acid and hydramethylnon against males, females and 4th in stars of *B. germanica* in the laboratory and at field level (actual living condition).

There was no any similar study conducted in Ethiopia. Such studies are important for public health regulatory and legislative framework by providing scientific evidence to create rational use of insecticides, and good management practices. The present study will try to answer the question, what should be done if the existing selected vector control methods or insecticides do not meet standards to control vectors? Selection of proven vector control methods based on knowledge of local (Ethiopia) vector biology and ecology, as well as disease transmission and morbidity is important. Use of a range of vector control interventions, separately or in combination and often synergistically have great impact on vectors of diseases.

Materials and methods

Laboratory efficacy test

Target insect: The test cockroaches were wild-caught *B. germanica,* as this species is the most prevalent in the whole of Addis Ababa. Adult cockroaches were collected from homes, hotels and hospitals in small glass jars baited dog food with sugar, banana, and placed around cockroach frequenting sites for overnight. Thus, the collected cockroaches were transported to Ethiopian Public Health Institute (EPHI) entomology laboratory.

Baits for the test: Fipronil is a phenylpyrazole insecticide, which is relatively new and made available in 1999 in bait formulations for use against domestic cockroaches and ants. The insecticidal properties of fipronil [-5- amino-1-(2, 6-dichloro-a, a,a-trifluoro-*p*-tolyl)-4-trifluoromethyl-sulfinylpyrazole-3-carbonitrile] were discovered by Rhone-Poulenc Agro in 1987 at Ongar, UK (Hatton et al. 1988; Colliot et al. 1992). This phenylpyrazole insecticide is neurotoxic which blocks the transmission of signals by the inhibitory neurotransmitter gamma-aminobutyric acid (GABA) (Colliot et al. 1992; Cole et al. 1993; Moffat 1993). Fipronil was reported as a highly effective insecticide, utilizing a low-dose technology, against both piercing-sucking and chewing agriculturally important insect pests and can be delivered via soil, foliar, bait or seed treatment applications (Colliot et al. 1992; My 1994).

To assess the efficacy of fipronil to *B. germanica* laboratory tests were carried out on gel bait supplied by ZERA PLC containing the active ingredient called fipronil at a concentration of 0.05% and other ingredients that serve as attractants within especially designed polypropylene packaging having four gates for the entrance of cockroaches" and two other types of insecticides for comparison purpose. The two insecticides are boric acid, the best roach eradicating insecticide available in a chalk form in Ethiopia; and roach killing gel with active ingredient of hydramethylnon at 2.15%.

Efficacy test procedure: The bio-efficacy tests were carried out following the methods described in OECD (Organization for Economic Co-operation and Development) (2013). The test design employed in this study was a 'no-choice test' (without alternative food source), which is the most effective practice for cockroaches collected from urban areas (Wang et al. 2004). The test was conducted in a room with temperature at 27 ± 1.0°C and a relative humidity at the range of 50-60%, along with 12:12 light/dark cycle. A single-chambered system arena was used for the test (a lab arena with width of 1m, height of 0. 27m and length of 1m) (Figure 1). A lodge (somewhere to stay) made of corrugated cardboard was placed at one end of the arena with a cotton- plugged water flask placed into the opposite end of the arena. In between, two Petri-dishes containing the test substance were deployed. Each Petri-dish was covered by a fine mesh to prevent test insects from entering (these serve as weight controls). Harborages made of compressed cardboard boxes were provided at the opposite end of the arena. A petroleum jelly and mineral oil mixture were applied to the arena's top half of the inner wall to prevent cockroaches from escaping. The collected wild cockroaches were then acclimatized for two days by transferring into single chamber arenas. Once all the cockroaches felt at home in their containers, 50 cockroaches (3-14 days old adults of 15 males and 15 non-gravid females; and 20 late nymphs) were assigned in each of the experimental and control arenas. All cockroaches look as if unhealthy showing the symptoms in test organisms; such as abdominal swelling, changes in body colour, odour, sluggish mobility and inactive behavior; and with other additional symptoms were removed and replaced by healthy one (Lopes and Alves 2010; OECD 2013).

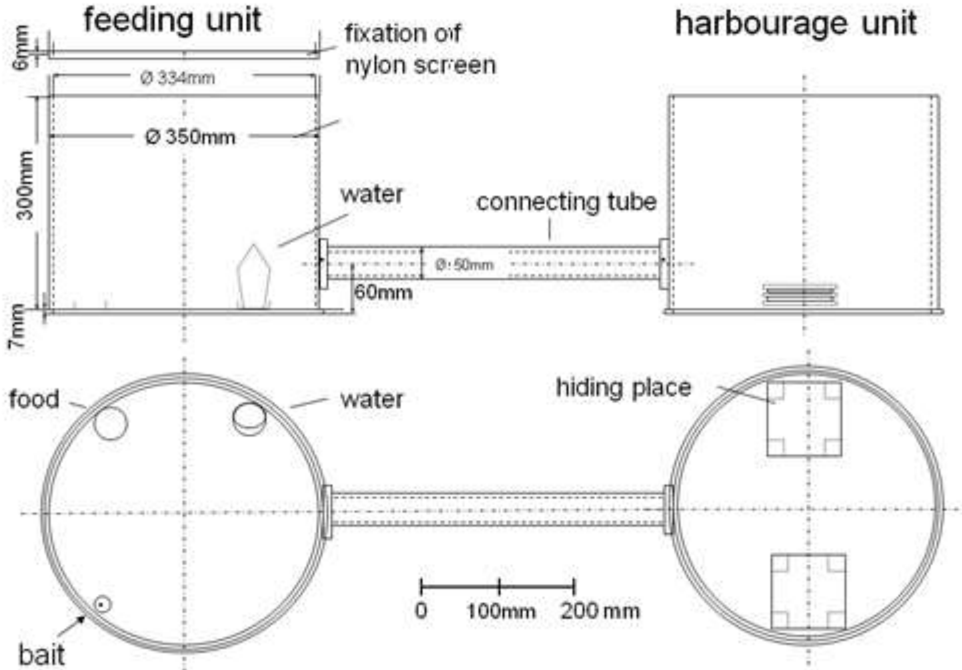

Figure 1: ***Harborages and feeding container layouts used for efficacy test of gel baits against B. germanica.***

Diets containing varying concentrations (% w/w) of active ingredients including 0.05% Fipronil, 0.5% boric acid and 2.15% hydramethylnon were pulverized to powder. Five gm of each formulation was later reconstituted with three ml acetone solution and six ml water. The resulting mixture was dried in a fume hood for 24 hours to yield pellet diets. After preparation, all test diets were stored at 5^0c for 24 hours before use in glass petri dishes lined with filter paper and containing moisture absorbing cotton balls. All baits were placed into a small Petri dish and introduced at the arena side opposite to the harborage. Besides, petri dish with purina dog chow and water were placed in the other arena and used as a control. Thus, cockroaches were allowed for a continuous exposure to the toxic diet and the control diet.

Mortality of cockroaches was checked daily for 14 days at an interval of six hours (6, 12, 18, 24, 30h…). Cockroaches were considered dead if they do not move, including paralysis of their legs when poked by a stick. Cockroaches that moved their legs even if they could not run away when flipped were not considered dead. Mortality counts were recorded separately for gender and maturity until all cockroaches die or the lethal time, LT_{50} and LT_{95} were determined. All of the tests were replicated four times in order to assure repeatability of the results. About, 800 cockroaches were used to test the three types of baits and the control.

Study design of field trial

In order to understand abundance and the contribution of the applied bait in the study and/or to supplement the result of the data obtained from the laboratory efficacy test, collection of adult cockroaches were carried out from the experimental and control facilities. Cockroaches were trapped during the night in empty jars covered with sticky materials of a thin film of Vaseline baited with a slice of bread soaked in attractants such as butter with banana and baking soda. The outer surfaces of the jars were covered with paper to allow the grasp of cockroaches as they climb up the sides of the jars. The sticky traps were placed in and around houses at different corners in the kitchens, toilets and bedrooms overnight. Especial attention was given to suspected places such as internal and external sides of cup-boards, kitchen furniture and fixtures, stoves, refrigerators and near-by dust bins. The number of cockroaches collected from each houses were recorded and used to compare the impact of the treatment among the experimental and control facilities. The collected cockroaches were killed by chloroform and preserved in vials containing 70% ethyl alcohol for identification. All the specimens collected from each breeding site were deposited in a labelled vial, transported to Addis Ababa (EPHI laboratory) for further laboratory test and stored in refrigerator maintained at −4 °C until prepared for laboratory test. Identification of cockroaches was then done using the procedures and keys described by Ross (1965). Furthermore, identified species were authenticated by an experienced entomologist from EPHI.

Collections of cockroaches were carried out once every month, in the middle of the night from 11:00 pm to 12:00 pm considering their tendency of nocturnal behaviour, after permission is granted from the head of household or owner of the facility. Monitoring of *B. germanica* cockroach population was done in 100 units of Restaurants, Bars and Dwelling homes in Hawassa town, which is located in Ethiopian rift valley region. Of these, 50 units (28 restaurants, 12 Bars and 10 dwelling homes) constituted to the treated (experimental) group, and the other 50 units (28 restaurants, 12 Bars and 10 dwelling homes) served for the untreated (control) group.

For pre-treatment counts of *B. germanica* cockroach populations, five sticky traps per unit were placed in a room with an average size of 16 m^2, in suspected sites where cockroaches were available and these places were also used for post treatment counts. The traps were picked up after three days and the number of cockroaches per trap was recorded. Basically, eight fipronil gel bait packs were placed in each room, with some additional gel bait packs placed according to room size and the degree of infestation. Post-treatment counts were carried out in the same way as pre-treatment counts. Evaluation was made every week for four consecutive weeks post-treatment. For field trial evaluation first, second, and fourth weeks post-treatment were recorded. All the counts made at the laboratory and field conditions were converted to the number of cockroaches per trap per day. Reduction rates were calculated using the formula:

% reduction = [(No. of pre-count - No. of post-count)/ No. of pre-count] × 100.

The numbers of B. germanica cockroaches were reduced spontaneously in untreated rooms (the control group) during the test period. Therefore, reduction rates in the treated group were corrected using the Abbot formula (Abbot, 1925):

Abbot Formula = [(% test mortality - % control mortality) / (100 - % control mortality)] × 100.

Data analysis

For efficacy test of the three gel baits, in daily observations beginning the day after insect release in the chambers, the dead individuals were counted, classified by age (nymphs or adults) and removed from the arenas. Numbers and age classes of lethally affected cockroaches were recorded cumulatively. If control mortality exceeds five percent in any specific developmental stage or gender, mortalities were corrected by control mortality using Abbott's formula (Abbott 1925). Efficacies of the formulations were then calculated as:

Efficacy = 100 * (t-c) / (100 c)

Where: t = % treated mortality; c = % control mortality

A significance level of $p = 0.05$ (two-sided testing) is usually considered sufficient performance standard. The same standard was accordingly used for the test. Efficacy is usually considered sufficient if 95% mortality rate– is recorded at the end of the test, with possibility of correction as per Abbott (1925) in a 'no-choice-test', and 90% in a laboratory 'choice-test' is achieved (SAS Institute 1990).

Results and discussion

Laboratory Efficacy test

The present study revealed highest efficacy of fipronil as compared with boric acid and hydramethylnon gel baits. Fipronil gel bait killed the cockroaches at a much faster rate, causing a shorter lifespan and high mortality of cockroaches (Figure 2). Fipronil gel bait eliminated all cockroaches after 14 days of insecticide application while the others did not. It did so in the shortest time of four days, where 100% mortality was achieved. The mortality rate curve indicates the rate of kill, which is especially important to determine how fast a treatment works. In this case, as shown in Figure 2, fipronil gel bait was proven to kill more than 74% (n=148) of the cockroaches in just one day (above LD_{50}), with 98.5% (n=197) mortality achievement in the third day (i.e. above LD_{95}). The control experiment demonstrated the validity of the efficacy test, as there was no significant effect of the testing condition on the mortality of the cockroaches. Therefore the other factors such as room temperature, container, food, water and harborage did not contribute to significant mortality of the cockroaches (Figure 2).

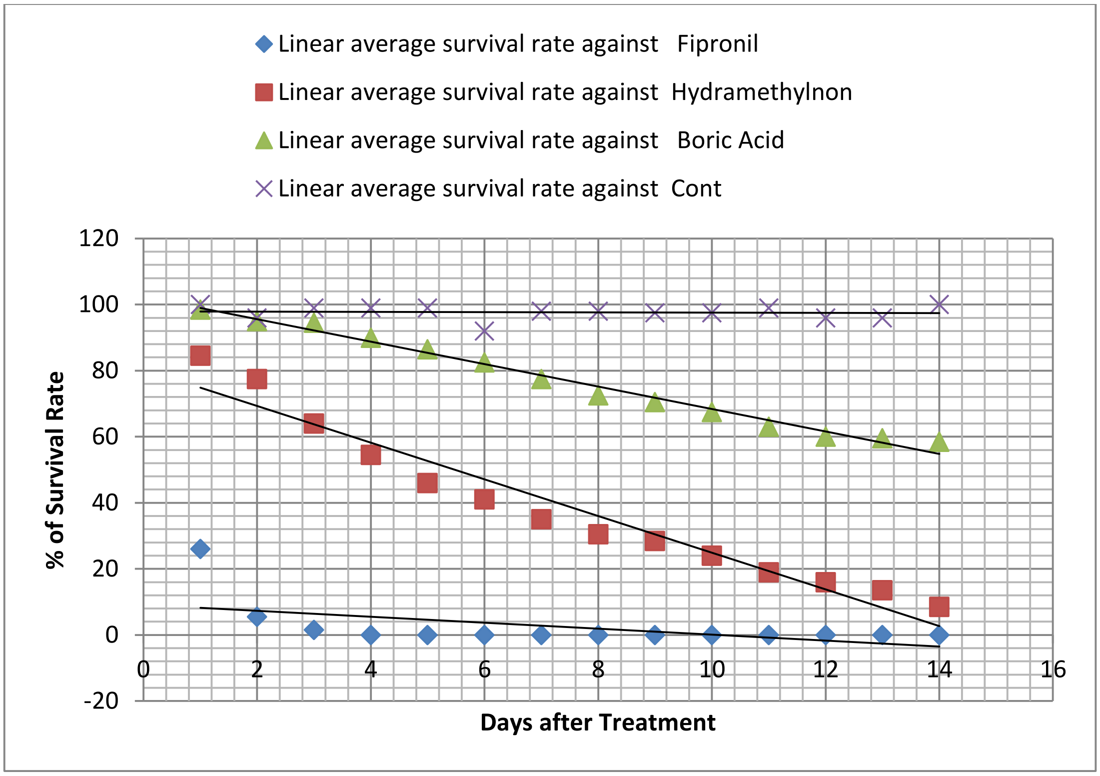

Figure 2: *Mean Survival rate of cockroaches (Blattella germanica) by day, treated with fipronil (Fipr), boric acid (BorA))and hydramethylnon (Hydr) baits and control (Cont), in the entomology laboratory of EPHI, from Sep to Oct 2019.*

The result of boric acid bait revealed 41.5% mortality after fourteen days of application, i.e. LD50 were not reached throughout the study period. This may be due to resistance, since boric acid was used for more than 20 years in Ethiopia. Whereas hydramethylnon gel caused 54% mortality within six days, thus, after five days LD50 were reached but LD95 were not reached up to the end of the study period (Figure 2). Overall, fipronil caused 100% mortality in adult males and females and 4th instars *B. germanica*, at the end of the three days test period. In general, feeding patterns of adults and nymphs differ markedly (DeMark, 1988), but active ingredient of the bait affect each stage differently (Reierson, 1995). This may be related to size differences, metabolism and physiology. Koehler et al. (1993) and Valles et al. (1996) have also shown that *B. germanica* nymphs are considerably more tolerant to insecticides than adult. The mechanism responsible for this phenomenon was due to enhanced detoxification (Valles et al. 1996). However, in this study, there was no any significant difference in susceptibility of the nymphal and adult stages of *B. germanica* to the insecticides.

Fipronil-induced mortality was significantly ($P < 0.5$) higher than those caused by hydramethylnon and boric acid. The highest percentage of mortality for control cockroaches until 14 days was 4% (Figure 2).

Difference in toxicity among fipronil, boric acid (chalk) and hydramethylnon bait against *B. germanica* was probably caused by differences in palatability (i.e., bait attraction and acceptance) of the bait. If the bait base is most attractive to the target insect species, some species specificity can be achieved so that risks to non-target organisms are reduced (Reid et al. 1990). Therefore, the use of toxic baits may be compatible with environmentally sound integrated pest management programs. Most insecticides are repellent to *B. germanica*, especially when offered in bait (Reierson 1995). However, based on the high percentage of mortality at the end of the 14 days test period, the three baits were not repellent to the tested cockroach species and some had good acceptance (i.e., fipronil and hydramethylnon in the bait attractant test). Good acceptance has also been reported for baits containing abamectin (Cochran 1985), sulfluramid and hydramethylnon (Reid et al. 1990).

Field trial: The field experimental group before poison baiting applied, a total of 392 cockroaches were collected from the three different kinds of facilities. The average percentage of cockroaches in 3 days collection was 22.7 (n=89) in restaurants, 58.4 (n=229) in bars and 18.9 (n=74) in dwelling home. Following fipronil bait application, the percentage of alive *B. germanica* cockroaches were reduced to 1.3 (n=5) in restaurants, 2.8 (n-11) in bars and 0.8 (n=3). in dwelling homes. rates within the three different types of facilities were 95.1% ($p<0.05$) after 4 weeks of fipronel treatment. Similarly, Kim et al. (1995) and Ree et al (1976) reported that the densities of German cockroaches in varied among different facilities In the control group, pre-sticky trap collection at the beginning a total of 388 cockroaches were collected from the three different kinds of facilities. The percentage of *B. germanica* cockroaches in 3 days collection were 24.2 (n=94) in restaurant, 53.4 (n=207) in bars and 22.4 (n=87) in dwelling home. At the end of the trial, in the control group the percentage of *B. germanica* cockroaches were collected in the three facilities stasticaly significant change were not observed, that is, the result showed reduction of 3.9% in restaurants and bars, besides 5.9% in dwelling homes. The total reduction rates within the three types of facilities were 13.7% (n=53) after 4 weeks (Table 1). The reduction of cockroaches in untreated facilities was probably resulted from three days of the sticky trap collections or other unknown factors. Generally, the result of reduction rate in the experimental and control groups were corrected by using the Abbot formula. Thus, the corrected overall reduction rate by using fipronil treatment after four weeks was 94.3% ($p<0.1$). Similarly, Ree et al. (1995) reported that a reduction of 93.1% in field trial with fipronil bait.

Table 1: ***Pre and post sticky trap collection of B. germenica in the control group at different facilities of Hawassa town after 4 weeks***

Facilities	Pre and post sticky trap collection of *B. germenica* in the control group				
	Pre-sticky trap collection		Post-sticky trap collection		Reduction of cockroaches in %
	No of cockroaches collected in 3 days	%	No of cockroaches collected in 3 days	%	
Restaurants	94	24.2	79	20.3	3.9
Bars	207	53.4	192	49.5	3.9
Dwelling homes	87	22.4	64	16.5	5.9
Total	388	100	335	86.3	13.7

Fipronil is an effective toxicant against *B. germanica* and has considerable potential for use in baits. However, additional research to test the resistance level of *B. germanica* against fipronil may be necessary to fully understand if there is unknown cross resistance occur in Ethiopia. In conclusion, the insecticidal properties of this compound make it well-suited for the control of cockroaches in Ethiopia.

Competing interests: The authors declare that they have no competing interests.

Acknowledgement: We would like to acknowledge ZERA PLC for financial support, supplying polypropylene packaging, fipronil gel bait and other types of insecticides for comparison purpose.

References

Abbott, WS (1925). A method for computing effectiveness of an insecticide. *Journal of Economic Entomology*, 18**:**265-267.

Appel AG (1990). Laboratory and field performance of consumer bait products for German cockroach *(Dictyoptera: Blattellidae)* control. *Journal of Economic Entomology*, 83: 153–159.

Appel AG (1992). Performance of gel and paste bait products for German cockroach control: laboratory and field studies. *Journal of Economic Entomology*, 85: 1176–1183.

Appel AG & Benson EP (1995). Performance of abamectin bait formulations against German cockroaches *(Dictyoptera: Blattellidae). Journal of Economic Entomology*, 88: 924–931.

Brenner RJ & Pierce RR (1991). Seasonality of peridomestic cockroaches (Blattoidea: Blattidae): mobility, winter reduction, and effect of traps and baits. *Journal of Economic Entomology*, 84: 1735–1745.

Cheng TH & Campbell FL (1940). Toxicity of phosphorus to cockroaches. Journal of Economic Entomology 33: 193–199. Cochran DG (1985). Mortality and reproductive effects of avermectin B1 fed to German cockroaches. *Entomologia Experimentalis et Applicata*. 37: 83–88.

Cole LM, Nicholson RA & Casida JE (1993). Action of phenylpyrazole insecticides at the GABA-gated chloride channel. *Pesticide Biochemistry and Physiology*, 46: 47–54.

Colliot FK, Kukorowski A, Hawkins DW & Roberts DA (1992). Fipronil: A new soil and foliar broad spectrum insecticide. *Brighton Crop Protection Conference (Pest and Diseases)*, Pp. 29–34.

DeMark JJ (1988). Effects of chitin synthesis inhibitors on nymphal and oothecal stages of the

German cockroach, Blattella germanica (L.). *M.S. thesis, Purdue University, West Lafayette, IN, (USA).* Pp 377

Frishman A (1982). Cockroaches. In: A. Mallis (ed.), *Handbook of Pest Control. 6th ed. Franzak and Foster, Cleveland, Ohio, USA*, Pp. 101–154.

Hagenbuch BE, Koehler PG, Patterson RS & Brenner RJ (1988). Peridomestic cockroaches (Orthoptera: Blattidae) of Florida: their species composition and suppression. *Journal of Medical Entomology*, 25: 377–380.

Hatton LR, Hawkins DW, Pearson CJ & Roberts DA (1988). Derivatives of N-phenylpyrazoles. *European Patent*, 295117.

Kaakeh, W & Bennett GW (1996). Speed of action in Siege and Maxforce gel baits (1995). In: A. K. Burditt (ed.), *Arthropod Management Tests, vol. 21. Entomological Society of America*. Pp 391-392

Kaku K & Matsumura F (1994). Identification of the site of mutation within the M2 region of the GABA receptor of the cyclodiene-resistant German cockroach. *Comparative Biochemistry and Physiology*, 108C: 367–376.

Kim MS, Yu HS & Kim HC (1995). Studies on relative densities of cockroach populations in 7 different habitats by using sticky traps in Suwon. *Korean Journal of Applied Entomology*, 34:391–405.

Koehler PG, Strong CA, Patterson RS & Valles SM (1993). Differential susceptibility of German cockroach (Dictyoptera: Blattellidae) sexes and nymphal age classes to insecticides. *Journal of Economic Entomology*, 86: 785.

Koehler PG, Atkinson TH & Patterson RS (1991). Toxicity of Abamectin to cockroaches (Dictyoptera: Blattellidae, Blattidae). *Journal of Economic Entomology*, 84: 1758–1762.

Lee DK (2002). Evaluation on the lethal choice and secondary effects of four insecticidal baits against the German cockroach (Blattaria, Blattellidae), *Korean Journal of Entomology*, 32: 107–112.

Litonjua AA, Carey VJ, Burge HA, Weiss ST & Gold DR (2001). Exposure to cockroach allergen in the home is associated with incident doctor-diagnosed asthma and recurrent wheezing. *Journal of Allergy Clinical Immunology*, 107:41–7.

Lofgren CS & Burden GS (1958). Tests with poison baits against cockroaches. *Florida Entomologist*, 41: 103–110.

Lopes RB & Alves SB (2005). Effects of Gregarina parasitism on the susceptibility of *Blattella germanica* to some control agents, *Journal of Invertebrate Pathology*, 88(3):261-264.

MacDonald RS, Annette GW & Kinoslita GB (1987). Control of German cockroaches, *Blattella germanica*, using hydramethylnon baits in an animal health facility. *Proceeding of Entomological Society, Ontario*, 118:7–12.

Moffat AS (1993). New chemicals seek to outwit insect pests. *Science*, 261: 550–551.

My J (1994). Nine new insecticides and acaricides. *Cultivar-Paris*, 357: 57–58.

OECD (Organization for Economic Co-operation and Development) (2013). 10-Jan-2013 ENV/JM/MONO (2013) 3. Pp 385-389.

Patterson RS & Koehter PG (1989). Peridomestic cockroaches' suppression with hydramethylnon bait. *Journal of Agricultural Entomology*, 6:37–42.

Ree HI, Hong HK, Shim JC, Lee JS & Yoon YH (1976). Studies on Korean *Blattaria* (IV) Population density of cockroaches at different habitats in Seoul city and Kwangju city, *Report NIH Korea*. 13:167–171.

Ree HI, Lee DH, Lee IY & Jeon SH. (1995). Field trial on control effect of poison baits against German cockroaches (*Blattella germanica*). *Korean Journal of Entomology*. 25:219–223.

Reid BL, GW Bannett & Barcay SJ (1990). Topical and oral toxicity of sulfluramid, a delayed-action insecticide, against the German cockroach (Dictyoptera: Blattellidae). *Journal of Economic Entomology*, 83: 148–152.

Reierson DA (1995). Baits for German cockroach control. In: JM. Owens, M. K. Rust and D. A. Reierson (eds.), Understanding and Controlling the German cockroach. Oxford University Press, Oxford, Pp. 231–265.

Rosenstreich DL, Eggleston P, Kattan M, Baker D, Slavin, RG, Gergen P, et al. (1997). The role of cockroach allergy and exposure to cockroach allergen in causing morbidity among inner-city children with asthma. *The New England. Journal of Medicine*, 336: 1356.

Ross HH (1965). A textbook of Entomology. Third ed. New York, NY: J. Wiley & Sons; 1965. Cockroaches. Google Scholar A Textbook of Entomology 3rd Edition Herbert H. ISBN 10: 0471736937 / ISBN 13: 9780471736936

Roth LM & Willis ER. (1957). Medical and veterinary importance of cockroaches, *Smithsonian Miscellaneous Collection*, 134 (10): 9-21.

Rueger ME & Olson TA (1969). Cockroaches as vectors of food poisoning and food infection organisms. *Journal of Medical Entomology*, 6: 185.

Rust MK (1986). Managing household pests. In: Bennett GW & Owens JM (eds.), Advances in Urban Pest Management. Van Nostrand Reinhold, New York. Pp. 335–386.

SAS Institute (1990). SAS User's Guide: Statistics. SAS Institute, Cary, NC, USA.

Sitthicharoenchai D, Chaisuekul C & Lee C-Y (2006). Field evaluation of a hydramethylnon gel bait against German cockroaches (Dictyoptera: Blattellidae) in Bangkok, Thailand. *Medical Entomology and Zoology*, 57: 361–364.

Stejskal V, Lucas J & Aulicky R (2004). Speed of action of 10 commercial insecticidal gel-baits against the German cockroach, *Blattella germanica. International Pest Control*, 46: 185–9.

Valles SM, SJ Yu & Koehler PG (1996). Biochemical mechanisms responsible for stage-dependent propoxur tolerance in the German cockroach. *Pesticide Biochemistry and Physiology*, 54: 172–180.

Wang C, Scharf EM & Bennett GW (2004). Behavioral and physiological resistance of the German cockroach to gel baits. *Journal of Economic Entomology*, 97:2067-72.

Whyatt RM, Camann DE, Kinney PL, Reyes A, Ramirez J, Dietrich J, et al. (2002). Residential pesticide use during pregnancy among a cohort of urban minority women. *Environmental Health Perspectives,* 110: 507–14.