Insecticidal efficacy of several boric acid formulations against the German cockroach, *Blattella germanica*

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Abstract: The efficacies of several formulations containing boric acid were tested against an insecticide susceptible strain (Watarida strain, abbr. SS) and field collected colony (abbr. field colony) of the German cockroach *Blattella germanica*. An arena treated with more than 400 mg/m\(^2\) of powdered boric acid or greater than 0.4% aqueous solution showed 100% mortality under laboratory conditions against the SS and the field colony. When the boric acid powder was mixed with powdered sugar and rice bran as food additives, the mortality increased compared with boric acid alone. Accumulated mortalities for a tablet bait formulation with more than 0.4% active ingredient against both colonies, and for gel bait formulations greater than 0.8% against the SS were lower compared with the powder or aqueous solution formulations. Harborages treated with 0.5% and 2% boric acid aqueous solutions in both colonies and 4% solutions for the field colony showed insufficient mortalities. The tested cockroaches may not intake boric acid because boric acid rapidly crystallizes as the solution dries. Direct spraying of 2% aqueous solution into the arena was less effective than the aqueous solution for the same reason. Overall, the boric powder is recommended for practical use because of high efficacy even for the field colony. When 12% boric acid powder aerosol was sprayed around a restaurant kitchen, German cockroach infestations were repressed for at least two months. Treatment of boric acid powder to the floor and the cracks and crevices is an adequate method for controlling German cockroaches in the field.

Key words: male German cockroach, boric acid formulations, gel formulation, aqueous formulation, laboratory and field test, field collected colony

**INTRODUCTION**

The German cockroach *Blattella germanica* (L.) has developed high levels of insecticide resistance against organophosphates and pyrethroids (Takayama et al., 1995; Yamada, et al., 1997) in Japanese urban environments. In addition, behavioral resistance or aversion to gel baits of hydramethylnon and fipronil in field collected German cockroaches has been reported (Silverman and Ross, 1994; Bao and Macom, 2005). Some formulations containing boric acid as an active ingredient have been used for several decades to control cockroaches. Ebeling et al. (1967, 1968), Tsuji and Ohno (1969), Moore (1972) and Tabaru et al. (1974) reported the efficacy of tablets or granulated boric acid formulations against susceptible German cockroaches. Boric acid is effective as a stomach poison without repellency, but is slow acting. Hirao (2000)
reported adequate efficacy of boric acid gel bait formulations against a susceptible strain. However, boric acid formulations are not in major use for controlling the German cockroach in Japan due to slow action and lack of market distributions of these formulations. There are few reports comparing the efficacy of boric acid formulations using field collected German cockroaches in Japan. The objective of the research presented here was to demonstrate the advanced use of boric acid formulations for controlling cockroaches.

MATERIALS AND METHODS

Cockroaches

The German cockroach *B. germanica* was the Watarida strain, a standard insecticide susceptible strain in Japan (SS strain), and a Kameido colony (field colony) collected on April 2006 from a restaurant in a high-rise building in Kameido, Kohto-ku, Tokyo reared in our laboratory. The third generation from the original colonies was used in the experiments. More than 90% of the colony survived after release for 48 hrs on filter papers (95 cm²) treated with 1,000 mg (a.i.)/m² of fenitrothion EC and chlorpyrifosmethyl EC (Watabe, et al., in press). Throughout the test periods the cockroaches were maintained under 14L:10D photoperiod of approximately 27°C and 75% RH. They were fed dried mouse chow (Oriental Kobo Co., Ltd.) and water. Only male adults were used for tests to avoid complications of reproduction during the test periods.

Test arena and harborage

Box type plastic arenas (35 cm × 25 cm, 25 cm high) were used for the tests. Liquid paraffin was spread along the upper part of the inner wall of the arena to prevent cockroaches from escaping. A harborage made of two 5 cm × 5 cm plywood panels with a single 5 mm void was used for resting. The harborage, water and other test materials were set at the center of the arena. Water was provided in cotton filled plastic tubes (30 mm diameter, 45 mm high) during test the periods.

Test formulations

A 100% boric acid powder (an ophthalmic medical use ortho-boric acid was supplied by Kenei Pharmaceutical Company, Osaka) was used directly, mixed with food materials, or dissolved in water. The following formulations were prepared.

*Boric acid powder* (PF): the boric acid was directly used.

*Boric acid powder mixed with food materials* (MPF): boric acid mixed with rice bran or powdered sugar and also mixed with all three, in equal amounts including boric acid and blended with a food mill (Tescom 16, Tescom Co., Ltd.) of 20,000 rpm for 5 minutes. The active ingredient (boric acid) was 250 mg/m² in each formulation.

*Aqueous solution* (AQ): boric acid was dissolved from 0.1% to 3.2% (w/v) in water at room temperature. Boric acid can dissolve 6% in water at 25°C (The Japanese Pharmacopeias, 15 edition).

*Aqueous solution* (AQ) floor spray test: A 2% AQ was directly sprayed onto the surface of the arena.

*Tablet formulations* (TAB): After mixing of each inactive ingredient; corn starch, onion powder and glycerin at 70%, 15% and 15% by weight, the boric acid was mixed at 0.2% to 3.2%. Subsequently each mixture was spread at 3 mm thickness and cut into 3 cm diameters (ca 2 g) to the make TAB. TAB was then set in plastic cups (3 cm diameter, 5 mm depth).

*Gel bait formulation* (GEL): 1% of ultra suction high molecular compound (Kenis Co., Ltd., Osaka) was mixed with aqueous formulations of boric acid. Each GEL contained 0.2%, 0.4%, 0.8% or 1.6% (w/w) of boric acid.

*Boric acid treated harborage* (HRB): The test harborage were treated with 0.5%, 2.0% or 4% (w/v) boric acid aqueous solutions. The harborage were dipped in aqueous solution for 5 min and dried for 24 hr at room temperature. Quantities of
boric acid in each harborage were not measured.

*Boric acid powder aerosol*: a 12% boric acid powder aerosol (commercial product) was used in the field tests.

**Test methods**

1. **Laboratory tests**

Twenty male cockroaches were released and kept in the test arena with mouse chow, water and harborage one day for taming before treatments. The next day the old food, water and harborage were removed from the arena. Then the test material, water, food or harborage were set in the arena. In the AQ direct spray test cockroaches were released after the solution dried.

The floor of the arena was uniformly treated with PF at a density of 100 mg (a.i.), 200, 400 or 800 mg/m² of boric acid after removal of the food, water and harborage. Then fresh water, mouse chow and harborage were placed in the center of the arena. The arena was treated with MPF at 250 mg (a.i.)/m² under the same conditions as PF.

A plastic bottle (30 mm diameter, 50 mm high) was filled with AQ (20 ml) and stopped with cotton. The bottle was set at the center of the arena with mouse chow and harborage. In the AQ test, boric acid-free drinking water was removed from the arena in order to compel cockroaches to intake the toxic AQ.

A 2% aqueous solution (AQ) was directly sprayed onto the surface of the arena at a rate of 3.5 ml with a glass atomizer (100 ml capacity, Maruhachi Industrial Ltd. Minato-ku, Tokyo). This quantity was nearly equal to 40 ml/m² (a.i. 800 mg/m²) in the test arena. The AQ was dried at room temperature for 24 hours, and then cockroaches were released into the arena. In addition the PF treatment of 800 mg/m² and the AQ treatment at the same dosage were compared for the SS and the field colony. A small plastic cup containing ca 2 g GEL was set in the center of the arena with food and harborage. In the GEL test water was removed because the GEL contained water. TAB (ca 2 g) was

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**Table 1. Test formulations, combinations and arrangement of materials in each treatment.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Placement of boric acid</th>
<th>Mouse chow</th>
<th>Boric acid treated harborage</th>
<th>Boric acid free harborage</th>
<th>Drinking water</th>
<th>Sugar</th>
<th>Rice bran</th>
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<tbody>
<tr>
<td>PF</td>
<td>Floor in arena</td>
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<td>*MPF</td>
<td>Floor in arena</td>
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<td><strong>MPF</strong></td>
<td>Floor in arena</td>
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<td>***MPF</td>
<td>Floor in arena</td>
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<td>AQ drink</td>
<td>Drink water</td>
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<tr>
<td>AQ spray</td>
<td>Floor in arena</td>
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<td>TAB</td>
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<td>GEL-choice</td>
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<tr>
<td>HAB</td>
<td>Harborage</td>
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</tr>
</tbody>
</table>

PF: powder treatment, MPF: mixed powder treatment (mixed with *sugar, mixed with **rice bran or ***mixed with both), AQ drink: aqueous solution of boric acid, AQ spray: aqueous solution sprayed on floor, TAB: tablet bait treatment, GEL-choice: gel bait and with mouse chow, GEL-no choice: gel bait only, HAB: treated harborage.

The v indicates the materials placed in the arena. The mouse chow (tablets) was set in small plastic cups. The drink water was put in a plastic tube with cotton. Harborage was 5 cm × 5 cm, single 5 mm void. The mouse chow, water and harborage were set at the center of the arena.
set in small plastic cups and placed at the center of the arena with water, food and harborage. The TAB test was conducted by two methods: a non-choice test (only boric acid used) and a choice test between boric acid and mouse chow. HRB was set at the center of the arena after the old harborage was removed.

Each test was repeated twice. Dead cockroaches were counted every day or every few days and then removed from the arena. Table 1 shows the arrangements and combinations of test materials in each treatment. In the AQ, PF and HRB tests, the SS and field colonies were used, whereas the other tests were conducted with only the susceptible strain.

2. Field trial
A field trial was conducted from March through August 2007 in a restaurant at the same location where the field colony was collected. A 12% boric acid powder (aerosol) was used to confirm the efficacy of boric acid in the field and also to resolve the limited success of cockroach control with organophosphate insecticides. A restaurant kitchen with 75 m² floor was selected for spraying. The cockroach indices in two trials before insecticide treatment were estimated to be 44.1 and 38.8 (mean: 41.5) as determined by trapped cockroach numbers / (5 traps × setting days). The insecticides were applied on March 23. Two bottles of 300 ml boric acid powdered aerosol was sprayed onto the surface of kitchen cabinets, gas ranges and refrigerators, into the gaps between cupboards and food storages, and onto space under the counter tables. The total amount of boric acid (a.i.) applied was estimated to be 72 g. After insecticide treatment, the cockroach infestations were evaluated five times for 3 months by collection with sticky traps. The sticky traps were set at the same 5 points for one week each time.

![Fig. 1. Accumulated mortalities of male cockroaches with boric acid powder. Numbers in legends indicate mg/m² of boric acid.](image)

![Fig. 2. Accumulated mortalities of male cockroaches with boric acid powder or powder mixed with sugar, rice bran or all of three. The boric acid was treated 250 mg/m² in each treatment.](image)

RESULTS AND DISCUSSION

1. Laboratory tests
   PF and MPF tests
Figure 1 shows the results of the PF tests. The Susceptible strain (SS) and the field colony were almost all killed by day 3 with application of 400 mg/m² or more. The sufficient mortality for the field colony was slightly delayed with 100 mg/m² and 200 mg/m² compared to the SS. At day 6 no cockroaches survived even with 100 mg/m² for the SS and the field colony. There is not sufficient evidence that the field colony developed resistance to boric acid.

The complete kill slightly increased when the boric acid (250 mg/m²) was mixed with food materials (MPF) in SS, compared with 400 mg in the PF test for
Fig. 3. Boric acid particles (left) around mouthparts of a cockroach (arrow), and crystallized boric acid (right) on the surface of an arena after spraying the aqueous solution (AQ).

Fig. 4. Accumulated mortalities of male cockroaches with aqueous solution in the drinking water against male cockroaches. Numbers in legends indicate concentrations (%) of boric acid. SS and Field indicate the standard susceptible strain and field collected colony.

The tested cockroaches may intake more boric acid from the MPF than the PF. The rapid effects obtained with PF and MPF indicate cockroaches must have taken a larger quantity of boric acid through grooming after contacting the boric acid. A small amount of the boric acid clung to their antennae, mouthparts and tarsi as a result of walking around the treated surface (Fig. 3, left-upper corner). Ebeling et al. (1967, 1968), Tsuji and Ono (1969), Tabaru et al. (1974) and Cornwell (1976) emphasized the non-repellent action, but slow efficacy when tablets or granule formulations of boric acid were applied against susceptible German cockroaches. However, treatments with the PF or the MPF on the surface of the arena were very effective and rapid compared to tablets or granule formulations.

AQ test

Test cockroaches were compelled to drink the AQ because there was no other source of water in the arena. Fig. 4 shows the results with the AQ test. The SS and the field colony were almost all killed by
day 3 with a 3.2% of boric acid and the most effective formulation was 400 mg/m² as also seen in the PF. Sufficient mortality was delayed to 9 days with 0.2% and 0.4% formulations. A 0.1% AQ was not sufficient to kill both the SS and the field colony. The boric acid crystallized around the water bottle by wandering of contaminated cockroaches after drinking the AQ. When the PF was compared with AQ direct spraying onto the surface of the arena at the same dosage 800 mg/m² the mortality changed: 100% for the PF and 12.5% for the AQ against the SS strain, and 100% and 7.5% against the field colony at 72 hrs (Table 2).

Tabaru and Koseki (2004) demonstrated that the secondary effect of hydramethlnon gel bait formulations was introduced by environmental contamination after crawling of contaminated cockroaches. However, the results of AQ direct spray test was not sufficient due to crystallization of boric acid on the treated surface. The crystallized boric acid rapidly adhered to the surface (Fig. 3, right) and remained there even after cockroaches walked on the surface. The efficacy of AQ seems to predominantly occur when cockroaches drink the AQ, but not by contact with crystallized boric acid. The AQ treatment may not be effective in the fields because cockroaches easily encounter water, and the boric acid crystallizes after spraying.

Table 2. Differences in efficacy of residual treatment between powder boric acid (PF) and aqueous formulation (AQ) against the SS strain and field colony of German cockroaches.

<table>
<thead>
<tr>
<th>Test formulations</th>
<th>Test colonies</th>
<th>Mortality (%)</th>
</tr>
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<tbody>
<tr>
<td>PF</td>
<td>SS</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Field colony</td>
<td>100</td>
</tr>
<tr>
<td>AQ</td>
<td>SS</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>Field colony</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Boric acid dosage in the arena was 800 mg/m² for both formulations. SS: a susceptible standard strain in Japan. Field colony was collected from a restaurant in Kameido, Tokyo, Japan.

Fig. 5. Accumulated mortality of tablet formulations with no-choice (tablet only) and choice (together with mouse chow) against the susceptible strain. Numbers in legends indicate concentrations (%) of boric acid.
**TAB test**

Figure 5 shows the results with TAB for the SS strain. In these trials both no choice and choice tests were performed. In the choice test cockroaches could select either mouse chow or the poison baits. Since the insecticidal effect increased at the higher concentrations, there were no differences in the efficacy between the two trials, suggesting no repellent activity for the boric acid. All of the cockroaches died at day 12 with 0.4% or more boric acid. However, 40% of cockroaches survived with 0.2% boric acid in both tests. These delayed insecticidal effects with TAB may be due to a limited uptake of boric acid only through the mouthparts. Tsuji and Ohno (1969) and Tabaru et al. (1974) reported the efficacy of solid boric acid against the susceptible strain. They concluded that the efficacy of boric acid was recommendable, but slow. The results of the TAB test in the present study were very similar to their results. Boric acid concentrations greater than 0.8% are recommended for practical applications with the baits.

**GEL test**

Figure 6 shows the results of the GEL for the SS. The cockroaches were all killed with 1.6% GEL at day 5, and 92% killed with 0.8% at day 8. However, the mortalities were not sufficient with 0.2% and 0.4%. Thirty percent of cockroaches survived at 0.4% and 50% at 0.2% on day 8. The efficacy of the GEL was inferior to the AQ drink even at the same concentration; 70% mortality in 0.4% for the former and 100% with the same concentration at day 8 for the latter in the SS. The different activities between the AQ and the GEL were not clear. Hirao (2000) reported the efficacy of commercial gel baits (a.i. 15% or more) of boric acid; 100% mortality was obtained around one week after application.

Since gel formulations have an advan-

![Fig. 6. Accumulated mortalities of male cockroaches with gel bait formulations. Numbers in legends indicate concentration (%) of boric acid against susceptible strain.](image)

![Fig. 7. Accumulated mortalities of male cockroaches released in the boric acid treated harborage. Numbers in legends indicate concentrations (%) of boric acid against susceptible strain or field colony.](image)
obtained good effects in harborage treatments with propetamfos MC against the field colony. However, crystallized boric acid in the harborage was not effective even when the cockroaches stayed there for long periods.

The laboratory results can be summarized; boric acid may be more effective when applied onto the floor as powder (PF) or powder mixed with food materials (MPF) than other formulations, and these formulations are effective for both the SS and the field collected colony. The aqueous formulation is not recommended because crystallization occurs.

2. Field trial

Figure 8 shows the results of field trials. Cockroach infestations dramatically decreased after spraying with a 12% boric acid powder aerosol. The mean cockroach index was 41.5 before treatment, and 4.9 after two weeks, 3.0 after one month and 14.5 after two months. The reduction rate (100-after treatment/before treatment×100) was calculated to be 88.2%, 92.8% and 65.1%, respectively. In the same restaurant a limited success in cockroach control was attained with organophosphate insecticides. This field trial was the first attempt in the past several years. The boric acid powder aerosol formulation may be a substitution for organophosphate compounds after development of organophosphate resistance in cockroach populations.

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