Toxicity and Repellency of Borate-Sucrose Water Baits to Argentine Ants (Hymenoptera: Formicidae)

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ABSTRACT The oral toxicity of boron compounds to the Argentine ant, *Linepithema humile* (Mayr), was evaluated in laboratory tests. The ants were provided 25% sucrose water containing 0.5 and 1% boric acid, disodium octaborate tetrahydrate, and borax. Lethal times of these solutions were a function of the concentration of boron. In field tests, the ants showed no discrimination between disodium octaborate tetrahydrate and boric acid. There was a significant reduction in consumption of sucrose water with >1% boric acid.

KEY WORDS *Linepithema humile,* ant baits, borates

BORON CONTAINING COMPOUNDS such as borax (sodium tetraborate decahydrate) and boric acid have been used since the early 1900s against ants (Rust 1986). Our studies with sucrose water containing boric acid for control of household ant pests have demonstrated that at low concentrations (<1%) boric acid is slow-acting and nonrepellent thereby enhancing long-term ingestion (Klotz and Moss 1996, Klotz et al. 1997). The delayed activity of boric acid promotes a thorough distribution of the active ingredient within the nest, leading to death of the entire colony (Stringer et al. 1964, Klotz et al. 1996).

Commercial ant baits with boric acid or borax as an active ingredient typically use concentrations of ≥5%. For example, Niban (Nisus, Rockford, TN) and Bushwhacker (Bethurum Research and Development, Galveston, TX) granular baits use 5 and 18% boric acid, respectively; and Terro Ant Killer II (Senoret Chemical, Kirkwood, MO) liquid bait uses 5.4% borax. The new liquid ant baits being developed use much lower concentrations of boric acid. Drax Liquidator (Waterbury Companies, Waterbury, CT), Dr. Moss's Liquid Bait System (JT Eaton, Twinsburg, OH), and Advance Liquid Ant Bait (Whitmire Micro-Gen, St. Louis, MO) use 1% boric acid in sucrose water. Another borate, disodium octaborate tetrahydrate, has been formulated at 1% in a sweet liquid bait, VG AB 3 (EPA registration pending), for use against carpenter ants (Wegner 1998).

Our two objectives in this study with Argentine ant, *Linepithema humile* (Mayr), were to (1) compare the oral toxicities of low concentrations of boric acid, borax, and disodium octaborate tetrahydrate; and (2) test for a feeding preference between disodium octaborate tetrahydrate and boric acid and for different concentrations of boric acid. Results of this study may help optimize development of boron liquid bait formulations for controlling ants.

Materials and Methods

Toxicity Tests. Argentine ants were collected from a citrus grove on the Riverside campus, University of California (Riverside County). The ants were provided water but no food for 1 d before bait exposure. Concentration-mortality was determined with procedures described by Klotz et al. (1998). Crystalline boric acid and anhydrous borax (99% [AI]; Sigma, St. Louis, MO), and TIM-BOR (98% disodium octaborate tetrahydrate; U.S. Borax, Valencia, CA) were dissolved in 25% (wt:vol) sucrose-deionized water solutions to produce two concentrations (0.5 and 1%) of each boron compound. Bait solutions were added to cotton plugs daily inside small petri dishes with 10 ants. Treatments and controls (25% sucrose-deionized water) were replicated five times. The bait solutions were available continuously to the ants for the duration of the test. Daily observations on cumulative mortality were recorded for 5 d.

Preference Tests. Binary choice tests were designed to determine feeding preferences of the ants on different solutions. The consumption of solutions delivered to the ants in side-by-side feeding stations attached to trees was used to measure preference. Feeding stations were constructed from 50-ml capped centrifuge tubes by drilling a 2-cm-diameter hole through a 3.2-cm-diameter cap. A 4.5-cm square of WeedBlock (Easy Gardener, Waco, TX), a porous plastic material through which the ants could drink, was centered over the top of the centrifuge tube filled with solution and the cap screwed down to secure it in place. The bait stations were inverted and taped at eye level to the trunks of trees containing foraging trails of Argentine ants. To test their preference between 1% disodium octaborate tetrahydrate and 1%

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Table 1. LT_{50} values for *L. humile* workers fed boron compounds in 25% sucrose water

Treatment	% concn	LT_{50} (95% CL), d	Slope ± SE	No. of ants	χ^2	*P*
Boric acid	0.5	2.4 (2.1–2.6)	6.7 ± 1.7	50	0.49	0.52
Boric acid	1.0	1.2 (1.0–1.4)	5.0 ± 0.6	50	6.64	0.20
Disodium octaborate tetrahydrate	0.5	2.2 (1.8–2.9)	3.0 ± 0.7	50	1.24	0.73
Disodium octaborate tetrahydrate	1.0	1.3 (1.1–1.5)	5.7 ± 0.9	50	1.38	0.76
Borax	0.5	2.3 (2.1–2.6)	6.7 ± 1.2	50	9.56	0.24
Borax	1.0	1.1 (0.9–1.3)	5.0 ± 0.9	50	1.14	0.71

boric acid (both in 25% sucrose water), tubes of each solution were taped next to each other on each of 15 trees.

A similar test with 10 trees each was conducted for sodium (Na^+) and pH preference in solutions containing equal concentrations of boron. When disodium octaborate dissolves in water the following reaction occurs:

$$Na_2B_8O_{13} \cdot 4\ H_2O_{(DSOBTH)} + 9\ H_2O \rightarrow 2Na^+ + 2OH^- + 8\ H_3BO_{3(boric\ acid)}$$

Because of the differences in molecular weight, a 1% (10 g/liter) solution of disodium octaborate tetrahydrate is equivalent to a 1.2% boric acid solution with 1.9 g/liter of NaOH added. Boric acid solutions were prepared with NaOH and NaCl, to equal the boron and Na^+ content of 1% disodium octaborate tetrahydrate solutions. All solutions were prepared in 25% sucrose water. The boric acid solution with NaCl (2.8 g/liter) was used to study the relative effects of Na^+ and pH preference. This solution had a pH that was similar to the boric acid solution (≈4.7), but had the same Na^+ concentration as the solution with NaOH. The boric acid + NaOH solution had a pH and Na^+ concentration that were similar to the 1% disodium octaborate tetrahydrate (≈7.7).

To test for discrimination (preference test) of different concentrations of boric acid in sucrose water, each boric acid solution (0.5, 1.0, 2.0, and 4.0%) was paired with a control containing only sucrose water. Each concentration was replicated on 10 trees. All test solutions and controls used in these studies contained 25% sucrose in deionized water (wt:vol).

The ants were allowed to feed on the various solutions for at least 24 h after which the amount consumed by the ants in each of the vials was recorded. Consumption was determined gravimetrically with 1% boric acid and disodium octaborate tetrahydrate. Consumption was determined volumetrically in the other preference tests and standardized in milliliters per hour by dividing the total volume consumed by the number of hours the ants were allowed to feed.

Statistical Analysis. Mortality data were corrected with Abbott's (1925) formula and analyzed by probit analysis (Raymond 1985) to determine lethal times (LT_{50}) for each concentration. The value of chi square was used to measure the goodness-of-fit of the probit regression line. Binary choice tests to determine feeding preferences of ants for different solutions were analyzed using a paired *t*-test comparison (StatView 1992). Regression analysis was performed on LT_{50}'s of the different borates as a function of boron concentration (Grapher 1996).

Results and Discussion

The time required to kill 50% of the workers of *L. humile* (LT_{50}) decreased with increasing concentration of the three boron compounds, indicated by nonoverlapping 95% CL (Table 1). Anhydrous borax, boric acid, and disodium octaborate tetrahydrate are 21.5, 17.5, and 21% boron by weight, respectively. When the compounds are expressed in boron equivalents, the LT_{50} values are a function of the boron concentration (Fig. 1). The log-linear relationship between LT_{50} and boron concentration for the different compounds was highly significant ($P < 0.01$) with an $r^2 = 0.94$.

Based on the consumption rates of 1% boric acid and disodium octaborate tetrahydrate in sucrose water

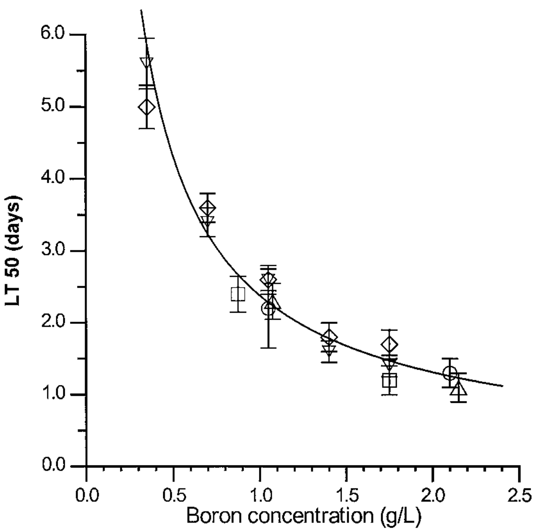

Fig. 1. Comparison of the relative toxicity of boric acid, disodium octaborate tetrahydrate (DSOBTH), and anhydrous borax to Argentine ants. The relationship between LT_{50} and boron concentration was log-linear and highly significant ($P < 0.01$). [□] Boric acid in 25% sugar water (this study), [○] DSOBTH in 25% sugar water (this study), [△] anhydrous borax in 25% sugar water (this study), [◇] boric acid in 25% sugar water (Klotz et al. 1998), [▽] boric acid in 10% sugar water (Klotz et al. 1998), — $\log(Y) = -0.83 * \log(X) + 0.85$ ($r^2 = 0.94$). Error bars are 95% CL.

Table 2. Consumption rate (ml/h) of Argentine ants feeding on 25% sucrose water and 25% sucrose water + boric acid solutions when ants were given a choice (10 trees per treatment)

Concn of boric acid, %[a]	Treated (mean[b] ± SE)	Control (mean[b] ± SE)
0.5	0.123 ± .019a	0.085 ± .016a
1	0.255 ± .034a	0.297 ± .059a
2	0.059 ± .009a	0.143 ± .018b
4	0.017 ± .008a	0.236 ± .040b

Means within a row followed by the same letter are not significantly different ($P = 0.05$, paired *t*-test comparison [StatView 1992]). NS, not significant.

[a] %, wt:vol.

placed side-by-side in the binary choice test, we could detect no preference (i.e., no significant difference) by the ants for either solution (paired *t*-test, 1.22, df = 14, $P = 0.24$). When the pH is made approximately equivalent for the two solutions by the addition of NaOH, no preference was shown by the ants for either solution (paired *t*-test, −1.46, df = 9, $P = 0.18$). Similarly, no preference was shown for solutions with different pH but equal Na^+ concentration when NaCl was added to the boric acid solution (paired *t*-test, −0.96, df = 9, $P = 0.36$). Although there is no toxicological difference or feeding preference between boric acid and disodium octaborate tetrahydrate that would make one better than the other, one advantage to disodium octaborate tetrahydrate is that it dissolves rapidly in water making it easier to formulate water soluble baits. All solutions made from boric acid or borate salts have in common the boron existing as uncharged boric acid molecules at pH < 8.

Consumption of sucrose water was significantly higher than consumption of the >1% boric acid solutions indicating unpalatibility of boric acid at 2 and 4% (Table 2). Likewise, in a consumption test conducted in the laboratory with *Solenopsis invicta* Buren, feeding on solutions of 0.25, 1, and 5% boric acid in 10% sucrose water there was a significant reduction in the amount of the 5% solution consumed (Klotz et al. 1997). Therefore, to avoid repellency in liquid baits with boron compounds as an active ingredient formulations should use ≤1%.

Although there is little information available concerning the physiological mode of action of borax and boric acid on insects (Rust 1986), it has been shown that borate ions form strong complexes with sugar alcohols, such as inositol, and other organic functional groups (Williams and Atalla 1981, Woods 1994, Hu et al. 1997). In addition, boron may be involved in the disruption of intercellular adhesion because saturated boric acid solutions can be used to dissociate cells (Goodrich 1942).

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