Toxicity of a Boric Acid–Sucrose Water Bait to *Solenopsis invicta* (Hymenoptera: Formicidae)

JOHN H. KLOTZ,[1] KAREN M. VAIL,[2] AND DAVID F. WILLIAMS

Center for Medical and Veterinary Entomology, USDA–ARS, Imported Fire Ant and Household Insects Research Unit, 1600 S.W. 23rd Drive, Gainesville, FL 32608

J. Econ. Entomol. 90(2): 488–491 (1997)

ABSTRACT Boric acid–sucrose water baits were evaluated in the laboratory for toxicity, consumption, and efficacy against the red imported fire ant, *Solenopsis invicta* Buren. Over the dosage range from 0.02 to 1.0% boric acid, LC_{50}s (95% CL) ranged from 1.27% (1.05–3.88%) at 3 d to 0.11% (0.09–0.13%) at 8 d. Amount of bait consumed was related inversely to the concentration of active ingredient. High concentrations of boric acid bait (5%) were consumed at a lower rate than the control (10% sucrose water). In large fire ant colonies exposed continuously to 4 concentrations (0.25, 0.5, 0.75, 1.0%) of boric acid bait, workers and brood were reduced by 90% at 6 wk. Therefore, low concentrations of boric acid are necessary for delayed toxicity and reduced repellency.

KEY WORDS *Solenopsis invicta*, pest ants, bait avoidance, boric acid

BORIC ACID IS an age-old insect poison which has been used in ant baits since the late 1800s and early 1900s (Riley 1889, Rust 1986). Advantages of this compound in pest control are its relatively low toxicity to mammals with an oral LD_{50} for rats = 3,160–4,080 mg/kg (Quarles 1992), and it is a slow-acting toxicant (Klotz and Moss 1996) that can be distributed by trophallaxis throughout an ant colony before taking effect. In the past, it has been used for control of Pharaoh ants, *Monomorium pharaonis* (L.) (Wright and Stout 1978), pavement ants, *Tetramorium caespitum* (L.), thief ants, *Solenopsis molesta* (Say), little black ants, *Monomorium minimum* (Buckley) (Hagmann 1982), and the Argentine ants *Linepithema humile* (Mayr) (Olkowski et al. 1991).

Several formulations of boric acid have been field tested against the red imported fire ant, *Solenopsis invicta* Buren, including mound drenches (Lemke et al. 1985) and baits (Diffie et al. 1987, Diffie 1991, Drees et al. 1991, Porter 1988). In all of these tests, boric acid failed to control *S. invicta*. In laboratory tests conducted by Porter (1988), a 2% boric acid in a 1-M solution of sucrose water initially killed large numbers of *S. invicta* workers and larvae, but not queens. The treated colonies later resumed brood production after 3–5 wk. The baits used in field studies had high concentrations of boric acid. For example, in Drees et al. (1991) the boric acid bait product evaluated contained 18% active ingredient. In laboratory tests with the Florida carpenter ant, *Camponotus abdominalis floridanus* (Buckley), Klotz and Moss (1996) showed that much lower concentrations of boric acid can be effective at killing ants. Over the dosage range from 0.13 to 3.13% boric acid, LT_{50}s (95% CL) ranged from 9.7 d (8.1–13.3) to 1.5 d (1.2–1.7). A delayed toxicity is an essential property of an effective ant bait (Stringer et al. 1964).

Two other properties of an effective ant bait are (1) a food attractant with some specificity toward the target species, and (2) an inert carrier that is highly palatable and readily gathered (Stringer et al. 1964). The sucrose water bait used in this study exploits the natural feeding habits of *S. invicta*, because liquids from honeydew, plant sap, and nectars comprise a major portion of its diet (Tennant and Porter 1991). Sucrose is a component in each of these liquids (Auclair 1963, Noggle and Fritz 1976, Baker and Baker 1975, Gottsberger et al. 1984) and has been shown to have excellent phagostimulant activity for *S. invicta* (Vander Meer et al. 1995).

In addition to providing moisture for the ants, water used as the carrier in this study is an ideal solvent for boric acid. Boric acid may disrupt water regulation (Klotz and Moss 1996), causing the ants to consume more bait to counterbalance dehydration and consequently increase dosage.

The purpose of this investigation was 3-fold: (1) to determine the dosage response of fire ant workers to a boric acid–sucrose water bait, (2) to determine consumption rate of different concentrations of boric acid in a sucrose water bait, and (3) to test the efficacy of various concentrations of bo-

[1] Current address: Department of Entomology, University of California, Riverside, CA 92521.

[2] Current address: Extension Entomology & Plant Pathology, University of Tennessee, Knoxville, TN 37901.

ric acid in a sucrose water bait against large laboratory colonies of fire ants.

Materials and Methods

Oral Toxicity Tests. Queenright colonies of fire ants were field collected in Gainesville, FL. In the laboratory (25°C, ambient relative humidity) the ants were provided water but no food. One day after collection, workers were selected from the colonies and distributed, 10 each, into plastic petri dishes (145 by 25 mm, Thomas Scientific, Swedesboro, NJ), each supplied with a scintillation vial (7 ml, Kimble, Vineland, NJ) plugged with cotton in which crystalline boric acid (99% AI, Sigma, St. Louis, MO) was dissolved in a 10% (wt:vol) sucrose-deionized water solution to produce 9 concentrations (0.02–1%) of boric acid. Treatments and controls (10% sucrose-deionized water) were replicated 5 times. The bait solutions were available continuously to the ants for the duration of the test. Daily observations on cumulative mortality were recorded for 10 d.

Bait Consumption Tests. Boric acid was dissolved in 10% deionized sugar water to produce solutions of 0.25, 1 and 5% (wt:vol). Controls consisted of 10% sucrose in deionized water. Each solution (50 ml) was added to test tubes (150 by 25 mm) and plugged with cotton. All colonies were starved for 1 d before bait exposure. The boric acid–sucrose solution was provided for 24 h to large monogyne colonies (>50,000 workers) without an alternative food source. Treatments and controls were replicated 3 times. In addition, to correct for evaporative water loss, 3 replicates for each of the treatments and control were concurrently run in adjacent nest boxes without ants. The consumption of bait after 24 h was calculated by subtracting the weight of the test tube and bait after the test from the weight of the test tube and bait before the test. The resulting difference was then corrected for evaporative water loss by subtracting the mean of the 3 evaporative standards.

Colony Tests. Laboratory tests were carried out using queenright (monogynous) colonies ≈10–20 mo old. Each test colony initially contained 60,000–75,000 workers and 60–70 ml of brood (eggs, larvae, and pupae). Colonies were reared according to methods described by Banks et al. (1981), except the diet consisted of 25% honey-water, crickets, and hard-boiled chicken eggs. Food was withheld for 1 d before treatment. The boric acid–sucrose solution was prepared in the same manner as described for the oral toxicity and consumption tests. Four different concentrations of boric acid bait were tested: 1, 0.75, 0.5, and 0.25%. Liquid bait (72 ml) was offered to each laboratory colony in 200- by 25-mm test tubes plugged with cotton. Water was provided continuously and ants were allowed ad libitum feeding on the bait (replaced every 2 wk), and crickets and eggs for the duration of the test. Worker mortality and queen status (dead or alive) were observed weekly. Brood reduction was determined by visually comparing a photograph of known quantities of brood with the brood present in a colony. The test was continued until it was noted that the queen either died or was small in size and not producing eggs, brood was absent, and there was at least a 99% reduction of workers. The experiment consisted of a control group and 4 treatment groups (1 for each of the 4 concentrations of boric acid bait), each with 3 test colonies. Treatment efficacy was determined by the percentage of reduction in a population index (PI) (Lofgren and Williams 1982). To determine the population index, each colony was rated before treatment and at weekly intervals after treatment. With this method, colonies are assigned a rating of 1–6 based on colony size (number of workers ranging from <100 workers to >50,000) and 1–25 on the basis of quantity of worker brood (0 to >30 ml). The products of these ratings are then used to calculate the percentage of reduction population index for each wk ($PI_{wk\,0} - PI_{wk\,x}/PI_{wk\,0}) \times 100\%$.

Statistical Analysis. For the oral toxicity tests, mortality data were corrected with Abbott's (1925) formula and analyzed by probit analysis (Raymond 1985) to determine lethal concentration (LC_{50} and LC_{90}) values for each day. Mean consumption of toxic baits was compared with the control using analysis of variance and the Scheffé *F* test ($P <$ 0.05; StatView 1992) for separation of means.

Results and Discussion

An effective ant bait must contain a nonrepellent toxicant that has a delayed action over at least a 10-fold range of dilution (Stringer et al. 1964), to ensure that the toxicant remains effective after trophallaxis, and that it is spread throughout the colony before taking effect. In the oral toxicity test, boric acid exhibited this delayed toxicity over a 10-fold range of dilutions (Table 1) with an LC_{50} (95% CL) of 1.27% (1.05–3.88%) at 3 d and 0.11% (0.09–0.13%) at 8 d. At these low doses, boric acid meets the criteria for an effective ant bait (i.e., nonrepellent and slow-acting).

In the consumption test, the effect of boric acid in 10% sucrose water solutions was significant (F = 14.68; df = 3, 8; P = 0.0013). At the high dose (5%), consumption (0.327 ± 0.046g) was significantly lower than the control (9.438 ± 1.25g), according to the Scheffé *F* test (P = 0.05). At a 1% dose, consumption (4.262 ± 0.439g) also was reduced but was not significantly different from either the control or 5%. The cause of this reduction was not determined but may be caused by the boric acid acting as an antiphagostimulant. Results of repellency tests with *Musca domestica* (L.) (Hogsette and Koehler 1994) and *Blatella germanica* (L.) (Strong et al. 1993) indicate a higher tolerance of these insects for boric acid. In the house fly tests, where concentrations ranged from 0.50 to

Table 1. LC_{50}s and LC_{90}s of *S. invicta* workers fed boric acid bait

Day	LC_{50} (95% CL) % (wt:vol)	LC_{90} (95% CL) % (wt:vol)	Slope ± SE	No. ants	χ^2	*P*
3	1.27 (1.05–3.88)	2.23 (1.48–34.87)	5.22 ± 1.42	50	0.52	0.47
4	0.77 (0.71–0.84)	1.24 (1.08– 1.59)	6.25 ± 1.54	50	4.53	0.10
5	0.44 (0.38–0.50)	0.98 (0.83– 1.24)	3.67 ± 0.46	50	4.24	0.24
6	0.22 (0.19–0.26)	0.57 (0.47– 0.72)	3.18 ± 0.32	50	4.67	0.46
7	0.14 (0.11–0.17)	0.32 (0.24– 0.53)	3.42 ± 0.51	50	2.04	0.36
8	0.11 (0.09–0.13)	0.26 (0.20– 0.41)	3.24 ± 0.45	50	1.95	0.58

4% boric acid in 10% sucrose water, consumption of the 2.25% solution was greatest. Consumption rates of boric acid in water solutions elicited no repellency with German cockroaches over the concentrations 0.5–4%.

Using the oral toxicity and consumption test as a guideline for dosage, large monogyne fire ant colonies were tested with 4 concentrations of boric acid (Fig. 1). A continuous exposure to 0.25, 0.5, 0.75, and 1% boric acid–sucrose water bait was effective in reducing colony size: at 6 wk there was >90% reduction in the population index at all 4 concentrations. By the 12th wk, queens were dead in 25% of the treated colonies. By the 16th wk, in all treated colonies, there was a 99% reduction of workers, no brood, and the remaining queens were small and not producing eggs.

The high doses of boric acid used currently in baits are probably designed to eliminate ants quickly. However, a high dose increases the likelihood of avoidance, kills quickly, and reduces trophallaxis. Each of these factors minimizes the potential effectiveness of ant baits.

Our research results indicate 2 new factors which are important for control of *S. invicta* using boric acid baits. First, the concentration necessary to kill ants is much less than is currently being used or recommended. Second, at current application rates, boric acid baits might be repellent. We suggest that if it is used at lower concentrations, boric acid has great potential for control of *S. invicta*.

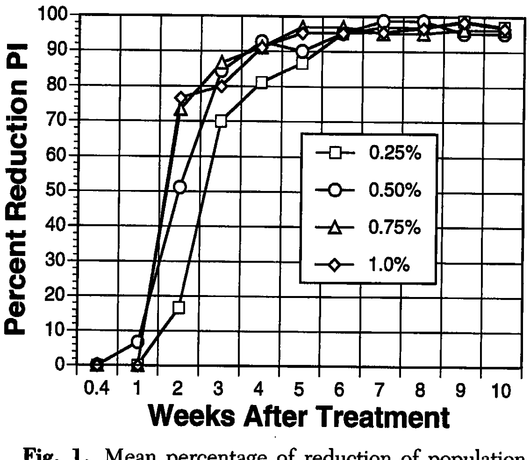

Fig. 1. Mean percentage of reduction of population index (PI) in *S. invicta* colonies exposed for 10 wk to various concentrations of boric acid in 10% sugar water. The population index is a combined value of worker number and brood quantity. Each point represents the mean of 3 colonies of fire ants, each with 1 queen and >50,000 ants at the beginning of the test. The 3 control colonies (not shown on graph) grew in size.

References Cited

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265–267.

Auclair, J. L. 1963. Aphid feeding and nutrition. Annu. Rev. Entomol. 8: 439–490.

Baker, H. G., and I. Baker. 1975. Studies of nectar consitution and pollinator-plant coevolution, pp. 100–140. *In* L. E. Gilbert and P. H. Raven [eds.], Coevolution of animals and plants. University of Texas Press, Austin.

Banks, W. A., C. S. Lofgren, D. P. Jouvenaz, C. E. Stringer, P. M. Bishop, D. F. Williams, D. P. Wojcik, and B. M. Glancey. 1981. Techniques for collecting, rearing, and handling imported fire ants. USDA Science Education Administration, AATS-S-21.

Diffie, S. 1991. Comparison of the efficacy of a boric acid product (Last Meal) with Orthene in controlling the red imported fire ant. *In* Imported fire ant management: results of applied research demonstrations. University of Georgia Division of Entomology, Research-Extension Publication, Athens.

Diffie, S., D. C. Sheppard, and T. D. Canerday. 1987. Imported fire ants: results of control tests. University of Georgia Division of Entomology, Research-Extension Publication, Athens.

Drees, B. M., C. L. Barr, and S. B. Vinson. 1991. Evaluation of Bushwhacker fire ant killer, a boric acid based bait product, pp. 35–38. *In* Red imported fire ant result demonstrations/applied research. Texas Cooperative Extension Service, College Station.

Gottsberger, G., J. Schrauwen, and H. F. Linskens. 1984. Amino acids and sugars in nectar and their putative evolutionary significance. Plant Syst. Evol. 145: 55–77.

Hagmann, L. E. 1982. Ant baits. Pest Control 50: 30–32.

Hogsette, J. A., and P. G. Koehler. 1994. Repellency of aqueous solutions of boric acid and polybor 3 to house flies (Diptera: Muscidae). J. Econ. Entomol. 87: 1033–1037.

Klotz, J. H., and J. Moss. 1996. Oral toxicity of a boric acid–sucrose water bait to Florida carpenter ants (Hymenoptera: Formicidae). J. Entomol. Sci. 31: 9–12.

Lemke, L. A., M. P. Knight, and J. B. Kissam. 1985. Evaluation of boric acid formulations for control of red imported fire ants, 1984. Insectic. Acaricide Tests 10: 345–346.

Lofgren, C. S., and D. F. Williams. 1982. Avermectin B1a: highly potent inhibitor of reproduction by queens of the red imported fire ant (Hymenoptera: Formicidae). J. Econ. Entomol. 75: 798–803.

Noggle, G. R., and G. J. Fritz. 1976. Introductory plant physiology. Prentice-Hall, Englewood Cliffs, NJ.

Olkowski, W., S. Daar, and H. Olkowski. 1991. Common-sense pest control. Taunton, Newton, CT.

Porter, S. D. 1988. Effects of boric acid baits on laboratory fire ant colonies, pp. 79–81. *In* M. E. Mispagel [ed.], Proceedings of the 1988 imported fire ant conference. The University of Georgia, Athens.

Quarles, W. 1992. Borates provide least-toxic wood protection. Integrated Pest Manage. Practitioner 14: 1–11.

Raymond, M. 1985. Presentation d'un programme basic d'analyse log-probit pour micro-ordinateur. Cah. O.R.S.T.O.M. Ser. Entomol. Med. Parasitol. 23: 117–121.

Riley, C. V. 1889. The little red ant. Insect Life 2: 106–108.

Rust, M. K. 1986. Managing household pests, pp. 335–368. *In* G. W. Bennett and J. M. Owens [eds.], Advances in urban pest management. Van Nostrand Reinhold, New York.

StatView. 1992. StatView user's guide. Abacus Concepts, Berkeley, CA.

Stringer, C. E., C. S. Lofgren, and F. J. Bartlett. 1964. Imported fire ant toxic bait studies: evaluation of toxicants. J. Econ. Entomol. 57: 941–945.

Strong, C. A., P. G. Koehler, and R. S. Patterson. 1993. Oral toxicity and repellency of borates to German cockroaches (Dictyoptera: Blatellidae). J. Econ. Entomol. 86: 1458–1463.

Tennant, L. E., and S. D. Porter. 1991. Comparison of diets of two fire ant species (Hymenoptera: Formicidae): solid and liquid components. J. Entomol. Sci. 26: 450–465.

Vander Meer, R. K., C. S. Lofgren, and J. A. Seawright. 1995. Specificity of the red imported fire ant (Hymenoptera: Formicidae) phagostimulant response to carbohydrates. Fla. Entomol. 78: 144–154.

Wright, C. G., and D. Stout. 1978. For better Pharaoh ant control. Pest Control 46: 26, 28, and 32.

Received for publication 16 April 1996; accepted 16 October 1996.