Delayed Toxicity as a Critical Factor in the Efficacy of Aqueous Baits for Controlling Argentine Ants (Hymenoptera: Formicidae)

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ABSTRACT Boric acid, imidacloprid, and thiamethoxam in sucrose aqueous baits had different delayed toxicities to worker Argentine ants, *Linepithema humile* (Mayr). The concentrations required to produce an LT_{50} (time required to produce 50% mortality) within 1–4 d were 3.63–0.55% boric acid, 9.2×10^{-3} to 7.1×10^{-4}% imidacloprid, and 3×10^{-4} to 2×10^{-5}% thiamethoxam. The three toxicants were not repellent. Other laboratory trials showed that 1% boric acid, 5×10^{-4} to 5×10^{-3}% imidacloprid, and 1×10^{-5} to 1×10^{-3}% thiamethoxam had delayed toxic effects, whereas 0.5% boric acid and $<5 \times 10^{-3}$% imidacloprid did not. Baits that provided an LT_{50} between days 1 and 4 were considered to have delayed toxic effects. The utility of aqueous sucrose baits and toxicants soluble in such systems and the negative impact of fast-acting toxicants on trail following, recruitment, trophallaxis, and control of Argentine ants are discussed.

KEY WORDS Argentine ant, bait, delayed toxicity, recruitment

ARGENTINE ANTS, *Linepithema humile* (Mayr), are an important invasive species in natural, agricultural, and urban settings. Conventional control strategies in agriculture include the use of insecticidal sprays and granules applied as barriers around structures, trees, and vines to exclude ants (Vega and Rust 2001, Rust et al. 2003). In urban settings, chemical sprays and granules provide limited control because of reinvasion after treatment by ants from nearby unaffected colonies (Vega and Rust 2003) and the limited activity of barriers because of environmental conditions, usually heat, rain, and irrigation (Rust et al. 1996, 2003). Scattered granular baits (Knight and Rust 1991, Krushelnycky and Reimer 1998b, Klotz et al. 2000a) or containerized solid bait (Forschler and Evans 1994a b, Blachley and Forschler 1996, Klotz et al. 2000a) have provided mixed results. No pest management strategy has yet been shown to be consistently effective.

Argentine ants forage carbohydrate liquids such as honeydew and also readily forage sugar water (Rust et al. 2000). A specialized adaptation of their crop allows workers to consume nearly their weight of such liquids at a single feeding (Markin 1970, Reierson et al. 1998). Foraged carbohydrates are readily disseminated to other workers and eventually to brood by trophallaxis (Markin 1970). Baker et al. (1985) found that *L. humile* preferred 25% honey or sucrose water over an assortment of other sweets and proteins. Over an entire year, 25% sucrose water was the most preferred bait base tested (Krushelnycky and Reimer 1998a, Rust et al. 2000). During the summer, 26–60% (weight) of the food foraged by workers was protein, whereas this declined to 16–40% during the winter (Rust et al. 2000). Liquid baits incorporating arsenical insecticides into honey were widely used for many years (Barber 1916), but although these baits killed worker ants quickly, they failed to kill queens in laboratory tests (Knight and Rust 1991). Liquid baits containing 0.5% boric acid in 25% sucrose provided ≈80% reductions in the number of workers foraging at monitoring stations (Klotz et al. 1998). Solutions of 1×10^{-4}% fipronil in 25% sucrose water significantly reduce the number of ants foraging around structures (Klotz et al. 2002, Vega and Rust 2003). One of the most difficult problems has been formulating toxicants into consistently acceptable baits (Baker et al. 1985, Silverman and Roulston 2001).

This study expands on previous work with liquid baits, emphasizing toxic baits with delayed toxicity. Important considerations are 1) the solubility of the toxicant in aqueous sucrose solution, and 2) its speed of toxic action (e.g., time required to produce 50% mortality, LT_{50}). The relationship and the biological relevance between speed of action and resultant interference with behaviors such as recruitment and trophallaxis are discussed.

Materials and Methods

Insects. Ants excavated by shovel from a citrus grove on the UC Riverside campus were removed from soil in a process described by Hooper-Bui and Rust (2000).

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Table 1. Selected physical and toxicological properties of the insecticides mixed into the 25% sucrose solutions

Insecticide	Solubility (%)			LD_{50} rat (oral mg/kg)
	H_2O at 20°C	Ethanol at 20°C	Acetone at 25°C	
Boric acid[a]	4.7	9.4	0.6	3,500–4,100
Imidacloprid[b]	0.051	0.3[c]	4.25	424
Thiamethoxam[b]	0.41[c]	∞	0.48	1,563

[a] Data provided by U.S. Borax.
[b] www.apuma.gov.au/publications/prsthi.pdf.
[c] at 25°C.

The ants were maintained in plastic boxes (26.5 by 30 by 10 cm, Tristate Plastics, Dixon, KY) coated with a thin film of Teflon (DuPont Polymers, Wilmington, DE) on the inner walls. The colonies were provisioned with three harborages consisting of plastic petri dishes (9 cm in diameter by 0.5 cm) filled with plaster of Paris with the center 4 cm hollowed out to serve as a nest and 25-ml water vials plugged with cotton for moisture. Food was provided ad libitum from polystyrene weighing dishes (3.8 by 2.5 cm, Fischer Scientific, Pittsburgh, PA) containing 25% sucrose water and cotton, and a few house fly pupae and freshly killed cockroaches scattered on the floor of each box (Hooper-Bui and Rust 2000).

Insecticides. The insecticides tested included boric acid (orthoboric acid; 99% tech [mass:vol], U.S. Borax, Los Angeles, CA), imidacloprid (1-{(6-chloro-3-pyridinyl)methyl}-*N*-nitro-2-imidazolidinimide; 95% tech [mass:vol], Bayer Environmental Science, Montvale, NJ), and thiamethoxam (3-[(2-chloro-5-thiazolyl)methyl]tetrahydro-5-methyl-*N*-nitro-4*H*-1,3,5-oxadiazin-4-imine, Syngenta Crop Protection, Inc., Greensboro, NC). Technical material was dissolved in 1 to 2 ml of ethanol or acetone before adding it to 25% sucrose solution. Small amounts of these solvents facilitate dissolving these technical materials and do not affect the acceptability of 25% sucrose solutions by Argentine ants (Baker et al. 1985). Important physical and toxicological properties of the insecticides are used in Table 1.

Toxicity Tests. To determine the toxicity of each insecticide, ants were continuously confined with 25% sucrose solution + toxicant in small plastic petri dishes (50 mm in diameter by 15 mm). Two small plastic caps from 1.5-ml microcentrifuge tubes (8 mm in diameter by 5 mm in height) were cemented to the bottom of each dish. A plug of cotton was placed in each cap and ≈0.5 ml of 25% sucrose + toxicant was added to one cap. The other cap was filled with 0.5 ml of water. Ten worker ants were placed in the petri dish and it was covered. The range of concentrations tested was as follows: boric acid (0.0, 0.125, 0.25, 0.5, 1.0, 2.0, and 5.0%), imidacloprid (0.0, 1×10^{-4}, 5×10^{-4}, 1×10^{-3}, 5×10^{-3}, 1×10^{-2}, and 5×10^{-2}%), and thiamethoxam (0.0, 1×10^{-5}, 3×10^{-5}, 5×10^{-5}, 1×10^{-4}, 5×10^{-4}, and 1×10^{-3}%). A 25% sucrose control was included in each series of toxicants tested. Sugar water and all other foods were removed from the ant colonies 96 h before testing.

The number of dead workers was counted daily for 7 d. Each toxicant, concentration, and the sucrose control for each toxicant were replicated 10 times. The LT_{50} was determined for each replicate, and an average LT_{50} was determined. Concentrations were transformed to $\log_{10}$, and linear regressions were calculated (Statistix 2000). The concentrations (±95% CL) of bait required to produce LT_{50}s at days 1 and 4 were determined (Sokal and Rohlf 1997).

Acceptance Tests. To determine the acceptability of toxicants formulated in 25% sucrose, choice tests with multichoice arenas were conducted at field sites where *L. humile* were actively foraging. Foraging ants were allowed to select from the toxicants serially diluted in 25% sucrose. A choice arena consisted of a round aluminum cake pan (21.5 cm in diameter by 3.8 cm in height) with four 10-cm-long glass tubes (50 mm i.d.) extended through four openings at 90° in the side of the pan, providing access to the ants to the center of the arena. When arenas were placed in areas infested with Argentine ants, no other arthropods were ever found in the arenas feeding on the sucrose or baits. The arena had small polystyrene weighing dishes glued to the floor of the pan in a circular pattern equidistant from one another. Approximately 1 ml of sucrose solution was loaded into preweighed 1.5-ml polypropylene microcentrifuge tubes. The tubes were capped, weighed again, and transported to the field. The weighed tubes were placed in the weigh boats in the arenas. The arenas were covered with transparent Mylar plastic and a piece of plywood covered with aluminum foil to provide shade. A brick on top of the plywood prevented wind or animals from disturbing the pans. The range of concentrations of toxicant tested was as follows: boric acid (0.0, 0.125, 0.25, 0.5, 1.0, 2.0, and 5.0%), imidacloprid (0.0, 1×10^{-4}, 5×10^{-4}, 1×10^{-3}, 5×10^{-3}, 1×10^{-2}, and 5×10^{-2}%), and thiamethoxam (0.0, 1×10^{-5}, 5×10^{-5}, 1×10^{-4}, 5×10^{-4}, and 1×10^{-3}%). The number of replicates tested for boric acid, imidacloprid, and thiamethoxam was 18, 7, and 9, respectively.

The choice arenas were left outside near active ant infestations overnight. After ≈12 h, the tubes were capped and returned to the laboratory. Dead and live ants were removed and the tubes were weighed. The difference in the weight (initial – final) represented the amount of ant feeding and weight loss due to evaporation. To serve as a control for weight loss, test solutions and the 25% sucrose control were placed in a protected outdoor location where ants were unable to forage and remove bait. The percentage of change in weight due to water absorption or loss was in this way adjusted for each solution over the period each test was conducted. The amount of bait removed (initial bait − final bait) was corrected by the percentage of reduction or gain in weight of the control bait with the following formula: $(\text{Test Bait}_{ai})\ (\text{Evap B}_a) - \text{Test B}_{af}/(\text{Test B}_{ai})\ (\text{Evap B}_a)$, where $\text{Evap B}_a = \text{Evap B}_{ai} - \text{Evap B}_{af}/\text{Evap B}_{ai}$ and if $\text{Evap B}_a < 0$, then add 1.

The amount of bait consumed for each serial dilution of toxicants was analyzed with a Kruskal–Wallis test (Statistix 2000). Fast-acting toxicants might reduce the amount of baits and 25% sucrose consumed. Therefore, the amount of 25% sucrose water consumed in each replicate for the three toxicants was analyzed with a Kruskal–Wallis test.

Laboratory Colony Tests. To determine the potential efficacy of baits against Argentine ants, laboratory colonies were allowed access to bait, and the resultant mortality of workers and queens was determined. Colonies were set up according to procedures modified from Hooper-Bui and Rust (2000) in which 300 workers and five queens were placed in plastic boxes (26.5 by 30 by 10 cm). The inside walls were coated with a thin film of Teflon emulsion to prevent ants from escaping. The ants were provided a disk of Plaster of Paris that had a central arena for ants to use as harborage. The disks were covered with dark cardboard and placed into the test box. The plaster was moistened to humidify the nest. The ants were allowed to acclimate for ≈7 d with a 25-ml water vial, a plastic dish containing fly pupae, and 5% sucrose water.

For the test, the fly pupae and sucrose water were removed from the boxes 72 h before baiting. The water vial was left in the box. Starvation of laboratory colonies for 72 h simulates the intensity of hunger and foraging of field populations (Markin 1970). Approximately 1 ml of liquid bait or 25% sucrose was placed in each colony and replenished as needed. Each test solution and the 25% sucrose controls for each toxicant were replicated five times. At 24 h, sugar water and fly pupae were again provided. The number of dead workers and queens was counted at day 1, 7, and 14 and dead ants were removed from each box. The tests were discontinued at day 14 and the number of live workers and queens was counted. Percentage of mortality at each day was determined by dividing the number of dead ants by the total number of dead ants and of live ants at day 14. The range of concentrations tested was as follows: boric acid (0.0, 0.5, and 1.0%), imidacloprid (0.0, 1×10^{-4}, 5×10^{-4}, 1×10^{-3}, and 5×10^{-3}%), and thiamethoxam (0.0, 1×10^{-5}, 5×10^{-5}, 1×10^{-4}, 5×10^{-4}, 1×10^{-3}, and 5×10^{-3}%).

The mortality of workers at day 14 was analyzed with an analysis of variance (ANOVA) and the means separated with Tukey's honestly significant difference (HSD) (Statistix 2000).

Results

For each toxicant, as the concentration increased, the time required to produce 50% kill of workers decreased (Table 2). The 25% sucrose controls failed to produce 50% kill within 7 d, with mortality ranging between 6 and 21%. The concentration of boric acid in 25% sucrose water needed to produce an LT_{50} at day 1 was 3.63%, but was only 0.55% for day 4, a nearly seven-fold lower rate. For imidicaloprid, the estimates for LT_{50}s at days 1 and 4 were 9.2×10^{-3} and 7.1×10^{-4}%, respectively, a 13-fold difference; and for thia-

Table 2. Regression coefficients for linear regression of $\log_{10}$ concentration and estimate of the concentration required to provide an LT_{50} at days 1 and 4

Toxicant[a]	Slope ± SEM	Constant ± SE	r^2	*F*	*P*	Estimated % Conc. at day (95% CI)	
						1	4
Boric acid	−3.64 ± 0.461	6.69 ± 0.471	0.93	62.30	0.0014	3.63 (0.974–21.218)	0.55 (0.151–1.815)
Imidacloprid	−2.69 ± 0.544	6.29 ± 0.822	0.83	24.52	0.0043	9.2×10^{-3} (2.0×10^{-3}–8.3×10^{-1})	7.1×10^{-4} (8.0×10^{-5}–2.3×10^{-2})
Thiamethoxam	−2.58 ± 0.608	4.82 ± 0.728	0.82	18.01	0.0132	3.0×10^{-4} (3.9×10^{-5}–1.3×10^{-1})	2.0×10^{-5} (4.0×10^{-6}–9.3×10^{-4})

[a] Ten replicates tested for each concentration.

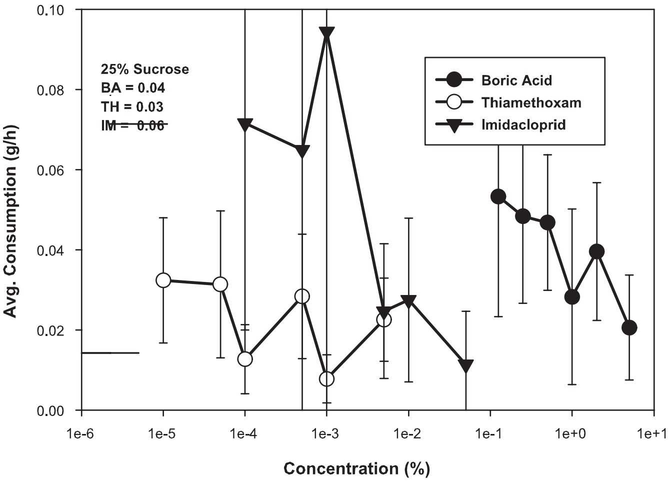

Fig. 1. Average consumption (±95% CI) of baits formulated in 25% sucrose. Consumption of 25% sucrose in upper left corner.

methoxam, the LT_{50}s were 2×10^{-5} and 3×10^{-4}%, a 15-fold difference. The slopes for both imidacloprid and thiamethoxam were not as steep as that for boric acid, providing a broader range of acceptable concentrations. Similarly, Klotz and Moss (1996) found about a six-fold range of toxicity for boric acid against the Florida carpenter ant, *Camponotus floridanus* (Buckley). Interestingly, Reid and Klotz (1992) found that the range of delayed toxicity of abamectin was about five-fold against *Camponotus pennysylvanicus* (DeGeer) and was too narrow to provide an effective bait.

There was considerable variation in the amount of each bait foraged and no significant difference in the amount of toxic bait solutions compared with sucrose solutions foraged (boric acid, $H = 5.77$, $P = 0.450$; imidacloprid, $H = 8.57$, $P = 0.199$; thiamethoxam, $H = 10.56$, $P = 0.103$). The average amount of toxic bait and 25% sucrose solution consumed for each choice test were not significantly different (Fig. 1).

Integrating the time required to kill workers and the consumption of bait into a graph for each toxicant is shown in Figs. 2, 3, and 4. The estimated concentrations that produced an LT_{50} at days 1 and 4 (Table 2) comprise the vertical sides of the rectangle. The bottom of the rectangle is drawn at LT_{50} of 1 d and the top at LT_{50} of 4 d. When both the consumption and toxicity lines are inside the rectangular boxes, the corresponding concentrations should provide the best acceptance and toxicity to ants.

In small laboratory colonies, all concentrations of thiamethoxam produced 100% kill of workers and queens within 14 d. Baits containing or 5×10^{-3}% imidacloprid and 1.0% boric acid provided significant worker kill at day 14 (Table 3).

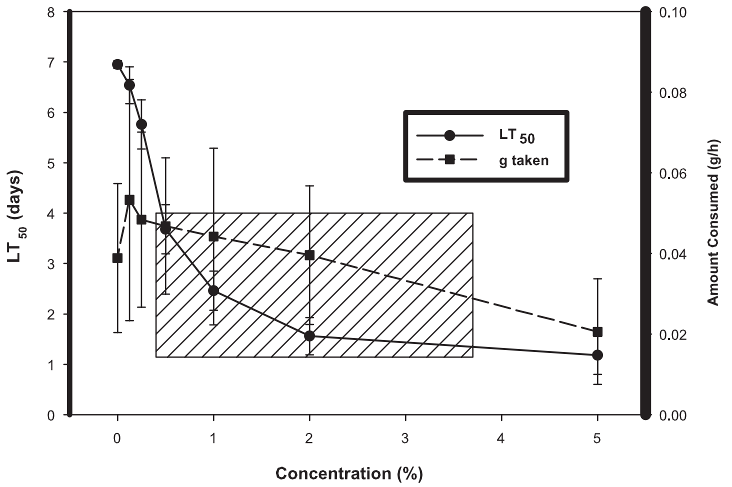

Fig. 2. Average time required for boric acid + 25% sucrose solutions to produce LT_{50} (days), and the amount of sucrose consumed per hour per total consumption in choice tests. The bars represent ±95% CI. The rectangle with cross-hatching represents the concentrations that provide delayed toxicity and acceptance.

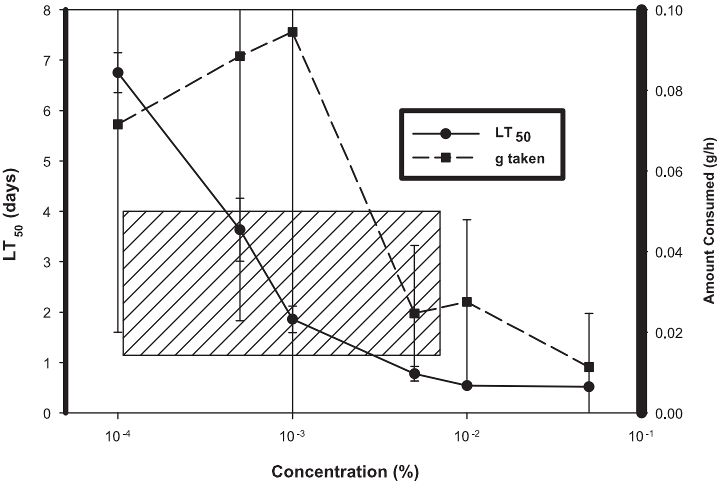

Fig. 3. Average time required for imidacloprid + 25% sucrose solutions to produce LT_{50} (days), and the amount of sucrose consumed per hour per total consumption in choice tests. The bars represent ±95% CI. The rectangle with cross-hatching represents the concentrations that provide delayed toxicity and acceptance.

Discussion

Important attributes of candidate toxicants to be incorporated into ant baits are that the toxicant must exhibit prolonged delayed toxicity over a wide dosage range, be readily transferred from one ant to another, and not be avoided by ants when incorporated in a bait. Stringer et al. (1964) defined delayed toxicity of red imported fire ants, *Solenopsis invicta* (Buren), as <15% kill at 24 h and >89% kill at the end of the test. In our studies, we have defined delayed toxicity for Argentine ants to be baits that produce an LT_{50} of forager worker ants between days 1 and 4. This allows ample time for bait to spread throughout the colony. Using ^{32}P-labeled sucrose bait, Markin (1968) found that within 4 h 53% of the workers of a single colony were positive for ^{32}P and by 96 h this had decreased to 32.8%. In 3 d, the tracer had spread 24.4 m away from the central colony. Similarly, Ripa et al. (1999) found that dyed sucrose solutions dispersed over 54 m within 72 h. Also, there is the likelihood that the original bait will be diluted via trophallaxis. Using ^{32}P-labeled baits, Markin (1970) determined that a single worker typically feeds 4–12 other workers. They pass it on to other workers so that in 48 h as many as 156 workers receive food from the initial ant. The bait is diluted to some extent in every exchange.

Because toxicants are diluted during trophollaxis, delayed toxicity is an extremely important component of an effective bait to control Argentine ants. Workers must survive long enough to repeatedly return to the colony with the toxic bait. Rapid kill effectively prematurely extinguishes foraging. In addition, the action

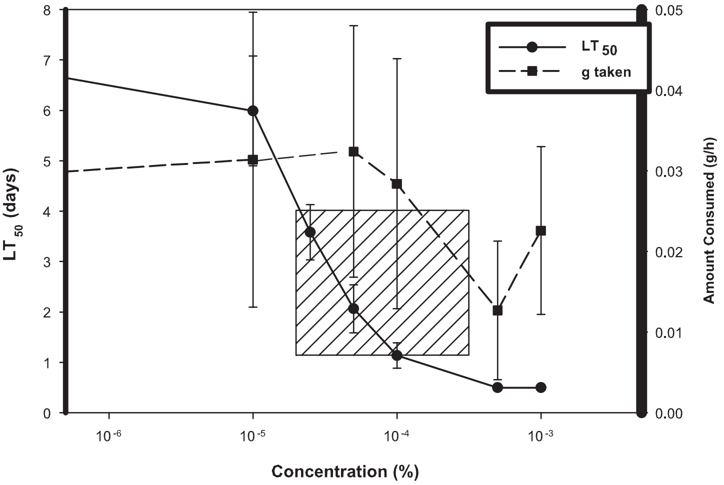

Fig. 4. Average time required for thiamethoxam + 25% sucrose solutions to produce LT_{50} (days), and the amount of sucrose consumed per hour per total consumption in choice tests. The bars represent ±95% CI. The rectangle with cross-hatching represents the concentrations that provide delayed toxicity and acceptance.

Table 3. Efficacy of boric acid, imidacloprid, and thiamethoxam baits in 25% sucrose water against small laboratory colonies of Argentine ants

Toxicant	Conc, (%)	Avg. no. dead workers (%)[a]		
		Day 1	Day 7	Day 14
Boric acid				
	1.0	16.7 (5.6)	76.0 (25.3)	262.0 (87.3)b
	0.5	13.3 (4.4)	46.7 (15.6)	161.0 (53.6)ab
Imidacloprid	0.005	52.0 (17.3)	160.7 (53.5)	264.0 (88.0)b
	0.001	119.3 (39.8)	176.0 (58.7)	206.7 (68.6)ab
	0.0005	118.7 (39.6)	146.3 (48.8)	188.7 (62.9)ab
	0.0001	18.0 (6.0)	35.0 (11.7)	60.7 (20.2)a
Thiamethoxam	0.005	300 (100)		
	0.001	264.0 (88.0)	300 (100)	
	0.0005	176.0 (58.7)	300 (100)	
	0.0001	107.3 (35.8)	300 (100)	
	0.00005	48.7 (16.2)	300 (100)	
	0.00001	89.0 (29.7)	266.3 (88.8)	300 (100)
Untreated		23.5 (7.8)	48.0 (16.0)	89.3 (20.1)a

[a] Colonies started with 300 worker ants and five queens ($n = 5$). Means in the column followed by the same letter are not significantly different at $P < 0.05$ (Tukey's HSD).

of the toxicant should be delayed so as maximize feeding, trail following, and mass recruitment. This is especially important in *L. humile* because workers lay trail-following pheromones directing them to and from food sources (Van Vorhis Key and Baker 1986). The addition of synthetic trail pheromone to bait stations increased recruitment and consumption of sucrose solutions by 29% in 4 h (Greenberg and Klotz 2000). The addition of 1×10^{-4}% fipronil + 20% sucrose + red dye decreased the maximum distance by 50% that the dye could be recovered compared with nontoxic baits. In addition, consumption of the bait by *L. humile* workers decreased from 685 to 103 ml (Ripa et al. 1999). They showed that toxic baits will ultimately disrupt recruitment and consumption. Disruption must be delayed long enough to ensure that sufficient amounts of toxicant are delivered to the colony.

Another desirable feature of prospective baits is that they are capable of being formulated in aqueous liquids when baiting ant species that principally forage on honeydew and nectar. *L. humile* prefers liquid sucrose baits (Baker et al. 1985, Krushelnycky and Reimer 1998a, Rust et al. 2000), feeding or handling time increasing proportionally with the thickness of the liquid (Markin 1970). Consequently, 25% sucrose solutions provide an ideal concentration for toxic baits. However, most toxicants are not highly soluble in water. Baker et al. (1985) incorporated low concentrations of emulsifiers such as hydroxyethyl cellulose (Tween 80), ethanol, and carboxymethyl cellulose to help suspend avermectin into sucrose solutions. *L. humile* preferred liquid baits over gel formulations and when combined with fipronil, more ants died in tests with the liquids (Silverman and Roulston 2001). Gel-like formulations resulted in increased handling times by ants (Silverman and Roulston 2001). Increased handling time results in faster worker kill, especially those toxicants that produce rapid mortality, probably from contact. Fortunately, boric acid, imidacloprid and thiomethoxam have sufficient solubility in water to be prepared in 25% sucrose solutions. All three toxicants are more soluble in ethanol and acetone than water, thereby assisting in their preparation into aqueous baits (Table 1).

Our toxicity studies with boric acid are consistent with Klotz et al. (1998) findings in which they reported LT_{50}s of 1.7 d for 1% boric acid and 5 d for 0.2%, a five-fold difference in concentration. Klotz et al. (2000b) found that the lethal time of boric acid, disodium octaborate tetrahydrate, and borax was directly related to the amount of boron in the bait. In colony tests in the laboratory, only 0.5% boric acid provided complete kill of workers and queens (Hooper-Bui and Rust 2000). In our study, alternative food placed in the colonies after 24 h probably contributed to the lower mortality with 0.5% boric acid baits. In field studies, 0.5% boric acid 25% sucrose baits provided a continuous 80% reduction of ants over 10 wk (Klotz et al. 1998). Clearly, the boric acid baits must be incorporated into a long-term baiting program for optimal results.

Contrary to Klotz et al. (2000b), we were unable to show significant differences in the amount of boric acid in 25% sucrose solution consumed over a range between 0.125 and 5%. Klotz et al. (2000b) conducted their choice studies for 24 h, allowing time for most of boric acid solutions to kill workers, thereby dramatically reducing recruitment and feeding. Klotz et al. (1997) reported that consumption of 5% boric acid bait by *S. invicta* was significantly less than in controls or a 1% bait solution. Their tests were conducted with large laboratory colonies containing >50,000 workers.

In our study, none of the toxicants formulated into sucrose water seemed to be repellent. As long as the baits are not repellent, the workers are not able to differentiate the difference in the amount of toxicant between each bait. Goss et al. (1990) concluded that selection of the best food source by ants is not because foragers or recruits in the colony make direct comparisons of food quality, but rather is an indirect consequence of individual foragers laying more pheromones to a better food source. Only the inability of workers to maintain foraging trails reduces foraging at bait stations. Therefore, fast-acting toxicants reduce trail establishment and maintenance.

All of the concentrations of thiamethexom produced 100% kill of workers and queens within 14 d (Table 3). However, only concentrations $\leq 1 \times 10^{-4}$% provided delayed kill of workers. In colony boxes, as concentrations of imidacloprid increased, mortality of workers also increased. Concentrations from 0.0005 to 0.005% imidacloprid and 1% boric acid provided delayed kill. These laboratory colony studies corroborate the findings of Klotz et al. (1996) that 1% boric acid + 10% sucrose baits produce ≈82% kill of workers at day 14. They found complete worker and queen kill within 12 wk.

Varying concentrations of boric acid, imidacloprid, and thiamethoxam displayed delayed toxicity to worker *L. humile.* In tests with *S. invicta*, Stringer et al. (1964) reported that an effective toxicant must exhibit delayed toxicity over at least a 10- to 100-fold concentration ranges, and preferably greater. Imidacloprid and thiamethoxam displayed a range of toxicities >10-fold that produced an LT_{50} within 1–4 d. If the 95% confidence intervals for the maximum and minimum ranges of imidacloprid and thiamethoxam providing LT_{50}s between day 1 and 4 are considered, the ranges are >1000-fold. In addition to being diluted by trophallaxis by the workers as they pass the toxicant-laden sucrose to other ants, evaporation of water from the bait stations poses a problem for toxicants that have a narrow range of toxicity (LT_{50}s). For example, if a bait station loses 10 or 50% of the water from the bait solution over 7 d, a 1% bait would become 1.11 and 2.0%, respectively. Such bait would become too toxic and begin to interfere with recruitment.

The effectiveness of bait to control social insect pests such as ants requires a delicate balance between the toxicant's speed of activity and its effects on the feeding, trophallaxis, and recruitment of new workers. Toxicants must be nonrepellent and readily transferred by trophallaxis. Another extremely important property, especially for species that feed primarily on honeydew and liquid nectars, is its solubility in aqueous sugar solutions. Because of their attributes, both imidacloprid and thiamethoxam are extremely promising candidates for sweet liquid ant baits.

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