Boric Acid Aversion in Adult House Flies, *Musca domestica* L.[1]

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ABSTRACT Considered relatively safe, boric acid formulations are commonly used in urban pest management and occasionally as baits in swine and poultry production facilities. Using the house fly, *Musca domestica* L. (Diptera: Muscidae), as a model insect, we conducted bait-consumption assays with 0.5% and 1.5% boric acid in 0.5 M sugar solution fed to flies in no-choice tests. Flies consumed little or no bait containing boric acid, and only fed on the boric acid bait as a last resort. House flies consumed up to seven times more untreated control solution per fly than they consumed the boric acid solutions. Consumption of aqueous bait and resultant mortality was not significantly different between either of the boric acid concentrations. We conclude that house flies were averse to feeding on sucrose solutions of greater than 0.5% boric acid.

KEY WORDS fly bait, aversion, avoidance, starvation

There is an increasing effort to manage fly populations by integrating pest management strategies, including the use of alternatives to traditional pesticides. Boric acid (H_2BO_3) has a long history of pesticide use, including a fly larvicide in barnyard manure (Midgley et al. 1943), carpenter ant control (Klotz & Moss 1996), urban cockroach control (Ebeling 1995), and as an effective alternative to conventional insecticides in swine production (Zurek et al. 2003). Boric acid has an excellent safety profile; it has a relatively high acute oral LD_{50} ($\geq$2000 mg/kg in rats), it is not classified as a carcinogen, and it is not considered a skin irritant. Liquid formulations of boric acid supplemented with 10% sucrose have great appeal for house fly control (Hogsette & Koehler 1992). Flies feeding on boric acid concentrations below 2.25% died within hours, while higher concentrations repelled flies (Hogsette & Koehler 1994). The LC_{50} value for the borate, disodium octaborate tetrahydrate, when mixed with dry sugar and fed to house flies, was 5.7%; embryonic death in gravid females occurred at 1% and 2% concentrations of the borate (Mullens & Rodriguez 1992). Furthermore, adult flies rejected borate-sugar mixtures at about 4% borate, with evidence of rejection beginning at 2%, suggesting a concentration-dependent repellency effect. In contrast, German cockroaches were successfully managed in swine production facilities with a unique delivery system using liquid boric acid and sugar baits (Gore et al. 2004). A 2% boric acid and 0.5 M sucrose solution was dispensed using a J-shaped tube fashioned from PVC pipes with a cotton plug serving as the

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feeding surface. Although the intention was cockroach control, house flies were observed resting on the bait station. Our objective was to determine if boric acid-sugar bait solutions could effectively control house flies.

Materials and Methods

House flies used for this study were originally isolated from a dairy farm near Ithaca, NY. The colony has been in continuous culture since 1982. Adults were maintained with water and a mixture of granulated sugar and milk powder. Larvae were reared on 250 ml Milk Plus pellets (Cargill, Minneapolis, MN), 2 L of wheat bran, and 1.5 L of water. Adults used in the following experiments were of mixed sex as previously described (Hogsette & Koehler 1994).

In no-choice assays, 25 adult house flies (3–5 days old) were provided bait solutions containing (1) 0.5 or 1.5% boric acid and 0.5 M sucrose, (2) a sucrose (0.5 M) and water solution without boric acid, or (3) no bait solution (starved). Blue food coloring was added to the bait solutions to help visualize the presence of the solution in the gut and in regurgitation and fecal droplets. Prior to treatment, the insects were fed water and crystalized sucrose. Bait solutions for feeding were contained within 1-ml glass pipettes. To facilitate fly feeding, a 0.5 mm diameter wire was inserted the entire length of the pipette and extended slightly from the tip to break the fluid surface tension and prevent the formation of an air pocket at the pipette tip. The opposite end was plugged with sealing putty to prevent draining. Pipettes were placed vertically in improvised pipette stands to prevent tipping. Test cages were constructed from 120 ml specimen cups with screw cap lids. The bottom of each cup was cut away and fiberglass window screen glued in place. Flies were anesthetized with CO_2 and transferred to the modified specimen cups (3 cups per treatment). The tip of a feeding pipette was inserted through the screen (Figure 1).

Two feeding assays were conducted at room temperature (~23°C) with a relative humidity of approximately 24% and continuous light. Volumes of solutions were recorded at 2, 4, 6, 8, and 12 hrs after the introduction of bait solution for the first experiment, and at two-hour intervals between 12 and 24 hrs after bait introduction for the second experiment. Both experiments were replicated three times. The numbers of dead flies (those that had ceased movement) were recorded at each time interval. Solution consumption values were corrected for the wire displacement in each 1 ml increment of solution (1 m = 0.9693 ml). In addition to the three treatments, a matching negative control (without flies) was set up to measure evaporative loss of the bait solutions. Some flies from each of the groups were dissected to compare relative consumption and existence of blue dye in the digestive tracts.

The second feeding assay aimed to establish time of death resulting from feeding on boric acid solutions. Mixed sex, 3-5-day old flies (n = 100) were starved (no food or water) in screened-lid tubs for 10 hrs. Flies were offered 1.5 and 0.5% boric acid sugar water solutions with blue dye added, and they were allowed to feed for 30 mins. A third group was given blue sucrose water for 30 mins as a control. After 30 mins, the flies were anesthetized with CO_2 and examined microscopically for blue coloration in the abdomens, indicating which flies had ingested the solutions. Then, the anesthetized flies were allowed to revive, fed on sucrose water (without boric acid), and monitored for mortality. This experiment was replicated three times.

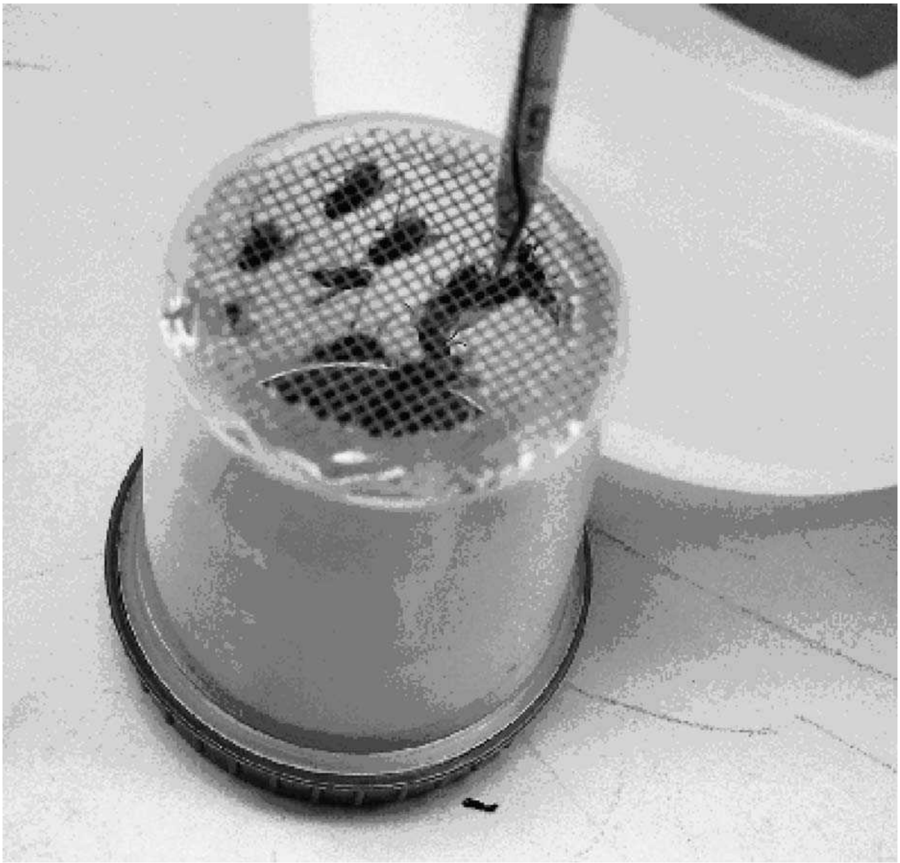


Fig. 1. The house fly feeding apparatus included a solution filled pipette inserted into the screened bottom of a specimen cup containing 25 house flies of mixed sex.

The potential repellency of boric acid-treated surfaces was examined by applying a spray solution of 10% boric acid to index cards and allowing the cards to air dry. Treated cards were hung on the right side of standard 30 × 30 × 30 cm screened cages while untreated cards were hung on the left side. Cage positions were rotated to alleviate location effects. Cages were provisioned with food and blue dyed water, 100 flies per cage and replicated three times at room temperature. Fly specking was counted after 24 hrs on each of the cards.

Statistical methods. Boric acid consumption data were analyzed using Tukey-Kramer, nonparametric statistics (JMP 7.0, SAS Institute, Inc., Cary, NC).

Results and Discussion

In no-choice assays, house flies consumed little of the boric acid-sugar water solutions. Mean consumption per fly was 4.7 ± 0.10 µl for the 0.5% concentration

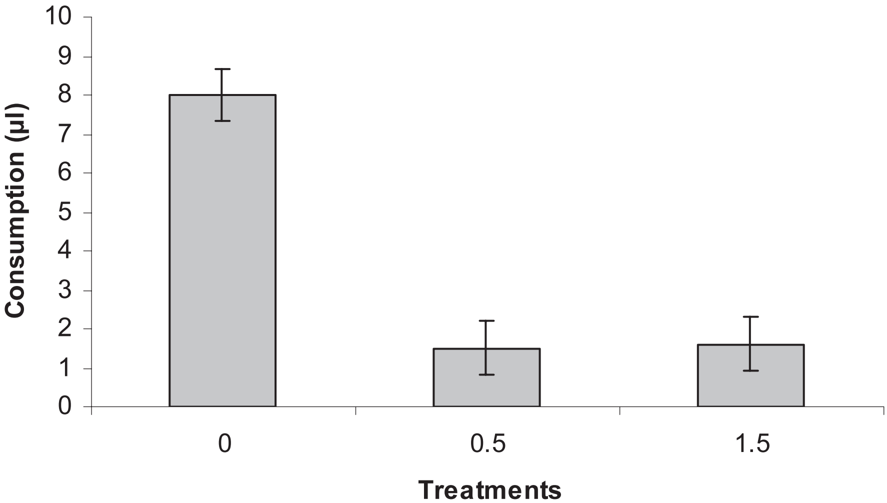


Fig. 2. Mean house fly consumption of sugar water solutions with 0.5% and 1.5% boric acid and untreated averaged over a 12 hr period.

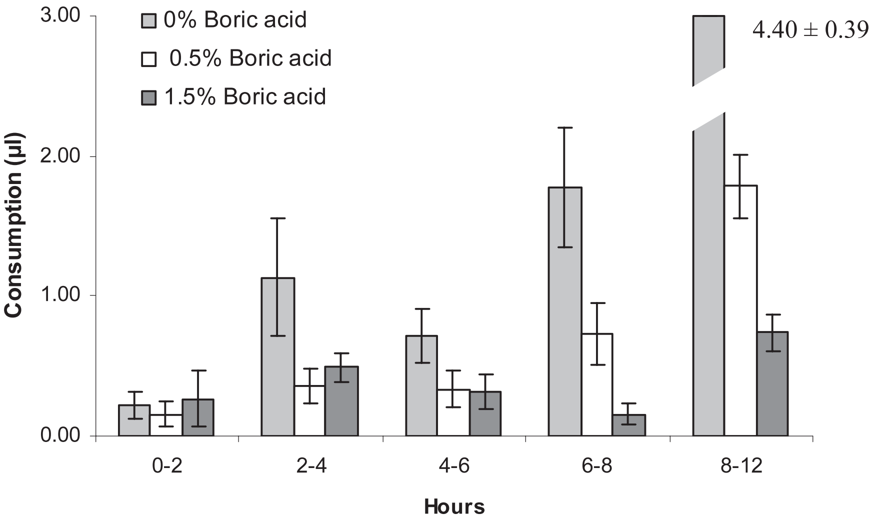
and 5.3 ± 0.16 µl for the 1.5% concentration of boric acid (Figure 2). In contrast, house flies in the control group consumed more than a 3-fold volume of the sucrose-only solution (17.1 ± 0.19 µl) (F = 122.1, df = 2, 51, $P \leq 0.0001$).

Consumption of treated and untreated sucrose solutions was similar during the first two hours (Figure 3) (F = 0.81, df = 2, 24, $P \leq 0.45$). Thereafter, consumption of boric acid-treated solutions was significantly less than for the untreated solution at the 6–8 hr observation (F = 8.5, df = 2, 24, $P \leq 0.0017$). We examined the gut of the test flies for the presence or absence of blue-colored solutions. Freshly dissected flies of the control group had full abdomens, while those that were provided the boric acid-laced bait solution were clearly emaciated and their guts were empty. In addition blue-colored regurgitation and fecal droplets were readily apparent on control cups, while little specking was evident for the boric acid treatments.

Accumulated mortality of boric acid treatments and starved flies were significantly different from the untreated control (F = 142.3, df = 3, 56, $P \leq$ 0.0001) (Figure 4). Mortality rates for boric acid bait-fed flies paralleled that of starved flies during the 12–24 h period (Figure 4). Total accumulated mortality after 24 hr for flies receiving the boric acid solution was not significantly different from that of starved flies (F = 2.0, df = 2, 18, $P \geq 0.164$).

The mode of action of boric acid toxicity in insects is not well understood (Klotz et al. 2000) but may be linked to disassociation of the midgut epithelium resulting in death by starvation and neurotoxicity (Habes et al. 2006). The accumulated mortality of the boric acid treatment groups and the absence of blue solution in the gut suggest that house flies died of starvation (Figure 4).

These results bring into question the utility of using boric acid sugar bait solutions for control of house flies in animal housing. In a swine nursery study, feeding stations containing boric acid equal to 2% in 0.5 M sucrose solution effectively controlled cockroaches (Gore et al. 2004). Although they observed flies



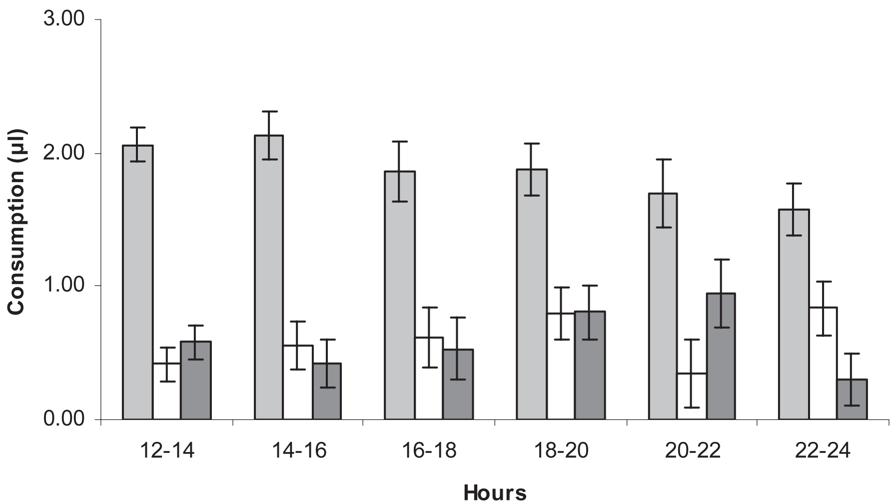


Fig. 3. Mean volume per fly (n = 25 flies) consumption at each 2 hr interval (12–24 hrs).

on the bait stations, it is likely that such high concentrations would not impact house fly populations if most flies were boric acid averse and there was an abundance of other available food sources. For example, we observed only slightly more than 12% of the flies fed on the boric acid solutions despite being starved for

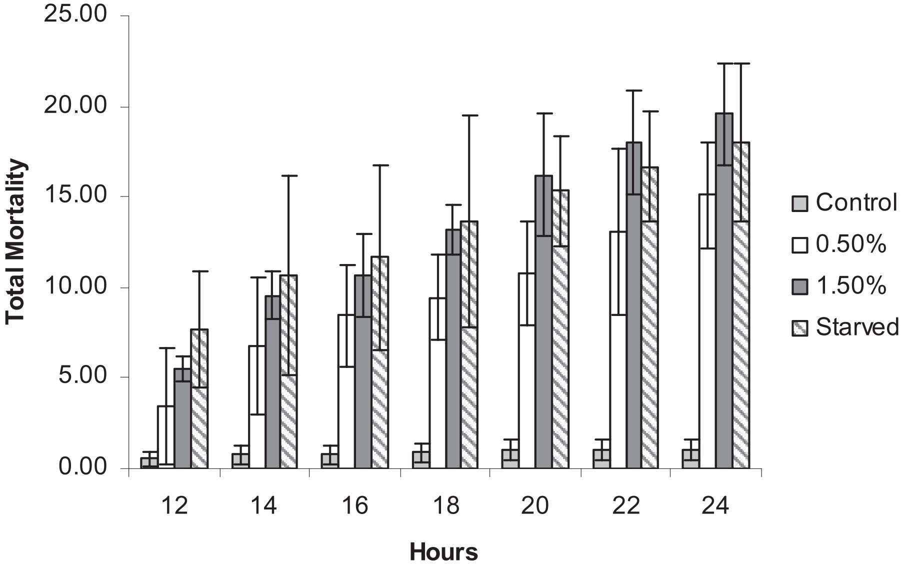


Fig. 4. Mean cumulative mortality (n = 25 flies) at each 2 hr interval (12–24 hrs).

10 hrs. In contrast, 68% of flies consumed the solution containing only sugar (Table 1). Of those that fed on the 1.5% boric acid solution, only 10% died after 120 hrs. This suggests that house flies avoid consuming boric acid in a liquid formulation and that more than a single feeding of these lower concentrations may be necessary to kill them.

Application of boric acid as a premises treatment may increase fly exposure. In caged experiments, fly specking on card surface-treated with a 10% boric acid solution was not significantly different than it was on untreated surfaces (F = 3.5, df = 1, 16, $P \leq 0.08$), 188 versus 131 mean spots per card, respectively. Perhaps, sprayed applications permitted to dry on landing surfaces may be a more efficient delivery by taking advantage of the house fly's grooming behaviors, leading to a greater cumulative dosage, and ingestion.

We expected that the boric acid solutions we tested would repel house flies based on previous studies suggesting boric acid-induced repellency was dose

Table 1. Number of flies feeding (%) on boric acid solutions (with 0.5 M sucrose) and cumulative mortality at 120 hrs (n = 300).

% Boric acid	No. flies fed (%)	No. dead flies (%)
1.50	37 (12.3)	4 (10.8)
0.50	39 (13.0)	2 (5.1)
0.00	204 (68.0)	3 (1.5)

dependent and a 2.25% boric acid solution was optimal (Hogsette & Koehler 1994). Interestingly, solution consumption was greatest at 2.25% boric acid. In contrast, we observed that house fly consumption of 0.5 and 1.5% boric acid was significantly reduced and flies starved in lieu of consuming boric acid. Starvation complicates any assumptions we may make about boric acid induced mortalities. We examined the digestive tracts of the test insects and observed little or no difference from insects that had died from the lack of food (Figure 4). Although mortalities were observed, Hogsette & Koehler (1994) did not examine flies for starvation.

From these data, it appears that a simple mixture of sugar water and boric acid as low as 0.5% is insufficient to induce fly feeding and formulation adjuvants would be needed to overcome borate aversion. Granular baits may have more promise (Mullens & Rodriguez 1992). Hogsette et al. (2002) reported success with freeze-dried baits created from sucrose and higher concentrations of boric acid (3 to 33%). However, these baits killed flies more slowly than by starvation. In our study, flies lived more than 120 hr after a single feeding on liquid boric acid and sucrose baits, suggesting that formulations that increase more frequent feeding are needed.

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