MORTALITY OF ANT (HYMENOPTERA: FORMICIDAE) PEST SPECIES EXPOSED TO SODIUM HYDROGEN CARBONATE

Authors: Mark A. Brinkman, and Wayne A. Gardner
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Laboratory bioassays enabled us to determine the mortality of Argentine ant (Linepithema humile [Mayr]) workers, and red imported fire ant (Solenopsis invicta Buren) workers exposed to sodium hydrogen carbonate (NaHCO$_3$), sodium bicarbonate). The median lethal concentration (LC$_{50}$) of NaHCO$_3$, for Argentine ants was 5.64 mg per cm$^2$ after 5 d exposure and 3.96 mg per cm$^2$ after 6 d. Cumulative mortality for Argentine ants exposed to 28 mg NaHCO$_3$, per cm$^2$ was 89.5% on day 6. Workers of both species were exposed to concentrations of 9.92, 17.70, or 152.00 mg NaHCO$_3$, per cm$^2$ in separate tests. Mortality of Argentine ants was significantly higher than that of fire ants following exposure to 9.92 mg NaHCO$_3$, per cm$^2$, while mortality for the two species did not differ following exposure to the two higher concentrations. Mortality of both species treated with the highest concentration exceeded 99% at 6 d. In tests with equivalent amounts of sodium in NaHCO$_3$, and NaCl treatments, mortality for fire ants exposed to NaHCO$_3$, was about 46% after 6 d. Mortality for fire ants exposed to NaCl was about 15% and was similar to that for untreated ants. Argentine ants were provided sugar water baits containing a range of NaHCO$_3$, concentrations. Argentine ant mortality after 6 d exposure to 5% NaHCO$_3$-sugar water treatment was about 50%. Mortality was not higher for workers exposed to higher concentrations of NaHCO$_3$, in sugar water baits. Enzymatic dysfunction caused by unfavorable increases in internal pH is the most likely explanation for worker mortality following exposure to NaHCO$_3$.

Key Words: Sodium bicarbonate, bicarbonate of soda, Argentine ant, red imported fire ant, pest ant, laboratory bioassays, Gut pH.

The Argentine ant, Linepithema humile (Mayr), and red imported fire ant, Solenopsis invicta Buren, are indigenous to South America. Both have become important pests in urban and agricultural areas in the southern United States (Callcott & Collins 1996; Suarez et al. 1999). Fire ants infest lawns and are nuisances as well as dangerous pests because of their aggressive behavior and sting. In surveys of South Carolina residents conducted by Lemke & Kissam (1989), 87% of respondents felt that they had a severe fire ant problem on their property, and 89% reported having one or more members of their immediate family stung by fire ants. Although Argentine
ants do not sting humans and livestock, they are considered a nuisance pest because they invade homes in search of food and nesting sites. Argentine ants are opportunistic feeders and will forage in garbage receptacles and pet food dishes (Rust et al. 2003).

Ant control in urban environments usually is accomplished with chemical insecticides (Pereira & Stimac 1997). Argentine ant control strategies have focused on the use of baits and the application of contact and barrier sprays and granules (Rust et al. 2003); however, most toxic or repellent barriers fail to provide long-term control, and commercial baits are not always accepted by foraging Argentine ants (Rust et al. 2003). Retreatments are often necessary, adding to the expense of ant control. Many homeowners find extensive use of insecticides in and around the home undesirable. Therefore, additional control methods with low toxicity are needed for urban pest ant management (Klotz et al. 1997a).

Brinkman et al. (2004) previously determined that S. invicta workers were susceptible to sodium hydrogen carbonate (NaHCO₃, also known as sodium bicarbonate) placed on surfaces and in liquid baits. Workers were not repelled by concentrations of NaHCO₃, and mortality was over 78% in treated arenas with liquid bait. They further reported that the median lethal concentration (LC₅₀) decreased from 9.66 mg per cm² on day 5 to 8.16 mg per cm² on day 6. Vinson (1970) tested the preferences of fire ants (S. richteri Forel) for various electrolytes (including NaHCO₃) in solution, but did not report on potential mortality following ingestion of those electrolytes. If effective against S. invicta and Argentine ants, NaHCO₃ could prove to be a safe alternative to conventional insecticides. The objective of this research, therefore, was to compare the mortality of Argentine ants and red imported fire ants after exposure to NaHCO₃ in simultaneous laboratory tests.

**MATERIALS AND METHODS**

Fire ant workers used in this study were obtained from monogyne field populations in Griffin, GA (Spalding Co.), and were removed from soil by procedures described by Jouvenaz et al. (1977). Argentine ants were collected from nests in logs and leaf litter on the Georgia Experiment Station campus. Although these ants were collected from different areas on the campus, they likely belonged to the same unicolonony (Giraud 2002). These laboratory colonies were maintained in plastic trays containing artificial nests constructed of plastic Petri dishes (150 × 10 mm) with dental plaster on the bottom to maintain moisture (Stimac et al. 1993). Fluon® (Northern Products Inc., Woonsocket, RI) was applied to the inside walls of trays to prevent ant escape. Ants were fed 10% sugar water (v/v) and tuna in oil.

The LC₅₀ of NaHCO₃ against Argentine ants was established in laboratory bioassays. Test arenas were clear 35-ml plastic cups. Each cup had a 5-mm diam hole in the bottom and contained dental plaster to about 10% of total cup volume. Lids for the cups were plastic and had a 1.2-cm diam hole to allow for air exchange. Fluon was applied to the inside walls of cups and undersides of lids. Ten cups were randomly assigned to each of the treatments.

Treatment concentrations were 0, 0.85, 1.7, 3.5, 7.0, 14.0, and 28.0 mg NaHCO₃ per cm². The NaHCO₃ was deposited as powder on the surface of dental plaster in the appropriate cups. Cups were lightly tapped to evenly distribute the material on the surface. Ten Argentine ant workers were placed in each container with a small quantity of sugar water for food. Cups were placed on a wet foam pad to maintain moisture within cups over the duration of the tests. Initially, the NaHCO₃ treatments were dry, but as water was drawn up through the dental plaster, they became slightly moistened. Mortality was checked daily for 6 d; dead workers were removed each day. Treatments were replicated 10 times in a randomized complete block design (RCBD). These tests were conducted four times between 03 October and 15 December 2003. Data were subjected to probit analysis (SAS Institute 1985) to obtain estimates of lethal concentrations and associated parameters. Concentration of NaHCO₃ was transformed by log (x + 1) prior to regression analysis and graphing of ant mortality data (SPSS Inc. 1998).

Potential differences in mortality of the two ant pest species from NaHCO₃ exposure also were determined in laboratory tests. Test arenas, application of treatments, and maintenance of ants and arenas were the same as previously described. In this test, fire ants and Argentine ants were exposed to 9.92 mg NaHCO₃ per cm², a concentration that approximated the LC₅₀ for fire ant workers following 5 d of exposure (Brinkman et al. 2004). Groups of 10 workers of each species were placed in the appropriate arenas and maintained as previously described. Mortality was checked daily for 7 d in the treatment and control arenas. Dead ants were removed each day. Treatments were replicated 5 to 10 times in a RCBD with each arena being a replicate. These experiments were repeated five times between 21 July and 5 August 2003.

Two higher concentrations were tested in separate assays by methods previously described. Both were compared to an untreated control. The concentration of 17.7 mg NaHCO₃ per cm² was evaluated three times between 18 December 2003 and 15 January 2004. The highest concentration of 152.0 mg NaHCO₃ per cm² was evaluated in five experiments between 16 January and 27 January 2004. Data resulting from these experiments were analyzed by the PROC MIXED procedure.
with repeated measures in SAS (Littell et al. 1996); means were separated with LSD ($P = 0.05$).

A range of concentrations of NaHCO$_3$ was tested in sugar water baits on Argentine ants. Test arenas and maintenance of ants and arenas were the same as previously described. A stock solution of sugar water was prepared by mixing 8.37 g (10 ml) of granulated sugar with 90 ml sterile distilled water. Concentrations of 0, 1, 5, 7.5, and 10% NaHCO$_3$—sugar water (v/v) were prepared (Table 2). Treatments were pipetted into 0.65-ml microcentrifuge tube lids, and these were individually placed on the dental plaster in cups. Treatments were replicated 10 times in a RCBD. Mortality was checked daily for 6 d. Dead ants were removed from cups each day. These tests were conducted three times between 20 February and 8 March 2004. Data were analyzed by the PROC MIXED procedure, and means were separated with LSD ($P = 0.05$).

Tests were conducted with equivalent amounts of sodium in the form of NaHCO$_3$ and sodium chloride (NaCl) to determine whether or not fire ant mortality would be similar for the two compounds. The total amount of either NaHCO$_3$ or NaCl placed in each test arena was 84.0 mg (11.898 mg per cm$^2$) of NaHCO$_3$ and 58.0 mg (8.215 mg per cm$^2$) of NaCl. Formula weight of NaHCO$_3$ is 84.00687 and is 58.44277 for NaCl (Whitten & Gailey 1981). Untreated arenas (control) were also included in these tests. Test arenas, treatment application, and maintenance of ants were the same as previously described. Treatments were replicated 10 times in a RCBD. Mortality was checked daily for 6 d, and dead ants were removed from cups each day. These experiments were repeated five times between 30 October 2003 and 18 January 2004 using fire ants from four different colonies. Data were analyzed by the PROC MIXED procedure with repeated measures in SAS (Littell et al. 1996), and means were separated with LSD.

**RESULTS AND DISCUSSION**

A positive linear relationship ($R^2 = 0.3665; F_{1,278} = 160.81; P < 0.0001$) occurred between NaHCO$_3$ concentration on surfaces and Argentine ant mortality (Fig. 1). Probit analysis of the concentration-mortality response of workers after 5 d exposure to NaHCO$_3$ yielded a LC$_{50}$ of 5.64 mg per cm$^2$ and 3.96 mg NaHCO$_3$ per cm$^2$ after 6 d (Table 1). This LC$_{50}$ is lower than that obtained for red imported fire ants on day 5, as reported by Brinkman et al. (2004). Argentine ant LC$_{50}$ followed a similar trend as that observed with fire ants by decreasing over time. Furthermore, fire ant mortality following exposure to 28 mg NaHCO$_3$ per cm$^2$ for 6 days was 66.0% (Brinkman et al. 2004), while Argentine ant mortality following 6 days of exposure to 28 mg NaHCO$_3$ per cm$^2$ was 89.5%. These results suggest that less NaHCO$_3$ is required to kill Argentine ant workers than fire ant workers.

Cumulative mortality for Argentine ants exposed to 9.92 mg NaHCO$_3$ per cm$^2$ was ($F = 9.85; df = 3.6; P = 0.0001$) higher than mortality of fire ants exposed to the same concentration over the 7 d of exposure. On day seven, cumulative mortality among Argentine ants exposed to NaHCO$_3$ was 38.9% ($\pm 5.5$) and was 35.6% ($\pm 4.9$) for fire ants exposed to NaHCO$_3$ (Fig. 2A).

### Table 1. Concentration—Mortality of Worker Argentine Ants after Exposure to NaHCO$_3$ for 5 to 6 d (N = 400 in Each Treatment).

<table>
<thead>
<tr>
<th>Day</th>
<th>LC$_{50}$ (95% CL)</th>
<th>LC$_{95}$ (95% CL)</th>
<th>Slope ± SE</th>
<th>$\chi^2$</th>
<th>$P &gt; \chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5.64 (2.74-13.10)</td>
<td>210.0 (50.0-26930.0)</td>
<td>1.05 ± 0.21</td>
<td>24.6</td>
<td>0.0001</td>
</tr>
<tr>
<td>6</td>
<td>3.96 (1.84-7.60)</td>
<td>150.0 (40.0-7700.0)</td>
<td>1.04 ± 0.20</td>
<td>28.2</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Mortality of Argentine ants and fire ants exposed to 17.7 mg NaHCO₃ per cm² was \((F = 24.20; \ df = 3,6; \ P = 0.0001)\) higher than mortality for their respective untreated controls over the 6 d of the test. Following correction for control mortality \(\text{(Abbott 1925)}\), Argentine ant mortality was 99.09% and fire ant mortality was 99.47% after 6 days of continuous exposure to 152.0 mg NaHCO₃ per cm² \(\text{(Fig. 2C, non-corrected mortality)}\). This concentration was the predicted LC₉₅ for Argentine ants following 6 d exposure to NaHCO₃. However, mortality for both species was higher than 95% in less than 6 d. In fact, almost all workers of both species were killed by this concentration after only 4 d of exposure. These results suggest that, at lower concentrations, there may be small differences in mortality of workers of these two species; however, as concentration of NaHCO₃ is increased, the mortality of the two species is similar.

Cumulative mortality for fire ants provided untreated sugar water was \((F = 14.46; \ df = 4,5; \ P = 0.0001)\) lower than for the three highest concentrations of NaHCO₃ in sugar water at 6 d. The highest corrected mortality was 49.56% in the 5.0% NaHCO₃-sugar water treatment \(\text{(Table 2, non-corrected mortality)}\). However, this was not \((P > 0.05)\) different from ant mortality for the 7.5% NaHCO₃-sugar water treatment. Corrected Argentine ant mortality in the highest concentration of NaHCO₃ in sugar water was 29.20% after 6 d. A range of concentrations of NaHCO₃ mixed in sugar water was tested, yet the greatest mortality was observed in the 5% NaHCO₃-sugar water treatments. A concentration-dependent relationship did not occur beyond this level. A similar trend was observed with fire ants provided sugar water treatments containing NaHCO₃ \(\text{(Brinkman et al. 2004)}\). Brinkman et al. (2004) concluded that excess NaHCO₃ had settled out of solution in the higher concentrations and was not available for ant consumption. In this study, some precipitate was observed in the bottoms of lids.

**TABLE 2. CUMULATIVE MORTALITY FOR ARGENTINE ANTS (N = 100 PER TREATMENT PER TEST) PROVIDED SUGAR WATER AND NaHCO₃.**

<table>
<thead>
<tr>
<th>Food Treatment</th>
<th>Mean # Dead (day 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated sugar water</td>
<td>24.67 ± 3.31a</td>
</tr>
<tr>
<td>0.113 g NaHCO₃ in 9.9 ml sugar water (1%)</td>
<td>30.33 ± 3.47a</td>
</tr>
<tr>
<td>0.563 g NaHCO₃ in 9.5 ml sugar water (5%)</td>
<td>62.00 ± 4.11c</td>
</tr>
<tr>
<td>0.844 g NaHCO₃ in 9.25 ml sugar water (7.5%)</td>
<td>55.67 ± 4.86c</td>
</tr>
<tr>
<td>1.125 g NaHCO₃ in 9.00 ml sugar water (10%)</td>
<td>46.67 ± 4.53b</td>
</tr>
</tbody>
</table>

Means (+ SEM) followed by same letter are not different \(\text{(LSD, } P > 0.05)\).
containing 10% NaHCO₃-sugar water treatment, yet mortality for Argentine ants exposed to this concentration was significantly higher than mortality for Argentine ants provided untreated sugar water. Therefore, we concluded that workers were not repelled by the higher concentrations of NaHCO₃ in sugar water. Vinson (1970) found that fire ants workers preferred NaHCO₃ in solution over NaCl in solution. Preferential response to sodium was variable in comparison with other cations (Vinson 1970). Brinkman et al. (2004) conducted tests in arenas in which fire ants could feed on sugar water or sugar water containing NaHCO₃. In those tests, fire ant mortality was much higher in arenas with both sugar water and sugar water containing NaHCO₃ than it was in arenas with sugar water only. Brinkman et al. (2004) concluded that fire ants were not repelled by NaHCO₃ in food.

Fire ant mortality following exposure to NaCl was \((F = 22.76; df = 2.5; P = 0.0001)\) lower than mortality occurring among those workers exposed to NaHCO₃ (Fig. 3). Worker mortality in response to NaCl was 15.4% at 6 d and did not differ \((P > 0.05)\) from mortality of untreated ants. Fire ant mortality following 6 d exposure to NaHCO₃ was 46.2%. Brinkman et al. (2004) found that whole-body pH of fire ant workers exposed to NaHCO₃ increased with increasing concentration of NaHCO₃. They theorized that fire ants ingested NaHCO₃ while cleaning appendages and that the resultant changes in internal pH were unfavorable to normal enzymatic functions. According to Tortora & Grabowski (1996), sodium hydrogen carbonate contributes hydroxide ions \((\text{OH}^–)\) to solutions causing increases in pH. However, Bigner et al. (1997) attributed the alkalinizing action of NaHCO₃ to Na⁺ and they based this on the strong ion difference theory. In the theory of strong ion difference in acid-base physiology (Stewart 1983), addition of non-metabolizable, positively charged cations to a body fluid compartment raises the pH of that compartment. Bigner et al. (1997) tested three Na compounds to determine which was best for treating metabolic acidosis in dairy cattle. Blood pH and blood HCO₃⁻ increased in the NaHCO₃ treatment, and was much higher than that observed for NaCl. They assumed, based on the theory, that the NaCl treatment did not alter blood pH because both the positively charged cation Na⁺ and the negatively charged anion Cl⁻ were absorbed equally well and added no net charge to the blood fluid compartment. This suggests that Na⁺ may have played a role in killing fire ants by raising pH, but only when delivered in the form of NaHCO₃, and not as NaCl. According to Audesirk et al. (2002), salts dissociate into ions in solution, and may then form bonds with enzymes and interfere with the enzymes’ normal three-dimensional structure. Also, changes in pH may modify the structure of enzymes and strongly alkaline solutions can denature enzymes (Conn & Stumpf 1976).

Hertel (1997) tested NaCl and KCl as protectants for pinewood against attack of a longhorn beetle species \((Hylotrupes bajulus\ (L.))\). Both compounds were effective, but NaCl provided better protection than KCl. Dehydration of beetle larvae after feeding on salt treated wood was offered as a possible explanation for mortality. In our study, the role of dehydration in deaths of fire ants exposed to NaCl and NaHCO₃ on surfaces was minimal because workers had unrestricted access to untreated sugar water.

Optimal procedures for use of NaHCO₃ as an ant control treatment in the home have yet to be determined. According to Klotz et al. (1997a), dusts are an excellent formulation for insecticides because ants readily pick up dusts that are applied to their trails. This may be an acceptable application strategy for NaHCO₃ in that Brinkman et al. (2004) determined that fire ants were not repelled by NaHCO₃ and would readily forage over treated areas. Crust will develop on NaHCO₃ powder if it is exposed to moisture and then dries. Therefore, retreatment may be necessary on unprotected ant trails. Klotz et al. (1997a) suggest that dusts could be applied during home construction when there is easy access to wall voids. Knight & Rust (1990) reported that repellency often determines how much contact an insect will have with a toxicant and that very low repellency treatments may produce high kill, even with only intermediate toxicity, because of increased contact with the treatment.
Sugar water has been used as a bait carrier for boric acid against fire ants (Klotz et al. 1997b) and Argentine ants (Klotz et al. 2002). Sucrose solutions are attractive to Argentine ants and are a means of transporting toxicants into the colony (Hooper-Bui & Rust 2000). Sodium hydrogen carbonate is inexpensive, easy to handle, and generally recognized as safe (GRAS) for use in foods (Montville & Goldstein 1987). Thus, sugar water baits containing NaHCO₃ could be used safely in the homes with children or pets. Toxicants that are effective in baits exhibit delayed action, are readily transferred between ants and kill the recipient, and are not repellent (Stringer et al. 1964). Perhaps an ant trail treatment with NaHCO₃ powder, sucrose baits containing NaHCO₃, or a combination of both, may provide safe methods of Argentine ant control in and around homes.

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References Cited


