Hunger in Red Imported Fire Ants and Their Behavioral Response to Two Liquid Bait Products

KATHRYN S. O'BRIEN AND LINDA M. HOOPER-BÙI

Department of Entomology, 404 Life Science Building, Louisiana State University Agricultural Center, Baton Rouge, LA 70803

J. Econ. Entomol. 98(6): 2153–2159 (2005)

ABSTRACT To help manage red imported fire ant, *Solenopsis invicta* Buren, invasion, several types of pest management systems have been developed, including baits. To accurately test liquid bait effectiveness in the laboratory, we determined that starvation time of 96 h is required for laboratory fire ants to simulate foraging ants in the field. We measured density and viscosity of two commercial baits and 20% sugar water at 25°C and then compared amount of material consumed per ant at these physical properties. Mean densities of 20% sugar water, Dr. Moss, and Terro were 1.051, 1.287, and 1.354 g/ml, respectively, and viscosity of each bait treatment varied in the same order but more drastically (1.7, 32, and 400 centipoises, respectively). Field and laboratory studies demonstrated that bait acceptability may be affected by toxicant and physical properties. Baits that are more dense have more mass per volume and may cause the ant to cease feeding with a lower crop load than when they feed on sugar water. Ants that feed on formulated baits exhibit feeding behaviors different from those that occur when feeding on sugar water. At first glance, one might conclude that the difference is because of the toxicant, but our findings suggest that physical properties of baits may be a factor in this change in feeding behavior.

KEY WORDS *Solenopsis invicta*, crop load, boric acid, starvation, viscosity

RED IMPORTED FIRE ANTS, *Solenopsis invicta* Buren, have been a major pest in southeastern United States since the early 20th century (Taber 2000), especially in and around homes, businesses, and anywhere there may be food or appropriate microhabitat. To help manage fire ant invasion, several types of pest management systems have been developed, including baits. Baits have three main advantages: baits require very low concentrations of insecticide, they eliminate the need to treat the nest, and they provide suppression of the entire colony, instead of just the foraging workers (Klotz et al. 1997).

Three forms of baits used for the management of ants are granular, liquid, and gel. Granular baits have been developed and are used more readily because they are easy to use and maintain. Most just need to be distributed around mounds or broadcast only once for adequate suppression. Liquid and gel baits are also available, but little research has been performed on these even though they may work more efficiently than granular baits, especially in areas with little water availability (Vail et al. 2003). Red imported fire ants will collect liquid 5 times more frequently than solid food (Tennant and Porter 1991); therefore, liquid bait may infiltrate the mound faster than granular bait. Also, Silverman and Roulston (2001) showed that *Linepithema humile* (Mayr) handled liquid sucrose solution more efficiently than the same solution given in a gelatin form. In contrast, Kidd and Apperson (1985) show that *S. invicta* recruitment to liquid soybean oil bait is slower than recruitment to granular soybean oil bait; however, the method of delivery of the liquid bait (vials fitted with cotton wicks) limited the surface area available to ants. The granular bait offered larger surface area, a major factor in foraging rates (Kidd and Apperson 1985). Given the importance of liquid food in the mound, bait provided in liquid form will attract many ants.

New liquid baits need to be tested for palatability and attractiveness to the target ants. Many times, researchers offer large colonies of ants the baits alone or with a choice test to determine attractiveness in the laboratory (Reid and Klotz 1992, Klotz and Reid 1993, Hooper-Bùi Rust 2000). Similar experiments are performed to determine palatability in the field. It is possible that physical properties of the baits and the time that the ants are starved affect the results of those experiments.

The amount of time food is withheld differs in laboratory bait acceptance studies. Sorensen et al. (1981) performed a feeding study with fire ants that were starved for 3 to 5 d. Klotz et al. (1997) and Glunn et al. (1981) only starved fire ants for 1 d. In another study, fire ants were starved 36 h before a foraging test (Pranschke et al. 2003).

0022-0493/05/2153–2159$04.00/0

Similar to starvation, sucrose concentration will also affect consumption in ants. Josens et al. (1998) tested multiple sucrose concentrations and found that *Camponotus mus* Roger will leave a diluted [5–15% (wt:wt)] sucrose source with partial crop loads after 2 d of starvation. They hypothesized that this behavior may be adaptive because the ant would leave the food source early to communicate with nestmates and perhaps find a better food source. This, however, would not explain why ants ingested the diluted source (low viscosity) at a low intake rate. In a later study by Josens and Roces (2000), crop load and differences in intake rate were found to depend on the nutritional conditions of the colony (feeding motivation). Also, another study that was conducted on *S. invicta* feeding on radiolabeled sucrose solution found that crop load depended on time starved (Howard and Tschinkel 1980). Given these results, *S. invicta* behavior and amount of food consumed will vary with time starved in bait preference studies.

To accurately test liquid and gel bait effectiveness in the laboratory, we determined the starvation time required for laboratory fire ants to simulate foraging ants in the field. We also wanted to determine whether the size of the fire ant could be associated with the amount of bait consumed. We measured the density and viscosity of each bait at 25°C and then compared the amount of liquid or gel consumed per ant to these physical properties. According to Cohen (2003), viscosity is the most important characteristic of diet texture, and it is a neglected topic in discussions regarding insect diets and liquid baits. The research described in this article provide data on the physical properties of selected baits that may be used to predict the response of ants to different types of liquid baits.

Materials and Methods

Physical Properties. Two types of commercial liquid baits were tested: Terro Ant Killer (Senoret Chemical Company, St. Louis, MO) containing 5.4% borax, and Dr. Moss's Liquid Bait System (J.T. Eaton & Co., Inc., Twinsburg, OH), containing 1% boric acid. We tested two serial numbers (1100A and 1200A) of Terro Ant Killer. Twenty percent sugar water (wt:wt) was used as an untreated control. We placed 1.5 ml of each treatment in a preweighed microcentrifuge tube and weighed them. Weight of the contents was divided by volume to obtain the density in grams per milliliter. The density measurement of each liquid was replicated three times. The viscosity of the sugar water and each bait was measured using a Brookfield digital viscometer (Brookfield Engineering Laboratories, Inc., Stroughton, MA), and values are reported in centipoises (cP = 100 kg/m s).

Ant Collection. Fire ant colonies were collected from Baton Rouge, LA, in February and April 2003. Colonies were taken to the laboratory and gradually flooded in large buckets to remove ants from the soil. One liter of water was poured into each colony every hour until the colony was floating for easy removal of ants from the soil. Each colony was placed in a large tray (580 by 350 by 90 mm) with Teflon (DuPont, Wilmington, DE) coated around the sides so ants could not escape. We provided each laboratory colony with "condos," 140-mm-diameter petri dishes with moist plaster of paris on the bottom and a lid darkened with black permanent marker to minimize light disturbance; water and 20% sugar water in 25-mm-diameter vials covered with mesh; and fresh dead crickets ad libitum. Colonies also were sampled from the field in Baton Rouge in June to compare with laboratory ants as a control. Approximately 30 ants were aspirated from each mound.

Bioassay. The purpose of this experiment was to determine the starvation time required for laboratory fire ants to simulate the levels of hunger among foraging fire ants in the field. Approximately 100 ants each from 12 monogyne, laboratory colonies were starved for either 72 or 96 h. Ants were collected outside of condos to improve the chance of collecting older workers/foragers. They were placed in a rectangular box (175 by 80 by 40 mm) coated with Teflon on the inside sides to prevent escape. The ants were given a small 35-mm-diameter condo and a 6-mm-diameter vial of water with cotton wick. Terro Ant Killer and Dr. Moss's Liquid Bait System were used as treatments, and 20% sugar water (wt:wt) was used as an untreated control.

Hooper-Bùi and Rust (2001) developed a method to measure toxicity of bait to individual ants. We modified their procedure to determine the acceptance of the bait to individual ants in the laboratory. Each ant was weighed individually to the nearest 0.1 μg in a 6-mm polyethylene genitalia vial (Bioquip Products, Inc., Rancho Dominguez, CA). The ant was released into a 20-mm petri dish and given a drop of sugar water or one of two baits on which to feed. After observing the ant drink to satiation and walk away from the food source, it was placed back in the vial and weighed again. The difference between the initial weight and the final weight determined the amount of liquid consumed.

All the replicates could not be done at the same time, so the experiment was conducted by subjecting the ants to the same starvation period, and all baits and the sugar water control were tested during this time. Individual ants were removed from three different colonies, starved, weighed, and offered the bait. We repeated this again for a total of six colonies and again for each starvation period. Ants from the field that were used as "controls" were aspirated from six different mounds. These ants were not analyzed for form (monogyne or polygyne); the landscape in Baton Rouge holds a mosaic of the two forms. Again, ants were captured outside the nest to improve the chance of collecting foragers. These field ants were used in the bioassay within 1 h after their capture to measure their bait consumption to represent the degree of hunger ants exhibit in the field. The field ant data created a standard to which we could compare our starved laboratory ant consumption. Colonies were considered replicates and individual ants from their respective colonies were considered subsamples. Only ants that fed were used in the analysis. We used the density of each liquid to calculate the volume that each ant consumed and the term we used for this is crop load after Josens et al. (1998). In cases where the body size was associated with crop load, we standardized the measurements by dividing the body weight into the crop load calculating relative crop load in microliters per milligram (Josens et al. 1998).

Field Choice Test. All baits and sugar water controls were placed near active foraging trails of fire ants. Measured amounts of bait and sugar water were placed in 1.5-ml microcentrifuge tubes, and they were placed on their sides equidistant from the ant foraging trail. This allowed the ants to make a choice between the baits and untreated sugar water control. We counted foragers visiting each vial at 20 min. Vials were collected at 1 h, weighed, and amount consumed was calculated. Ants trapped in vials after collection were counted for the number of ants visiting at 1 h.

Statistical Analysis. *Physical properties.* We compared the density of liquids using a one-way analysis of variance (ANOVA) and determined differences between the means using Tukey's adjustment (SigmaStat 3.0, SPPS Inc. 2003).

Size. We compared initial ant weights using a one-way ANOVA to determine whether there were differences among the weights of ants for each starvation period and bait type. We used a regression to determine whether the initial weight of the ant could be used to predict the amount of liquid the ant would consume. Regression was performed with weight of ant as the independent variable and amount consumed as the dependent variable for each starvation time and bait type (SigmaStat 3.0). We categorized the ants that fed into three weight categories and used an analysis of covariance model in PROC MIXED to determine whether larger ants could discriminate between bait and control sugar water (SAS Institute 2002).

Baits. We tested for difference in acceptance between the batches (based on serial numbers) of Terro (*t*-test). To determine whether the ants differentially fed on the baits and sugar water control, we analyzed the data with a two-way ANOVA model. We transformed the data with a natural log (ln) transformation to meet the requirements of the parametric test (SigmaStat 3.0). We used the number of hours starved, 72 and 96, as treatments and field-collected ants to test for differences; we also compared mean amount of bait consumed with 20% sugar water. We tested for interactions between time starved and amount of each bait consumed. For data with significant regressions of ant weight and crop load, we analyzed the relative crop load for each time period using one-way ANOVA (SigmaStat 3.0). Means were separated by a Tukey adjustment with $\alpha < 0.05$.

Field Test. A one-way ANOVA was performed to determine whether there were differences in amount of each bait taken when compared with the control. Significant means were separated by a Tukey adjustment with $\alpha < 0.05$. We regressed the number of individuals at the bait at 20 min and 1 h with the amount removed using linear regression (SigmaStat 3.0). Last, we performed a repeated measures analysis using PROC MIXED [type = autoregressive(1) on log plus 1 transformed data to see whether the number of ants visiting at 20 and 60 min was different for each bait; SAS Institute 2002]. Sample size requirements were met for the repeated measures analysis according to Von Ende (2001).

Table 1. Density and viscosity of tested baits

Bait	Density (g/ml)	Viscosity (cP)
20% sugar water	1.051 ± 0.004a	1.7
Dr. Moss	1.287 ± 0.010b	32
Terro	1.354 ± 0.006c	400

Density (mean ± SEM) was calculated by dividing the measured mass by a known volume of a sample of bait. Viscosity was measured using a digital viscometer. Means with different letters are significantly different ($P < 0.05$; Tukey adjustment).

Results

Physical Properties. Density and viscosity was found to change with change in treatment. The densities of 20% sugar water, Dr. Moss, and Terro were 1.051 ± 0.004 (mean ± SEM), 1.287 ± 0.010, and 1.354 ± 0.006 g/ml, respectively (Table 1). Significant differences were found between all density values ($F = 470.9$, df = 2, $P < 0.001$). The viscosity of each bait treatment varied in the same order (sugar water < Dr. Moss < Terro) but more drastically (1.7, 32, and 400 cP).

Size. The initial size of ants did not depend on their origin; however, the decision to feed at a food source depended on the type of food. The mean initial weights of laboratory ants starved for 72 and 96 h were similar (0.824 ± 0.138 [mean ± SEM] and 0.824 ± 0.129 mg, respectively), whereas ants from the field initially weighed more (1.20 ± 0.123 mg) but not significantly more ($F = 2.91$, df = 2, $P = 0.060$). Sixty-six percent of ants (or 34 ants, $n = 51$) fed after 72 h of starvation, 61% (or 24 ants, $n = 39$) fed after 96 h of starvation, and 45% (or 33 ants, $n = 72$) field ants fed. Thirty-five percent (or 15 ants) of all ants offered Dr. Moss were observed to feed compared with 62% (or 46 ants) and 66% (or 30 ants) of ants offered Terro and sugar water, respectively (Fig. 1). Grouped by bait treatment types, ants feeding on sugar water, Dr. Moss, and Terro initially weighed 0.861 ± 0.133 (mean ± SEM), 0.935 ± 0.1912, and 1.040 ± 0.110 mg, respectively, and were not significantly different ($F = 0.47$, df = 3, $P = 0.702$).

The association of initial ant weight and amount consumed depended upon whether the ants came directly from the field and how long the laboratory ants were starved. Initial weight of ants from the field was associated with amount of liquid (both baits and sugar water) consumed ($R^2 = 0.34$, $F = 16.2$, $P < 0.001$). Laboratory ants that were starved for 96 h also exhibited an association of initial weight with amount of liquid consumed ($R^2 = 0.54$, $F = 34.5$, $P < 0.001$),

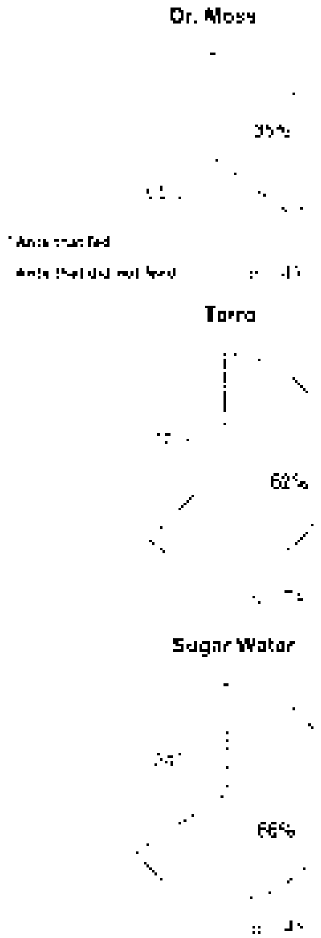

Fig. 1. Percentage of *S. invicta* that were observed to feed on the offered bait. The number of ants observed to feed for Dr. Moss, Terro, and sugar water was 15, 46, and 30, respectively.

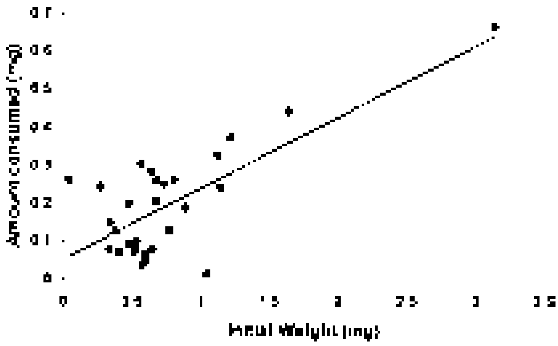

Fig. 2. Plot of initial weight versus sugar water consumed. Linear regression represented, $R^2 = 0.54$, $P < 0.001$.

but those that were starved for 72 h did not ($R^2 = 0.01$, $F = 0.31$, $P = 0.58$).

Initial weight of fire ants can be used as a predictor of how much sugar water they will consume in the laboratory. When all baits and the control are considered, initial weight of all the ants in the study was significantly associated with consumption of bait ($R^2 = 0.29$, $F = 35.9$, $P < 0.001$). Sugar water consumption (mass) was significantly associated with initial ant weight ($R^2 = 0.54$, $F = 95.5$, $P < 0.001$; Fig. 2), but both Dr. Moss and Terro consumption by ants were not associated with initial ant weight ($R^2 = 0.26$, $F = 4.61$, $P = 0.051$ and $R^2 = 0.053$, $F = 2.45$, $P = 0.12$, respectively). When we categorized sugar water control ants as small (0–0.61 mg), medium (0.62–1.0 mg), and large (1.01–4.3 mg), only the weight of ants that were in the medium and large categories was associated with amount consumed ($t = 2.31$, $P = 0.02$ and $t = 7.38$, $P < 0.0001$, respectively). The initial weight of small ants was not associated with amount consumed ($t = 1.01$, $P = 0.31$). When all ants were analyzed together, only the weight of the large ants was significantly associated with amount of sugar water consumed ($t = 4.72$, $P < 0.0001$).

Baits. No significant difference was found between the amount consumed for each starvation period/bait combination ($F = 1.892$, df = 6, $P = 0.092$). The degree of hunger in ants affected their consumption of the baits ($F = 4.226$, df = 2, $P = 0.018$; Fig. 3). When the amount consumed by starved and field ants offered all bait types was compared, no significant difference was found between those starved for 96 h and ants from the field ($P = 0.987$). Significant differences were found between both 96 and 72 h ($P = 0.027$) and 72 and 0 h ($P = 0.05$).

The amount consumed also was affected by bait treatment type ($F = 8.073$, df = 3, $P < 0.001$). There were no differences ($P = 0.983$) between the batches (based on serial numbers) of Terro; therefore, all the data for Terro were then combined. Ants fed on sugar water (0.242 ± 0.04 mg [mean ± SEM]) more readily than Terro (0.081 ± 0.05 mg) and Dr. Moss (0.112 ± 0.07 mg). Significant differences were found between the amount consumed for sugar water and Terro ($P = 0.002$) and sugar water and Dr. Moss ($P = 0.008$); however, the amounts of Terro and Dr. Moss consumed were not different ($P = 0.993$). For ants that fed on Terro and Dr. Moss, comparison of the means between starvation groups shows no significant difference between 96-h group and ants from the field (Fig. 4). The mean amount consumed for the 72-h group was less than the amount consumed for the 96-h group and ants from the field for both baits and sugar water. Terro contains 5.4% borax (equivalent to 3.6% boric acid; Anonymous 1997), whereas Dr. Moss contains only 1% boric acid. These percentages (3.6% for Terro) were multiplied by the amount consumed for each bait and starvation period to obtain the total amount of toxicant consumed for each combination (Fig. 4). Ants that fed on Dr. Moss consumed 0.251, 1.547, and 1.563 μg of toxicant, and those that fed on Terro consumed 1.646, 2.88, and 3.275 μg of toxicant after 72-, 96-, and 0-h starvation (field ants), respectively.

The amount taken, after conversion from mass to volume (crop load), changed differentially as a con-

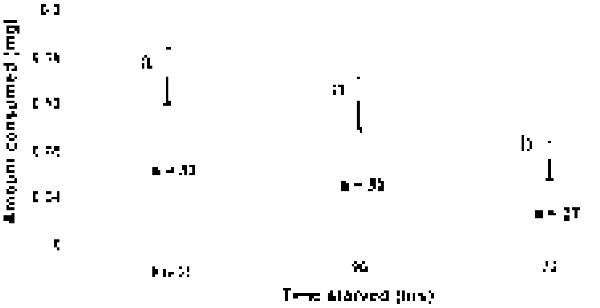

Fig. 3. Period of starvation as categories and the amount consumed for all baits. *n*, sample size; different letters are significantly different ($P < 0.05$).

sequence of the density of each bait (Table 1). The volumes of bait (mean ± SEM) ants removed were 0.231 ± 0.04, 0.06 ± 0.05, and 0.087 ± 0.06 of sugar water, Terro, and Dr. Moss, respectively. When volume was used as the dependent variable in a two-way ANOVA analysis, the patterns of significance did not change although when comparing bait types, the differences of means according to the Tukey adjustment were larger. If only comparing the starvation groups, conversion to volume is not necessary. When we analyzed relative crop load for sugar water ants (ants feeding on sugar water had a final crop load that was significantly related to the initial weight), significant differences in amount removed were not observed ($F = 1.997$, df = 2, $P = 0.155$).

Field Test. In the field choice test, the mean ± SEM amount of sugar water, Terro, and Dr. Moss consumed was 0.182 ± 0.06, 0.104 ± 0.03, and 0.058 ± 0.01 g, respectively. No significant differences were found between amount consumed and liquid type ($F = 2.913$, df = 2, $P = 0.082$). The number of individuals visiting sugar water, Terro, and Dr. Moss vials was 7 ± 3.61 (mean ± SEM), 2 ± 1.36, and 0.286 ± 0.18 ants at 20 min and 42.14 ± 16.5, 21.86 ± 10.7, and 9.71 ± 6.5 ants at 60 min, respectively. Significant differences were found between the number of ants at 20 and 60 min at each bait type ($F = 19.15$, df = 1, $P = 0.0072$) but not between the baits ($F = 2.55$, df = 2, $P = 0.114$). However, when individual bait types were examined, correlations exist between the number of ants counted

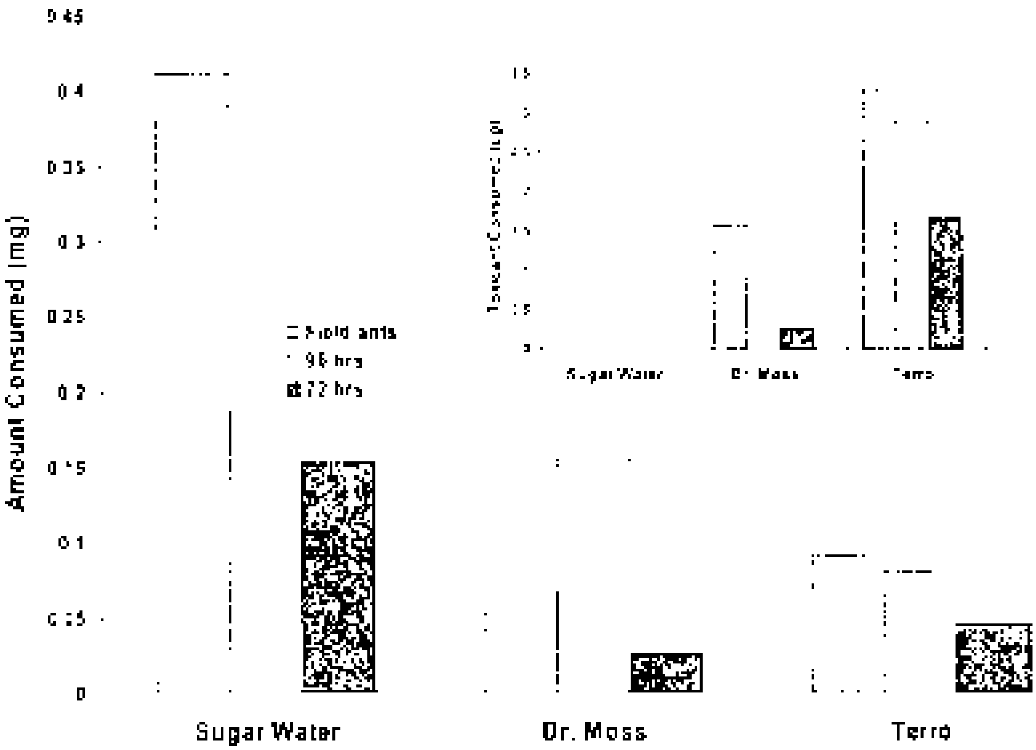

Fig. 4. Average amount consumed for each bait and starvation period in bar graph; the toxicant consumed represented in insert.

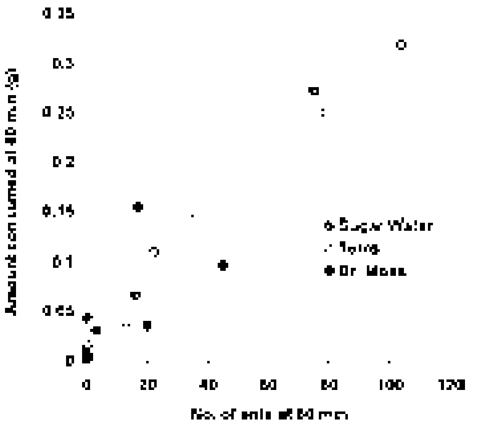

Fig. 5. Number of ants counted at vials after 60 min and the total amount consumed after 60 min for all three baits. Sugar water, $R^2 = 0.967$, $P < 0.001$; Terro, $R^2 = 0.967$, $P < 0.001$; Dr. Moss, $R^2 = 0.757$, $P = 0.011$.

at vials and amount consumed. A significant relationship was found between the number of ants visiting sugar water vials at 20 min and amount consumed ($R^2 = 0.971$, $F = 101$, $P = 0.002$), but the number of ants visiting Dr. Moss and Terro vials at 20 min was not related to amount consumed ($R^2 = 0.107$, $F = 0.480$, $P = 0.526$ and $R^2 = 0.541$, $F = 4.718$, $P = 0.096$, respectively). At 1 h, both baits and sugar water were significantly correlated with amount consumed (sugar water: $R^2 = 0.887$, $F = 31.4$, $P = 0.005$; Dr. Moss: $R^2 = 0.757$, $F = 15.6$, $P = 0.011$; and Terro: $R^2 = 0.967$, $F = 145$, $P < 0.001$; Fig. 5).

Discussion

Our results indicate that 96 h of withholding food is ideal for *S. invicta* compared with only 72 h of starvation. However, when starvation levels are compared in the sugar water group, the amount consumed was similar between 72- and 96-h groups. One reason for this interaction is the laboratory ants were accustomed to feeding on sugar water, whereas the field ants reacted differently to the unique sucrose food source. The major differences between the 72- and 96-h groups are seen when comparing the commercial bait types. The mean differences in the amount consumed between Terro and Dr. Moss baits for each starvation period were heavily dependent on the acceptability of the baits. Almost two-thirds of the ants offered Terro accepted the bait compared with a little over one-third of the ants offered Dr. Moss. This is also evident in the field choice test in which a more natural foraging pattern is seen for sugar water compared with the other bait types. Acceptability may be affected by the toxicant and the physical properties of the baits discussed below.

A significant relationship was shown for initial fire ant weight and amount of sugar water consumed. This relationship was highly significant ($P < 0.001$), which also has been found with *C. mus* (Josens et al. 1998). However, when ants fed on Terro and Dr. Moss, a significant relationship between ant weight and bait consumed was not found. There are two possibilities for this change in behavior: 1) the insecticide in each commercial ant bait may produce a negative behavioral reaction, such as avoidance or irritation, and interrupt the normal feeding pattern of an individual (Ave 1995); or 2) the viscosity of the bait changes foraging behavior (discussed below). Hooper-Bùi and Rust (2000) suggest that Argentine ant feeding behavior changes as concentration of boric acid increases. Although the total amounts of Terro and Dr. Moss consumed were not significantly different, the toxicant load of ants that fed on Terro was higher than for those that fed on Dr. Moss, especially for ants starved 96 h and ants from the field. Changes in feeding behavior with increasing toxicant concentration were shown previously in *S. invicta.* Klotz et al. (1997) fed multiple concentrations of boric acid in 10% sugar water solution to *S. invicta.* All solutions would have had the same viscosity, which eliminates it as a possible cause of varying ant behavior. At 5 and 1% boric acid, consumption was reduced compared with the 10% sugar water control.

Ants offered Terro ate 62% of the time, about the same as sugar water. Knowing that only 35% of ants offered Dr. Moss in the bioassay consumed some bait, avoidance or irritation may have occurred because of the Dr. Moss bait matrix. However, Terro may not cause negative effects on the behavior of red imported fire ants until after some portion is consumed. It is possible that the differences in consumption that we measured are not because of concentration of toxicant or viscosity of the bait but to the individual hunger of the foraging ant. Future experiments will tease out these details.

Physical properties were different among the two baits and the sugar water control. In addition to the effects of a toxicant, Terro also has the negative effects of viscosity on intake rate, which may explain why the amount consumed for Terro was less than sugar water in the time allotted in the field test. According to the number of ants that fed on each bait in the laboratory, Dr. Moss is less attractive than Terro or 20% sugar water, which explains why the Dr. Moss bait was least preferred in the field choice test, irrespective of the viscosity. Baits that are more dense have more mass per volume and may cause the ant to cease feeding with a lower crop load than when they feed on sugar water for all starvation times. As with diluted solutions, Josens et al. (1998) found that *C. mus* ants will leave a concentrated (70%) sucrose source with partial crop loads. They proposed that, as sucrose concentrations increased past 15%, the final crop load was dependent on the physical properties of the solution such as viscosity and density.

Along with mass values, we also analyzed the data using units of volume. Because all of the densities were greater than 1, volume values were less than mass values. The difference between mass and volume values varied with the type of bait treatment. So, mean differences and P values of crop load will be different than those associated with mass when compared between bait types but will be the same when compared between starvation times. For example, the mean mass of Dr. Moss bait taken is 0.112 mg, and the mean volume of Dr. Moss taken is 0.087 μl. The amount of sugar water taken is 0.242 mg or 0.231 μl. It is important to understand which measurement is appropriate for the question one is trying to answer. When we compared the differences in starvation, the crop load was irrelevant and need not be calculated, and when considering differences in consumption between bait types, crop load could be crucial.

The reason we analyzed the crop load was to calculate the relative crop load for sugar water-fed ants. When we analyzed the relative crop load, we may have negated the nutritional state of the colony. That is, ants that were starved for 96 h may weigh less than similar ants that were starved for a shorter time. This may explain why no significant differences were found in the relative crop load between the starvation times of sugar water-fed ants.

In conclusion, ants that feed on formulated baits exhibit feeding behaviors different from those that occur when feeding on sugar water. At first glance, one might conclude that it is the presence of the toxicant, but our findings on the physical properties of the baits indicate that they may be a factor in this change. When concentration of toxicant for liquid baits is investigated initially, the effective dose may be investigated with sugar water before formulation. The final formulation of the liquid bait may be vastly different from that which was tested and the physical properties of the bait may be a factor in ant acceptance of the bait. We highlight these differences in ant behavior; however, more research is needed to further describe the effects of viscosity and toxicants on *S. invicta* at liquid baits.

Acknowledgments

We thank Derek Dorman from the Department of Chemistry at Louisiana State University for help with viscosity measurements. This work was supported by funding from the State of Louisiana Legislature special grant to L.M.H.-B. We also acknowledge a scholarship to K.S.O. from the National Conference on Urban Entomology in 2004.

References Cited

Anonymous. 1997. Ecotoxicology of some inorganic borates. Special Report No. 11. European Centre for Ecotoxicology and Toxicology of Chemicals, Brussels, Belgium.

Ave, D. A. 1995. Stimulation of feeding: insect control agents, p. 347. *In* R. F. Chapman and G. de Boer [eds.], Regulatory mechanisms in insect feeding. Chapman & Hall, New York.

Cohen, A. C. 2003. Insect diets: science and technology. Boca Raton, FL.

Glunn, F. J., D. F. Howard, and W. R. Tschinkel. 1981. Food preference in colonies of the fire ant *Solenopsis invicta.* Insectes Soc. 28: 217–222.

Hooper-Bùi, L. M., and M. K. Rust. 2000. Oral toxicity of abamectin, boric acid, fipronil, and hydramethylnon to laboratory colonies of argentine ants (Hymenoptera: Formicidae). J. Econ. Entomol. 93: 858–864.

Hooper-Bùi, L. M., and M. K. Rust. 2001. An oral bioassay for the toxicity of hydramethylnon to individual workers and queens of Argentine ants, *Linepithema humile.* Pest Manag. Sci. 57: 1011–1016.

Howard, D. F., and W. R. Tschinkel. 1980. The effect of colony size and starvation on food flow in the fire ant, *Solenopsis invicta* (Hymenoptera: Formicidae). Behav. Ecol. Sociobiol. 7: 293–300.

Josens, R. B., W. M. Farina, and F. Roces. 1998. Nectar feeding by the ant *Camponotus mus:* intake rate and crop filling as a function of sucrose concentration. J. Insect Physiol. 44: 579–585.

Josens, R. B., and F. Roces. 2000. Foraging in the ant *Camponotus mus:* nectar-intake rate and crop filling depend on colony starvation. J. Insect Physiol. 46: 1103–1110.

Kidd, K. A., and C. S. Apperson. 1985. Recruitment of the red imported fire ant, *Solenopsis invicta,* to soybean oil baits. Fla. Entomol. 68: 253–261.

Klotz, J. H., L. Greenberg, H. H. Shorey, and D. F. Williams. 1997. Alternative control strategies for ants around the homes. J. Agric. Entomol. 14: 249–257.

Klotz, J. H., and B. L. Reid. 1993. Oral toxicity of chlordane, hydramethylnon, and imidacloprid to free-foraging workers of *Camponotus pennsylvanicus* (Hymenoptera, Formicidae). J. Econ. Entomol. 86: 1730–1737.

Pranschke, A. M., L. M. Hooper-Bùi, and B. Moser. 2003. Efficacy of bifenthrin treatment zones against red imported fire ant. J. Econ. Entomol. 96: 98–105.

Reid, B. L., and J. H. Klotz. 1992. Oral toxicity of abamectin, dechlorane, and sulfluramid to free-foraging workers of *Camponotus pennsylvanicus* (Hymenoptera, Formicidae). J. Econ. Entomol. 85: 1822–1829.

SAS Institute. 2002. Version 9.0. SAS Institute, Cary, NC.

SPSS Inc. 2003. SigmaStat, version 3.0. SPSS Inc., Chicago, IL.

Silverman, J., and T. H. Roulston. 2001. Acceptance and intake of gel and liquid sucrose compositions by the Argentine ant (Hymenoptera: Formicidae). J. Econ. Entomol. 94: 511–515.

Sorensen, A. A., J. T. Mirenda, and S. B. Vinson. 1981. Food exchange and distribution by three functional worker groups of the imported fire ant *Solenopsis invicta* Buren. Insectes Soc. 28: 383–394.

Taber, S. 2000. Fire ants. Texas A&M University Press, College Station, TX.

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.

Vail, K. M., D. Bailey, and M. McGinnis. 2003. Perimeter spray and bait combo. Pest Control Technol. July: 96–100.

Von Ende, C. N. 2001. Repeated-measures analysis, p. 138. *In* S. M. Scheiner and J. Gurevitch [eds.], Design and analysis of ecological experiments. Oxford: Oxford University Press, Oxford.

Received 1 June 2005; accepted 9 August 2005.