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Effects of Diet on the Growth of Laboratory Fire Ant Colonies (Hymenoptera: Formicidae)

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ABSTRACT: Laboratory colonies of the fire ant, *Solenopsis invicta*, were fed one of six diets: 1) sugar-water only, 2) insects only, 3) both insects and sugar-water, 4) an artificial diet, 5) an artificial diet plus insects, and 6) no food. Colonies with access to both insects and sugar-water grew almost 10-fold by the end of the experiment. Insects were essential; colonies lacking insects ceased brood production entirely. A sugar source, though not essential, was very important. Growth was reduced by 60% in colonies raised without sugar-water. A commonly used artificial diet was not a suitable substitute for insect prey. Even when this diet was supplemented with insects, it was no better than insects and sugar-water alone.

The diet of the fire ant, *Solenopsis invicta*, is generally assumed to consist primarily of insects and other small invertebrates (Vinson and Greenberg, 1986). However, a recent field study has shown that foragers often collect much larger quantities of liquids (Tennant and Porter, unpubl.). Sugars contained in these liquids are probably essential in fueling worker activities because workers are incapable of ingesting solid foods (Glancey et al., 1981). Williams et al. (1980) have shown that access to honey-water substantially increases the growth of laboratory colonies. Other studies have demonstrated that insects are essential for normal larval growth (Williams et al., 1987; Sorensen et al., 1983). Considerable

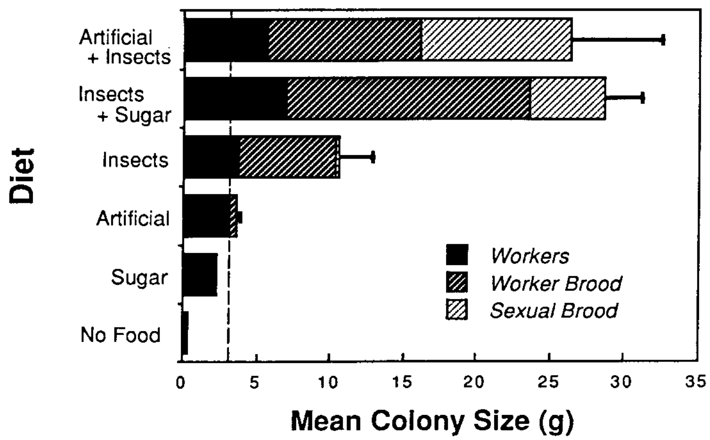

Fig. 1. Effects of diet on the live weights of experimental colonies after six weeks. Average weights of workers, worker brood and sexual brood are shown for each treatment. The dashed line shows the initial weight of test colonies. Each bar is the mean of four test colonies. Error bars show standard errors for total weight. All treatments were significantly different from each other in total weight ($P < 0.05$, Duncan's new multiple range test) except the top two and the fourth and fifth ones.

information is available concerning the flow and distribution of food within fire ant colonies (Sorensen and Vinson, 1981; Howard and Tschinkel, 1981); however, information about how diet affects colony growth is very limited. This study was designed to compare importance of both insects and sugar in the diet of fire ant colonies and also to test the effectiveness of a commonly used artificial diet.

MATERIALS AND METHODS: Ten large polygyne colonies were collected from the field and mixed together, a procedure that is possible because they were all polygynous. These colonies were mixed together in order to produce a sufficiently large source of workers and brood to set up 24 essentially homogeneous test colonies. Each test colony was initially composed of 2 g of workers (ca. 3000), 1 g of brood (ca. 1500) and 5 queens. Test colonies were established individually in 40 by 55 cm foraging trays with two large (15 cm) petri dish nests (Banks et al., 1981). Additional nests were added as colonies grew, taking care that excess nest space was always available. Colonies were maintained at 30 ± 2°C under natural lighting conditions.

Six diets were tested: 1) sugar-water only, 2) insects only, 3) both insects and sugar-water, 4) an artificial diet, 5) an artificial diet plus insects, and 6) no food. Four replicate colonies were used for each treatment. Sugar-water was provided in the form of "sugar wads" which consisted of small laboratory tissues wadded up and soaked in 1 M sucrose. Insects were provided in the form of frozen crickets (*Acheta domestica* L.) cut into several pieces. The artificial diet consisted of eggs, a vegetable purée, sugar wads, and gelatin food cubes each presented separately. The eggs (12) were hard-boiled, shelled, and ground in a blender with about 200 ml of water. Sorbic acid (2.5 ml) was added as a preservative. The vegetable purée consisted of 16 oz (470 ml) cans of the following: applesauce, creamed corn, sliced carrots, mixed vegetables, and stewed tomatoes. These vegetables were mixed with 5 ml of sorbic acid and a small amount of instant potatoes to thicken the mixture. Both the egg mixture and the vegetable purée were frozen until use. The food cubes were similar to those described by Banks et al. (1981) which were based on an earlier diet by Bhatkar and Whitcomb (1970). These cubes were made by blending together cooked ground beef (0.45 kg), peanut butter (15 ml), eggs (8), multiple vitamins (2 ml; Poly-Vi-Sol®, Mead Johnson), salt (2.5 ml), sorbic acid (5 g), and table sugar (237 ml). Next, dry baby formula (380 ml), and unflavored gelatin (50 g; Knox®, Knox Gelatine, Inc.) were dissolved in water (420 ml). Both mixtures were then combined and heated to boiling for several minutes. Baby cereal (120 ml) was then added and the mixture was poured into cake pans to jell. After several hours in the refrigerator, the jelled mixture was cut into small cubes and dipped in paraffin wax. Wax prevented the cubes from drying out too rapidly. The ants readily cut holes thorough the wax and removed the food as needed.

Food for each of the first five treatments was provided in excess quantities. Sugar wads were remoistened daily and replaced weekly or more frequently if warranted. Crickets, eggs and the vegetable purée were also provided daily to appropriate treatments. Food cubes were replaced twice a week. Workers in test colonies collected, dried, and stored large quantities of finely chopped crickets in and around their nests; the same behavior was also observed with the food cubes. Each colony also had continuous access to water from a test tube plugged with a cotton wad.

The total weight of each test colony was measured after 6 weeks. I also determined weights of workers, worker brood, and sexual brood for each colony. Workers and brood were separated using a combination of sieves and sorting sheets (Porter and Tschinkel, 1985). Average weights of colony queens and worker pupae were also determined. Finally, all colony queens were dissected to determine if they were inseminated.

RESULTS: After six weeks, the total weight of workers and brood in the treatments differed substantially (Fig. 1; one-way ANOVA; $F = 80.4$; d.f. = 5,18; $P = 0.0001$, data were log-transformed to equalize the variance). Colonies that received crickets plus sugar-water and those that received the artificial diet supplemented with crickets both grew dramatically and produced large quantities of sexual brood. Differences in brood production between these treatments were not significant ($P > 0.05$). Colonies that were fed only crickets also grew substantially (Fig. 1), but they were about 60% smaller than colonies which also received sugar-water. Colonies which only received the artificial diet grew slightly and contained only a small amount of worker brood. Colonies fed only sugar declined slightly and contained almost no brood. Colonies that were not fed declined substantially in weight so that only the queens and several hundred workers remained at the end of the experiment.

Average weights of nest queens and worker pupae differed among treatments, but these differences paralleled colony size. Seventy percent of queens were inseminated, and all test colonies contained at least two inseminated queens. No correlation was observed between colony growth and the number of inseminated queens. Only three of the original 125 nest queens died during the experiment.

DISCUSSION: Sugar solutions and arthropod prey are both very important components of fire ant diets (Fig. 1). Arthropod prey is essential for brood production. Colonies fed only sugar-water terminated larval production within a few days, probably because protein was not available. Studies of food flow in fire ant colonies have demonstrated that protein-rich foods are primarily channeled to the larvae (Sorensen and Vinson, 1981; Howard and Tschinkel, 1981); in fact, fourth instar larvae are the only members of a colony capable of ingesting solid food (Petralia and Vinson, 1978). This is probably why laboratory colonies without larvae ignore insect prey even though sugar-water remains attractive (unpubl. obs.).

Sugar solutions are also very important to fire ant colonies. Test colonies fed only insects exhibited substantial growth, but the absence of a sugar-water reduced growth potential by 60% (Fig. 1). Williams et al. (1980) reported very similar results using honey-water. These authors also found that honey-water was more attractive after 5 min trials than sucrose-water, but it is unknown whether this taste preference would translate into higher growth rates. I used sucrose-water in these tests because it is easier to handle and does not seem to spoil as rapidly. Granular sugar, heavy syrups, and pure honey are generally ignored by foragers.

Studies of colony food flow (Howard and Tschinkel, 1981) show that sugar solutions are initially directed to the workers. As stated by Brian (1983) "sugars as fuel save prey"; in other words prey can be reserved for larval production when sugar solutions are available to power worker activities. The importance of sugar solutions to fire ants is illustrated by the fact that worker respiration requires about 60% of a colony's total energy budget (Porter and Tschinkel, 1985). Workers in many other ant species also rely heavily on sugars to fuel their worker force (Brian, 1983; Quinlan and Cherrett, 1979); this has been particularly well demonstrated with the ant, *Myrmica rubra* (Brian, 1973).

As mentioned previously, fire ant workers are not capable of ingesting solid food. This presents the problem of how my test colonies grew and survived on a diet of only insects (Fig. 1). Apparently workers in these colonies were able to obtain enough energy either directly from hemolymph fluids or indirectly from liquids regurgitated by the larvae. The absence of sugar-water might have had even more serious effects on these colonies had not copious amounts of insect food been available.

Tests of the artificial diet were disappointing (Fig. 1). Colonies fed the artificial diet gradually ceased brood production. The artificial diet supplemented with crickets was much more satisfactory; nevertheless, growth was no better than in colonies fed crickets and sugar-water alone. The artificial diet might reduce the need for large quantities of insects, but the cost of crickets (ca. $15.00/1000) is probably less than costs of preparing and distributing the artificial diet. This study only lasted six weeks. Vitamins provided in the artificial diet might benefit colonies over a much longer time frame, but this seems unlikely considering the diet's poor performance alone. Furthermore, I have maintained healthy laboratory colonies using only crickets and sugar-water for periods of more than a year.

The problem with the artificial diet appears to be nutritional rather than gustatory because colonies readily collect and store large quantities of this diet. The problem could be a missing nutrient or a nutrient that is not accessible for digestion and assimilation. Perhaps boiling the mixture destroys essential nutrients. Williams et al. (1987) reported that hamburger is nutritionally deficient as a substitute for insects. Colonies fed hamburger produced unpigmented workers, a condition that was reversed with the availability of insects. In conclusion, this study has addressed several basic dietary requirements of fire ants, but considerable work remains to be done in regards to specific nutrients. A number of artificial diets have been proposed (Banks et al., 1981; Bhatkar and Whitcomb, 1970), but none has yet proven to be a suitable substitute for insect prey.

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