Fly Pupae as Attractant Carriers for Toxic Baits for Red Imported Fire Ants (Hymenoptera: Formicidae)

D. F. WILLIAMS, C. S. LOFGREN, AND R. K. VANDER MEER

Insects Affecting Man and Animals Research Laboratory,
USDA–ARS, Gainesville, Florida 32604

J. Econ. Entomol. 83(1): 67–73 (1990)

ABSTRACT Eight laboratory-reared ant species were fed baits of house fly, *Musca domestica* L., pupae treated with hydramethylnon. Two fire ant species, *Solenopsis invicta* Buren and *Solenopsis geminata* (F.), and *Pheidole morrissi* (Forel) were killed; average percentage of mortality of the five other species was <20%. In contrast, all species that were fed the commercial fire ant bait containing hydramethylnon (Amdro) died or were adversely affected. In the field, applications of house fly pupae and eye gnat, *Hippelates pusio* Loew, pupae dipped in acetone solutions of fenoxycarb significantly reduced population indices of the red imported fire ant, *S. invicta*, compared with commercial formulations of fenoxycarb (Logic) and hydramethylnon (Amdro). Field observations showed that the pupae of either species can be carried or moved by one or two worker ants. The smooth, hard cuticle of the pupae make them easy to handle and apply with application equipment. The current cost of house fly pupae is considerably more than the cost of a granular carrier, pregel defatted corn grits. However, if mass-production methods reduce this price differential, fly pupae could become an effective and more species-specific fire ant bait carrier.

KEY WORDS Insecta, *Solenopsis invicta*, baits, Diptera pupae

CHEMICAL BAITS have been preferred for control of the red imported fire ant, *Solenopsis invicta* Buren, in the United States since the early 1960s when a corn cob grit-soybean oil bait containing the highly effective toxicant mirex was developed (Lofgren et al. 1964). However, by the early 1970s, studies indicated that mirex residues were occurring in nontarget organisms (Ludke et al. 1971, Baetcke et al. 1972). The Environmental Protection Agency (EPA) discontinued all registrations of mirex in the United States at the end of 1977 (Johnson 1976). Since then, four new chemicals have been registered by EPA for fire ant control. One is a toxicant, hydramethylnon, marketed in a bait called Amdro (American Cyanamid Company, Wayne, N.J.). Two are juvenile hormone mimics, 1-(8-methoxy-4,8-dimethylnomyl)-4-(methylethyl) benzene marketed in a bait called Pro-Drone (Stauffer Chemical Company, Westport, Conn.) and fenoxycarb, formulated as Logic (Maag Agrochemicals, Vero Beach, Fla.). A toxicant and queen sterilant, abamectin, is derived from the soil fungus *Streptomyces avermitilis*, and formulated in the bait Affirm (Merck, Sharp & Dohme Research Laboratories, Three Bridges, N.J.). All of the baits were formulated by dissolving the chemical in the food attractant (soybean oil) and impregnating this solution on a granular carrier, pregel defatted corn grits.

Mention of a pesticide, commercial, or proprietary product does not constitute an endorsement or recommendation by the USDA.

Although these new baits are effective and do not leave residues in the environment, they lack species-specificity because of the soybean oil food attractant. Some nontarget ants feed on the bait, and populations of these species may be reduced. This problem was documented for mirex (Markin et al. 1972, 1974; Summerlin et al. 1977) and has been investigated with the newer bait toxicants (Edmunson 1981, Apperson et al. 1984, Lemke 1986, Phillips et al. 1986). Although these reports indicate that nontarget ant populations recover from a single bait treatment, they do not address the potential effects of multiple treatments. From previous studies we can assume that in areas where *S. invicta* is a serious pest or public health threat, repeated treatments will result in reduced populations of some nontarget insects.

Williams (1986) suggested the possible use of *S. invicta* pheromone attractants, phagostimulants, and biocontrol agents as methods to make bait formulations more specific. He also suggested that pupae of certain dipterans might be the basis of an entirely different bait, and he presented limited field data on the effectiveness of house fly, *Musca domestica* L., pupae treated with hydramethylnon or fenoxycarb for control of *S. invicta*. Here we present data on the efficacy of house fly pupae-fenoxycarb baits in the field; the potential of eye gnat, *Hippelates pusio* Loew, pupae as a bait carrier; the attractiveness and toxicity of house fly pupae-hydramethylnon baits to other ant species; and cost of pupae baits in comparison with commercial baits formulated with a pregel defatted corn grit carrier.

Materials and Methods

Laboratory Bait Tests. The efficacy and species specificity of house fly pupae as a carrier of the toxicant hydramethylnon was determined with colonies of *S. invicta*, *S. geminata* (F.), *Iridomyrmex pruinosum* (Roger), *Conomyrma bureni* (Trager), *Monomorium minimum* (Buckley), *Crematogaster clara* (Mayr), *Pogonomyrmex badius* (Latreille), and *Pheidole morrissi* (Forel). Queenright colonies were collected in or near Gainesville, Fla., at least 2 mo before they were tested. The ant species were reared according to the procedures described by Banks et al. (1981), except that 10-ml glass pipettes with tips removed were used as rearing containers for *C. clara* and grass seeds were added to the diet of *P. badius*. The house fly pupae were obtained from colonies reared by the Fly and Household Insect Research Management Unit of the Insects Affecting Man and Animals Research Laboratory, USDA–ARS, Gainesville, Fla.

Pupae were immersed in an acetone solution of 2.5% technical hydramethylnon (AC 217300; American Cyanamid Company, Princeton, N.J.) for 30 min, after which they were rinsed for 5 s in acetone and air dried in an enamel pan under a fume hood for 24 h. Ant colonies were starved for 5 d before tests. Five grams of the house fly pupae bait was then offered to each colony, and the ants fed ad libitum for 4 d. The remaining bait was removed and the colonies were provided with their normal diet. With the exception of *S. invicta* ($n = 8$) and *S. geminata* ($n = 4$), two colonies of each species were tested with the house fly pupae bait. Two colonies, with the exception of *S. invicta* ($n = 4$) and *S. geminata* ($n = 4$), were offered commercially formulated Amdro bait (5 g, 0.88% AI). Ten colonies of each *Solenopsis* species and two of the other species were maintained under the normal rearing regime as untreated controls. A combined estimate of brood and worker mortality was made weekly. Previous tests had shown that the effects of ingestion of Amdro bait were apparent within this time. Colonies were examined carefully each week to determine if the queen was alive. If the queen, eggs, and brood were present at the end of 9 wk, the colony was considered normal; if not, the colony was considered dead.

Field Bait Tests. Preliminary field tests by Williams (1986) showed that house fly pupae baits treated with the insect growth regulator fenoxycarb were significantly more effective than those treated with hydramethylnon. Because of these results, two field tests with baits were done only with fenoxycarb. In one of the tests, we also evaluated eye gnat pupae as a bait-toxicant carrier. These pupae were obtained from the West Florida Arthropod Research Laboratory, Health and Rehabilitative Services, State of Florida, Panama City, Fla.

House fly pupae and eye gnat pupae baits were prepared in a manner similar to those for the laboratory tests except that the pupae were immersed in various acetone concentrations (3, 6, 12, or 18%) of fenoxycarb for either 30 min or 24 h, after which they were either air dried directly under a fume hood for 24 h or rinsed for 5 s in clean acetone and then air dried. A commercial formulation of fenoxycarb (Logic) or hydramethylnon (Amdro), or both, was applied as the standard for comparisons. Untreated plots were used as controls.

The tests were done on natural populations in ungrazed pastures in Brooks County, Ga., and Alachua County, Fla. In the Brooks County test, we compared three different formulations of house fly pupae applied at different rates per hectare. In the Alachua County test, we compared different fenoxycarb concentrations and application rates. A formulation of fenoxycarb in soybean oil impregnated on pregel defatted corn grits was also applied as a standard in both tests.

All treatments were applied with a tractor-mounted auger applicator (Williams et al. 1983) to 0.4-ha plots located on ungrazed permanent pastures. Each treatment was replicated three times; however, some of the plots in Brooks County were only replicated twice. Observations before and after treatment and evaluations of all active nests were done on 0.2-ha circles within the center of the treated plots. Each nest within the circles was carefully examined to estimate the number of workers and whether or not worker brood (eggs, larvae, and pupae) was present. This procedure was done at 15 and 24 wk in the first test (November application), and at 8 and 16 wk in the second (June application). The time intervals differed because fall treatments act very slowly. The rating system developed by Harlan et al. (1981) and later revised by Lofgren & Williams (1982) was used to place a numerical index on the size of each colony. The sum of the ratings for all the colonies in a plot was the population index for that plot. Population indices before and after treatment of each plot were used to calculate the percentage of control. Untreated plots were examined in the same manner.

Data were analyzed by the general linear model (GLM) procedures (SAS Institute 1985, 433–506) with percentage of reduction as the dependent variable. Mean values were compared with Duncan's multiple range test (Duncan 1955) at the $P = 0.05$ level.

Chemical Analysis for Fenoxycarb. Because bait preparation involved soaking the fly pupae in an acetone solution of a chemical, we did not know how much remained on or within the pupae. Consequently, we analyzed pupae for fenoxycarb content. The sample to be analyzed was weighed and macerated with three times the volume of acetonitrile (CH_3CN) (high-pressure liquid chromatog-

Table 1. Comparative mortality ($\bar{x}$ ± SEM) in laboratory colonies of eight ant species offered house fly pupae (HFP) or soybean oil-pregel defatted corn grit baits containing hydramethylnon (Amdro)

Bait carrier[a]	No. of replicates	Mortality of brood and workers after following week for species indicated						
		1	2	3	4	5	8	9
				Solenopsis invicta				
HFP	8	43 ± 4.0	64 ± 5.1	75 ± 4.0	90 ± 3.9	99 ± 0.6	100 QD	—
Amdro	4	85 ± 9.3	100 QD	—	—	—	—	—
Control	10	2 ± 0.8	3 ± 0.9	3 ± 0.9	5 ± 1.1	6 ± 1.2	9 ± 1.6	10 ± 1.8 CN
				Solenopsis geminata				
HFP	4	21 ± 16.3	77 ± 19.0	79 ± 19.6	80 ± 19.8	80 ± 19.9	81 ± 19.5	82 ± 18.8 QD
Amdro	4	100 QD	—	—	—	—	—	—
Control	10	2 ± 0.8	3 ± 0.9	3 ± 0.9	5 ± 1.1	6 ± 1.2	9 ± 1.6	10 ± 1.8 CN
				Iridomyrmex pruinosum				
HFP	2	1 ± 0.2	3 ± 1.6	8 ± 5.0	13 ± 8.4	16 ± 10.0	18 ± 10.7	18 ± 10.7 CN
Amdro	2	3 ± 0.4	7 ± 2.1	10 ± 2.9	13 ± 4.5	28 ± 12.5	35 ± 10.4	39 ± 7.9 QD
Control	2	1 ± 0.4	20 ± 14.3	21 ± 13.9	21 ± 13.9	22 ± 13.9	23 ± 14.3	23 ± 14.3 CN
				Conomyrma bureni				
HFP	2	8 ± 5.0	11 ± 5.4	13 ± 5.4	15 ± 3.6	17 ± 3.0	19 ± 2.1	20 ± 2.1 CN
Amdro	2	15 ± 7.1	20 ± 10.7	23 ± 12.5	29 ± 12.5	33 ± 12.5	65 ± 17.9	87 ± 4.6 1QD
Control	2	0	0	2 ± 0.4	3 ± 1.1	4 ± 1.8	6 ± 1.4	8 ± 0.9 CN
				Monomorium minimum				
HFP	2	5 ± 1.1	6 ± 1.1	7 ± 1.1	9 ± 0.4	10 ± 0.4	14 ± 2.1	14 ± 2.1 CN
Amdro	2	51 ± 31.4	53 ± 31.1	54 ± 30.7	61 ± 27.5	80 ± 14.3	100 QD	—
Control	2	1	1 ± 0.7	1 ± 1.1	2 ± 0.4	3 ± 0.4	6 ± 0.4	6 ± 0.4 CN
				Crematogaster clara				
HFP	2	2 ± 0.4	4 ± 0.4	5 ± 0.4	5 ± 0.4	6 ± 0.7	7 ± 0.4	7 ± 0.7 CN
Amdro	2	39 ± 25.7	48 ± 30.4	54 ± 32.5	56 ± 31.8	56 ± 31.8	60 ± 28.6	60 ± 28.6 1QD
Control	2	0	1 ± 0.7	1 ± 0.7	2 ± 1.1	2 ± 1.1	3 ± 1.1	3 ± 1.4 CN
				Pogonomyrmex badius				
HFP	2	3 ± 1.8	6 ± 1.4	12 ± 0.4	18 ± 1.8	25 ± 3.9	40 ± 7.7	57 ± 5.0 CN
Amdro	2	6 ± 0.4	18 ± 0.4	27 ± 0.4	33 ± 0.4	41 ± 1.4	91 ± 2.5	92 ± 1.8 QD
Control	2	1 ± 0.7	3 ± 1.8	4 ± 2.5	5 ± 2.5	5 ± 2.9	22 ± 6.1	38 ± 14.6 CN
				Pheidole morrissi				
HFP	2	30 ± 14.3	53 ± 26.8	73 ± 18.6	79 ± 15.4	84 ± 11.4	97 ± 2.5	100 QD
Amdro	2	53 ± 26.8	96 ± 2.9	100 QD	—	—	—	—
Control	2	0	2 ± 0.4	4 ± 1.4	7 ± 2.5	8 ± 3.6	15 ± 6.1	43 ± 12.5 CN

QD, queen dead; CN, colony normal (queen alive with eggs and all stages of brood).
[a] Concentrations of hydramethylnon on Amdro bait 0.88%; HFP carrier was soaked in 2.5% concentration of hydramethylnon for 30 min, after which it was rinsed for 5 s in acetone and air dried for 24 h.

raphy [HPLC] grade; Baker Chemical Company, Philipsburg, N.J.) necessary to cover the sample. The extract was filtered with a syringe through a Zefluor filter (13 by 0.5 mm pore size) in a stainless steel filter apparatus (Alltech Associates, Deerfield, Ill.). The syringe and filter system were washed with an additional volume of fresh CH_3CN. The CH_3CN solution was evaporated to dryness under a stream of nitrogen, and reconstituted with an appropriate volume of CH_3CN that depended on the expected amount of fenoxycarb present. An aliquot of the reconstituted sample was passed through the syringe and filter system without washing the sample with fresh solvent. This sample was used for HPLC analysis.

Table 2. Analysis of fenoxycarb concentrations on or in house fly pupae soaked in different acetone solutions of this chemical

Pupal treatment time, h	% Fenoxycarb concentration in acetone	Fenoxycarb (% wt/wt)		
		On cuticle	In homogenate	Total
0.5	3	0.28	0.028	0.308
	6	0.66	0.053	0.713
	9	1.12	0.076	1.196
Control	0	0	0	—
24	3	1.22	0.22	1.44
	6	3.34	0.31	3.65
	9	3.80	0.37	4.17
Control	0	0	0	—

Samples were analyzed on a Varian Vista Series (Varian Associates, Sunnyvale, Calif.), equipped with a 10-μl sample loop, Varian MCH-10 reverse phase column, and a Perkin Elmer LC-75 (Perkin Elmer, Norwalk, Conn.) variable wavelength spectrophotometric detector set at 228 nm. The eluting solvent was composed of methanol/water/acetic acid (65:35:0.3). At a flowrate of 1.5 ml/min, fenoxycarb had a retention time of 9.5 min. Solvent blanks, extracts of untreated substrates, and several concentrations of fenoxycarb standard (for determination of a calibration curve; supplied by Maag

Table 3. Control of *S. invicta* in Brooks County, Ga., with house fly pupae baits containing fenoxycarb compared with Amdro

Bait formulation method[a]	% Toxicant concentration ($\bar{x} \pm$ SD)[b]	Bait application rate/0.4 ha			Population index before treatment	% Mean reduction in population index after weeks indicated	
		Pupae or grits, g	No. pupae (× 10[3])	AI (g)		15	24
Fenoxycarb							
A	0.15 ± 0.04	200	1.0	0.31	548	79ab	81a
B	0.40 ± 0.04	177	1.4	0.71	453	72b	76a
C	0.15 ± 0.01	214	1.7	0.31	33[c]	84a	81a
Amdro[d]	0.88	454	—	4.00	590	87a	83a
Control	—	—	—	—	266[c]	13c	9b

Means within columns followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [Duncan 1955]).

[a] Technical fenoxycarb was dissolved in acetone and the house fly pupae were then treated as follows: (A) Pupae dipped in 3% solution for 30 min, air dried for 24 h; (B) Pupae dipped in 6% solution for 30 min, air dried for 24 h; (C) Pupae dipped in 6% solution for 24 h, rinsed 5 s in acetone and air dried for 24 h.

[b] Average of 3 replications unless otherwise specified; baits applied in November.

[c] Average of two 0.4-ha plots.

[d] Commercial formulation of 70% pregel defatted corn grits impregnated with 30% of the soybean oil-toxicant solution; concentration shown is that of label.

Agrochemicals, Vero Beach, Fla.) were run before the extracted samples. Results of all analyses were quantified with a Varian Vista 401 Data Processor (Varian Associates).

To determine the amount of fenoxycarb on the surface and absorbed internally, samples of house fly pupae that had been soaked in three concentrations of fenoxycarb (3, 6, and 9%) for 0.5 or 24 h were weighed and rinsed with CH_3CN. Pupae were removed and homogenized in a tissue grinder with CH_3CN. The CH_3CN from the two activities were evaporated to dryness and analyzed by HPLC as described above. A control (pupae soaked in acetone) was also processed.

Results

In laboratory tests, all of the species feeding on the Amdro standard were either killed or the colony size was reduced (Table 1). One colony each of *Conomyrma bureni* and *Crematogaster clara* died while the other survived. In contrast, only three species—the two *Solenopsis* spp. and *Pheidole morrissi*—were killed by the house fly pupae-hydramethylnon baits. With the exception of the *Pogonomyrmex badius* colonies, mean percentage of mortality of the five unaffected species did not exceed 20% during the 9-wk period. All control colonies were healthy at the end of the test.

In all cases, the amount of fenoxycarb on the surface of the house fly pupae was approximately 10 times greater than the amount of material found in homogenized flies (Table 2). For each soak period, the amount of fenoxycarb increased with the concentration of compound in acetone. The 24-h soak time was more effective in placing material on and in the house fly pupae.

Both of the field tests (Tables 3 and 4) showed that the house fly pupae-fenoxycarb baits effectively reduced the population indices of the red imported fire ant. In the Brooks County test (Table 3), the baits were applied in November. Because of the cool winter weather that followed, evaluations were made at 15 and 24 wk. The only significant difference in control between the house fly pupae baits and Amdro after 15 wk occurred at the lowest house fly pupae application rate (1.4×10^4 pupae per 0.4 ha) with the highest toxicant rate (0.71 g/0.4 ha); however, after 24 wk (May), all treatments resulted in similar population reductions. In the Alachua County test (Table 4), the baits were applied in June. Population reductions ranged from 81 to 93% after 8 wk with no significant differences in any bait treatments. However, at 16 wk, control with the lowest application rate of eye gnat pupae (0.42 g [AI]/0.4 ha) and two application rates of the house fly pupae baits treated with 0.29% fenoxycarb (0.17 and 0.87 g [AI]/0.4 ha) were significantly less effective than the Logic and Amdro standard.

Discussion

Future control programs for managing *S. invicta* populations must incorporate strategies to minimize effects on the environment. This includes enhancing the survival of competitor ant species. Although organisms other than fire ants might be attracted to and feed upon the fire ant baits, not all of them would necessarily be affected by the toxicant. In addition, the quantity of toxicant used in various fire ant baits (<10 g [AI]/ha), as well as type of toxicological action they exhibit, could provide a safety factor.

We investigated potential effects of fly pupae-toxicant baits on other ant species that occupy the same habitat as fire ants. The data revealed a de-

Table 4. Control of *S. invicta* with two fenoxycarb pupal baits (house fly pupae and eye gnat pupae) in comparison with Logic and Amdro in Alachua County, Fla.

% Fenoxycarb concentration in treatment solution[a]	% Fenoxycarb concentration in pupae[b] ($\bar{x} \pm$ SD)	Bait applied/0.4 ha			Population index before treatment[c]	% Mean reduction in population index after weeks indicated	
		Weight, g	No. pupae or grits	AI (g)		8	16
House fly pupae							
6	0.29 ± 0.07	59	4.7×10^3	0.17	448	84a	68bc
		100	8.0×10^3	0.29	457	85a	75abc
		300	2.4×10^4	0.87	422	84a	69bc
12	0.52 ± 0.02	59	4.7×10^3	0.31	407	81a	73abc
		132	1.6×10^4	0.69	403	81a	85abc
		218	1.7×10^4	1.14	358	91a	81abc
18	0.59 ± 0.05	82	6.6×10^3	0.47	383	92a	76abc
		110	8.8×10^3	0.63	347	83a	87ab
		214	1.7×10^4	1.23	398	88a	76abc
Eye gnat pupae							
6	0.54 ± 0.09	80	1.6×10^6	0.42	268	87a	58c
		240	4.8×10^6	1.27	478	82a	76abc
Logic[d]	1.00	431	3.2×10^5	4.31	462	92a	96a
Amdro[e]	—	385	2.9×10^5	3.39	473	93a	84abc
Control	—	—	—	—	336	29b	19d

Means within columns followed by the same letter are not significantly different ($P > 0.05$; Duncan's multiple range test [Duncan 1955]).

[a] Pupae were dipped in acetone-toxicant solution for 24 h, washed in clean acetone for 5 s, and air dried under a fume hood for 24 h.

[b] Pupal concentrations determined by chemical analysis (three replications). Toxicant concentration in Logic and Amdro baits is that specified on label.

[c] Population index, average of three replications.

[d] Commercial formulation of Logic containing 1% fenoxycarb, 29% soybean oil, and 70% pregel defatted corn grits.

[e] Commercial formulation of Amdro containing 1% hydramethylnon, 29% soybean oil, and 70% pregel defatted corn grits.

gree of specificity toward the house fly pupae-hydramethylnon baits because only the two *Solenopsis* spp. and *Pheidole morrissi* were killed. In contrast, Amdro bait killed one or both colonies of all species. Although no analysis of the house fly pupae for hydramethylnon content was made, chemical residue tests of fenoxycarb absorbed by the pupae (Table 2) suggest that the Amdro bait contained more toxicant than the house fly pupae bait. However, the fact that the house fly pupae bait killed the fire ants but not the other species indicates either a lack of feeding on the house fly pupae bait or a differential susceptibility to hydramethylnon.

Our field tests showed that house fly pupae and eye gnat pupae baits containing fenoxycarb are very active against red imported fire ants because application rates ranging from 0.17 to 1.27 g [AI]/0.4 ha produced similar results after 15 wk in the Brooks County test and after 8 wk in the Alachua County test. Red imported fire ants were highly attracted to the pupae, which were readily harvested because application rates as low as 4.7×10^3 pupae per 0.4 ha with house fly pupae and 4.8×10^6 pupae per 0.4 ha with eye gnat pupae (Table 4) gave control.

Assuming that a fly pupae bait could provide a means to control *S. invicta* with reduced effects on other ant species, the question that still remains is whether or not their physical properties and production costs would permit commercialization. Critical physical properties that must be considered are size of particles in relation to the ants' ability to carry or move them, flowability and distribution with various types of application equipment, attraction as food to the foragers, and toxicant absorption. Production costs are related to the feasibility of rearing, storing, treating, and packaging the pupae into an effective bait product.

A listing of some of the physical properties and costs of the Amdro, house fly pupae, and eye gnat pupae baits are presented in Table 5. Our field observations have shown that the pupae are highly attractive to the ants and that their size is within the range of that which can be carried or moved by one or two foragers. The slick, smooth, hard cuticle of the pupae makes them easy for humans to handle and apply. We encountered no problems in distributing them evenly and accurately with our auger driven applicator (Williams et al. 1983). The bulk density of the pupae is higher than that of the pregel defatted corn grits. This is advantageous because a larger area can be treated with comparable volumes of bait. Numbers of pupae per kilogram is quite different for house fly pupae and eye gnat pupae (8.0×10^4 to 2.0×10^6); however, results of our field tests do not indicate an advantage associated with larger numbers of pupae per unit area. In fact, with house fly pupae containing about 0.5% toxicant, we did not find a significant difference between application rates of 59 and 218 g of pupae per 0.4 ha (Table 4).

Table 5. Comparison of physical characteristics and costs of carriers for fire ant baits

Carrier[a]	Mesh size[b]	Bulk density, kg/m^3	Particles per kg	Recommended application rate		Cost[c], $ per			
				kg/ha	lb/acre	kg	lb	ha	Acre
PDCG[d]	8–30	257–321	9.4×10^5	1.12	1.0	0.70	0.32	0.78	0.32
HFP	8	465	8.0×10^4	0.15	0.13	12.52	5.69	3.88	1.57
EGP	18–25	369	2.0×10^6	1.12	1.0	—	—	—	—

[a] PDCG, pregel defatted corn grits; HFP, house fly pupae; EGP, eye gnat pupae.
[b] U.S. standard sieve specifications, American Society for Testing and Materials.
[c] Costs based on 1983 data.
[d] Information supplied by the Anderson Company, Maumee, Ohio; physical data and application rates based on PDCG formulated with soybean oil; cost data apply to PDCG without soybean oil.

At this time we do not know how long frozen pupae would remain attractive to the ants, but we have maintained red imported fire ant colonies in the laboratory with house fly pupae stored in a freezer at −5°C for >1 yr. The pupae used in our field tests had been collected and stored at −5°C for 1–4 wk.

Data on the production costs for the pregel defatted corn grits in Table 5 are based on 1983 data from Lauhoff Grain Company, Danville, Ill. The house fly pupae costs are based on mass rearing data provided by the Insects Affecting Man and Animals Research Laboratory, Fly and Household Insect Management Unit, Gainesville, Fla., which supplied the pupae. The comparative cost indicates that house fly pupae are about 18 times as expensive to produce as pregel defatted corn grits. However, our field data on control suggest that adequate control of red imported fire ants could be attained with application rates of about 59 to 82 g of house fly pupae per 0.4 ha (0.13 to 0.18 lb/acre) provided that the fenoxycarb concentration was >0.5% (see Table 4). This application rate (see Table 5) would reduce cost of house fly pupae carrier to $3.88/ha ($1.57/acre). Lower application rates of the house fly pupae would probably result in a final bait that was two to three times more expensive than current formulated products on the market, which range from about $13.20 to $33.00 per kg ($6.00 to $15.00 per lb). However, the price of pupae could probably be reduced through mass-production methods. If so, house fly pupae could be a viable alternative for providing an effective bait that is more species-specific than those now available.

We do not have specific costs on mass rearing of eye gnat pupae. Estimates developed during the rearing of the eye gnat pupae at the West Florida Arthropod Research Laboratory, Health and Rehabilitative Services, State of Florida, Panama City, Fla., suggest that they are less expensive to rear than house fly pupae. Our data indicate that the application rate of eye gnat pupae needed for control (240 g/0.4 ha; 0.54% fenoxycarb) may be higher than that for house fly pupae. However, eye gnat pupae may actually be the preferred pupae carrier because their size allows them to be carried easily by an individual worker ant. Because eye gnat pupae are smaller and less conspicuous than house fly pupae or pregel defatted corn grits, they also might be less of a target to be fed upon by other animals such as birds.

Acknowledgment

We express our appreciation for technical assistance to J. K. Plumley and D. M. Hicks and for statistical assistance to B. E. Lingo and S. W. Avery. We also thank S. A. Phillips, L. A. Lemke, and D. L. Kline for reviewing the manuscript.

References Cited

Apperson, C. S., R. B. Leidy & E. E. Powell. 1984. Effects of Amdro on the red imported fire ant (Hymenoptera: Formicidae) and some nontarget ant species and persistence of Amdro on a pasture habitat in North Carolina. J. Econ. Entomol. 77: 1012–1018.

Baetcke, K. P., J. D. Cain & W. E. Poe. 1972. Residues in fish, wildlife, and estuaries: mirex and DDT residues in wildlife and miscellaneous samples in Mississippi—1970. Pestic. Monit. J. 6: 14–22.

Banks, W. A., C. S. Lofgren, D. P. Jouvenaz, C. E. Stringer, P. M. Bishop, D. F. Williams, D. P. Wojcik & B. M. Glancey. 1981. Techniques for collecting, rearing, and handling imported fire ants. USDA, Science & Education Administration. Advances in Agricultural Technology S-21.

Duncan, D. B. 1955. Multiple range and multiple *F* tests. Biometrics 11: 1–42.

Edmunson, M. B. 1981. The effect of Amdro on nontarget ant species associated with *Solenopsis invicta* Buren in Florida. M.S. thesis, University of Florida, Gainesville, Fla.

Harlan, D. P., W. A. Banks, H. L. Collins & C. E. Stringer. 1981. Large area tests of AC 217300 bait for control of imported fire ants in Alabama, Louisiana and Texas. Southwest. Entomol. 6: 150–157.

Johnson, E. L. 1976. Administrator's decision to accept plan of Mississippi Authority and order suspending hearing for the pesticide chemical mirex. Fed. Regist. 41(251): 56694–56704.

Lemke, L. A. 1986. Biological studies, control investigations, and public attitudes regarding the red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae), in South Carolina. Ph.D. dissertation, Clemson University, Clemson, S.C.

Ludke, J. L., M. T. Finely & L. Lusk. 1971. Toxicity of mirex to crayfish, *Procambrus blandingi*. Bull. Environ. Contam. Toxicol. 6: 89–96.

Lofgren, C. S. & D. F. Williams. 1982. Avermectin B1a: highly potent inhibitor of reproduction by queens of the red imported fire ant (Hymenoptera: Formicidae). J. Econ. Entomol. 75: 798–803.

Lofgren, C. S., F. J. Bartlett, C. E. Stringer & W. A. Banks. 1964. Imported fire ant toxic bait studies: further tests with granulated mirex-soybean oil bait. J. Econ. Entomol. 57: 695–698.

Markin, G. P., J. H. Ford, J. C. Hawthorne, J. H. Spence, J. Davis, H. L. Collins & D. C. Loftis. 1972. The insecticide mirex and techniques for its monitoring. USDA, Animal Plant Health Inspection Service, 81-3 Series, November 1972.

Markin, G. P., J. O'Neal & H. L. Collins. 1974. Effects of mirex on the general ant fauna of a treated area in Louisiana. Environ. Entomol. 3: 895–898.

Phillips, S. A., Jr., S. R. Jones, D. M. Claborn & J. C. Cokendolpher. 1986. Effect of Pro-Drone, an insect growth regulator, on *Solenopsis invicta* Buren and nontarget ants. Southwest. Entomol. 11: 287–293.

SAS Institute. 1985. SAS user's guide: statistics, version 5 ed. SAS Institute, Cary, N.C.

Summerlin, J. W., A. C. F. Hung & S. B. Vinson. 1977. Residues in nontarget ants, species simplification, and recovery of populations following aerial applications of mirex. Environ. Entomol. 6: 193–197.

Williams, D. F. 1986. Chemical baits: specificity and effects on other ant species, pp. 378–386. *In* C. S. Lofgren and R. K. Vander Meer [eds.], Fire ants and leaf cutting ants: biology and management. Westview Press, Boulder, Colo.

Williams, D. F., C. S. Lofgren, J. K. Plumley & D. M. Hicks. 1983. Auger-applicator for applying small amounts of granular pesticides. J. Econ. Entomol. 76: 395–397.

Received for publication 13 January 1989; accepted 18 May 1989.