Pharaoh Ant (Hymenoptera: Formicidae): Fenoxycarb Baits Affect Colony Development

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ABSTRACT Fenoxycarb, an insect growth regulator, was highly effective against the Pharaoh ant, *Monomorium pharaonis* (L.). Fenoxycarb acts by reducing egg production in the queens; the colonies eventually die because of worker attrition. The best laboratory results were obtained using concentrations of 0.25, 0.5, and 1% in peanut oil. These concentrations significantly reduced worker numbers by 12 wk and quantity of brood by 5 wk, if not sooner; however, more than one baiting was necessary to eliminate the colonies completely. Also, in some tests, colonies fed fenoxycarb baits at concentrations of 0.1, 0.25, and 0.5% significantly delayed the production of winged reproductives. Intermediate castes (individuals that were larger than workers yet smaller than queens) were produced at lower concentrations (0.05, 0.1, and 0.25%). Higher concentrations of 2.5 and 5% were not effective, probably because of repellency of the chemical. These results demonstrate that fenoxycarb is as effective as the commercially available bait, Pharorid (methoprene), for the control of the Pharaoh ant.

KEY WORDS *Monomorium pharaonis*, fenoxycarb, IGR

THE PHARAOH ANT, *Monomorium pharaonis* (L.), is cosmopolitan in its distribution, having been carried by commerce to all regions of the world (Wheeler 1910). This ant probably originated in the North Africa–Middle Eastern region and is a major indoor pest in most parts of the world, including the United States (Edwards 1986). Although it normally does not nest outdoors except in tropical climates, it has been reported to persist outdoors in temperate regions where the temperature is artificially maintained, such as in refuse dumps (Kohn & Vlcek 1986). Infestations usually occur in large office buildings and apartment complexes, factories, food establishments, and hospitals (Edwards 1986). In hospitals, it causes problems by contaminating equipment and sterile packaging, penetrating intravenous solutions and tubing, and feeding on dressed wounds. Worker ants can carry several pathogens including *Clostridium*, *Salmonella*, *Staphylococcus*, *Streptococcus*, and *Pseudomonas* (Beatson 1972).

Control methods for *M. pharaonis* were reported by Bellevoye (1889), Riley (1889), and Lintner (1895), with later reports by Rogers & Herrick (1953), Morgan & Price (1954), and Papworth (1958). For an in-depth review of control methods, see Edwards (1986).

Sprays and dusts are generally not effective against *M. pharaonis* because treatments do not result in complete elimination of the infestation. The colonies are polygyne (two or more egg-laying queens present), and the majority of queens survive and continue to produce large numbers of eggs (Edwards 1986). Even if queens do not survive, workers can rear reproductives from existing brood (Peacock et al. 1955). Also, sprays and dusts affect only foraging workers which are not needed for the colony to survive long periods (Kretzschmar & Berndt 1976). The use of toxic baits is the control method of choice, although residuals can be used following bait applications when a rapid reduction or elimination of foraging workers is needed.

The insect growth regulator fenoxycarb (Maag Agrochemicals, now part of CIBA-GEIGY, Greensboro, NC) is an ethyl carbamate chemical that exhibits IGR (juvenile hormone) activity against scale insects, mosquitoes, fleas, stored-product insects, and some lepidopterous pests (Dorn et al. 1981, Masner et al. 1981, El-Gazzer et al. 1986). In addition, it caused dramatic changes in oviposition and brood development and finally death in colonies of the red imported fire ant, *Solenopsis invicta* Buren (Banks et al. 1983). Fenoxycarb is currently registered as a bait (Logic) for the control of the fire ant (Banks et al. 1988). This study was conducted to evaluate the effects of fenoxycarb on colony development of the Pharaoh ant.

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Materials and Methods

Laboratory colony rearing and maintenance were as described by Williams (1990).

Acceptability of Fenoxycarb. Four fenoxycarb concentrations (0.10, 0.25, 0.50, and 1% [wt:wt] in peanut oil) were tested together with peanut oil (0% fenoxycarb) and water in a food-acceptance test (Williams 1990) for repellency to the Pharaoh ant. Briefly, a rearing cell containing ≈45 queens, 12,500 workers, and 5 g of brood (immature stages) was placed in the middle of a shoebox, and the ants were allowed to equilibrate for 1 h. The six baits were randomly placed three at each end of the box and the number of workers feeding on each bait was recorded at 5-min intervals for 30 min. The number of ants feeding on each bait was then totaled. Regression analysis was performed (y, total number of workers feeding for 30 min; x, fenoxycarb concentration) using the chart function in the software program Freelance Plus version 3.0 (Lotus Development 1988).

Small-Colony Evaluations. Evaluations (Williams 1990) were conducted with small laboratory colonies containing three fertile queens, 0.2 g of brood, and 0.1 g (≈500) workers in which laboratory food had been removed for 24 h before the bait was introduced. Fenoxycarb dissolved in peanut oil was tested at the following concentrations: 0, 0.01, 0.05, 0.1, 0.25, 0.5, 1, 2.5, and 5% (wt:wt). The bait solutions were offered to each colony in micropipettes (40 μl per colony) for 72 h, after which the bait was removed and the colonies were returned to the regular laboratory diet of adult mosquitoes and houseflies, hardboiled chicken egg yolk, and honey–agar. References to consumption of fenoxycarb baits are based on visual estimates. Baits were applied once for tests 1–6 and twice (1 wk apart) for test 7. In test 7, in addition to testing 0, 0.1, 0.25, 0.5% fenoxycarb in peanut oil, Pharorid (methoprene; Zoecon, Dallas, TX), a commercially available insect growth regulator, was formulated in liver powder/honey/sponge cake (2:1:1 [wt:wt]). Approximately 40 mg of Pharorid was given to each of the appropriate test colonies.

For each test, three colonies were treated per dosage; three control colonies were given the same quantity of peanut oil alone. Weekly observations were made on the status of the colony including queen number, type and quantity of brood, estimated worker numbers, and obvious morphological anomalies. The three main criteria for efficacy were (1) the total number of workers present, (2) the brood rating, and (3) the first appearance (time in weeks) of winged reproductives. Brood was rated by visually comparing a photograph of known quantities of brood with the brood in a cell. Each quantity of brood in the photograph was given a rating which was assigned as follows: 1, 0.012 g; 2, 0.085 g; 3, 0.270 g; 4, 1.30 g; 5, 2.60 g; and 6, ≥ 3.50 g. Observations were continued for at least 20 wk or until the colony died or completely recovered and returned to normal. The colony was considered to be normal when the queens began normal egg-laying, all stages of brood were present, and the amount of brood and worker numbers were similar to or greater than before treatment. Once a colony returned to normal, it was removed from further evaluation and the data from the final reading for this colony were recorded for each subsequent reading until the end of the experiment.

Large-Colony Evaluations. In the large-colony evaluations, the most effective concentrations of fenoxycarb in the small-colony evaluations were tested against large laboratory colonies consisting of 100–200 queens, 7 g of brood, and 5,000–7,000 workers. In test 8, the fenoxycarb was dissolved in peanut oil at 0.1, 0.25, 0.5, and 1%, whereas in test 9, only 0.25, 0.5, and 1% were evaluated. Each colony was offered 1.0 ml in micropipettes for 72 h, after which the bait was removed and the colonies were returned to the regular laboratory diet. Also, three colonies were given methoprene as formulated in the small-colony evaluations, in both tests 8 and 9. Because 1 ml of peanut oil was ≈0.9 g, this amount of methoprene was used per colony. In test 8, colonies were starved for 24 h, whereas colonies in test 9 were not starved before the bait was introduced. In test 8, two baitings were made, whereas in test 9, four were applied; each baiting was applied 1 wk apart. In both tests (8 and 9), three colonies were treated per dosage and three control colonies were given an equal amount of peanut oil without fenoxycarb. Weekly observations similar to those in the small-colony evaluations were made. The two main criteria for efficacy in the large-colony evaluations were the total number of workers present and the brood rating. The initial appearance of winged reproductives was not used because the large colonies used in these evaluations contained numerous winged reproductives before treatments. Observations were continued for at least 20 wk or until the colony died or completely recovered and returned to normal.

A summary of the protocols for small- and large-colony evaluations of fenoxycarb and methoprene against laboratory colonies is shown in Table 1.

Statistical Analysis. Data from the small-colony evaluations with one baiting were averaged for tests one through six. Data were analyzed by the general linear model (GLM) procedures (SAS Institute 1988, 549–640) with initial appearance of winged reproductives, number of workers, and brood rating as the dependent variables in the small-colony evaluations. Analyses of large-colony evaluations used number of workers and brood rating as the dependent vari-

Table 1. Summary of protocols for evaluation of fenoxycarb against laboratory colonies of the Pharaoh ant

Test no.	Worker numbers	Insect growth regulator		Amount of bait	No. baitings
		Name[a]	% Concn in PO[b]		
		Small-colony evaluations			
1–6	≈500	Fenoxycarb	0.01, 0.05, 0.1, 0.25, 0.5, 1, 2.5, 5	40 μl	1
7	≈500	Fenoxycarb	0.1, 0.25, 0.5	40 μl	2
		Methoprene	0.5	40 mg	2
		Large-colony evaluations			
8	5,000–7,000	Fenoxycarb	0.1, 0.25, 0.5, 1	1 ml	2
		Methoprene	0.5	0.9 g	2
9	5,000–7,000	Fenoxycarb	0.25, 0.5, 1	1 ml	4
		Methoprene	0.5	0.9 g	4

[a] Methoprene was formulated using the commercial product Pharorid in liver powder, honey, and spongecake.
[b] PO, peanut oil.

ables in the GLM procedures. Ryan-Einot-Gabriel-Welsch Q test was used for means separation ($P = 0.05$; SAS Institute 1988).

Results and Discussion

Acceptability of Fenoxycarb. The fenoxycarb acceptance test indicated that the Pharaoh ant workers were repelled by increasing concentrations of fenoxycarb (Fig. 1). The number of workers feeding on the baits decreased exponentially with increasing concentrations of fenoxycarb ($y = 119.0e^{-2.05x}$, where y is the total number of workers feeding for 30 min and x is fenoxycarb concentration). These results are similar to those observed in fire ants where increasing the concentrations of fenoxycarb decreased the feeding on the solutions (Banks et al. 1988).

Small-Colony Evaluations (Single Baiting). In small-colony evaluation tests 1–6, using the total number of workers as the evaluation criterion, the most effective concentrations of fenoxycarb in peanut oil were 0.1, 0.25, and 0.5% (Fig. 2a). These were the only concentrations having significantly ($F = 10.72$; df = 8, 63; $P < 0.0001$) fewer workers than the control between 8 and 12 wk after baiting. Based on the number of workers in the colonies, these concentrations continued to give control; however, as time progressed, most of the colonies began to recover from the effects of the baits and eventually returned to normal (28 wk). As with most IGRs, fenoxycarb causes little worker mortality but prevents worker replacement by significantly reducing worker brood.

When brood rating was used as an evaluation criterion (Fig. 2b), by 2 wk after treatment, the 0.1, 0.25, and 0.5% concentrations were significantly lower than the control ($F = 6.48$; df = 8, 63; $P < 0.0001$) and remained so until the last reading (20 wk); however, all colonies had returned to normal by the termination of the experiment (28 wk). Although fenoxycarb decreased the amount of worker brood in treated colonies rather quickly, the colonies in these studies still recovered regardless of concentration. Either not enough fenoxycarb was distributed throughout the colony, or high enough titres of fenoxycarb were not maintained within the colony to cause complete breakdown in colony organization.

The results of the third and final criterion used in the small-colony evaluation, the first appearance of winged reproductives, indicated that col-

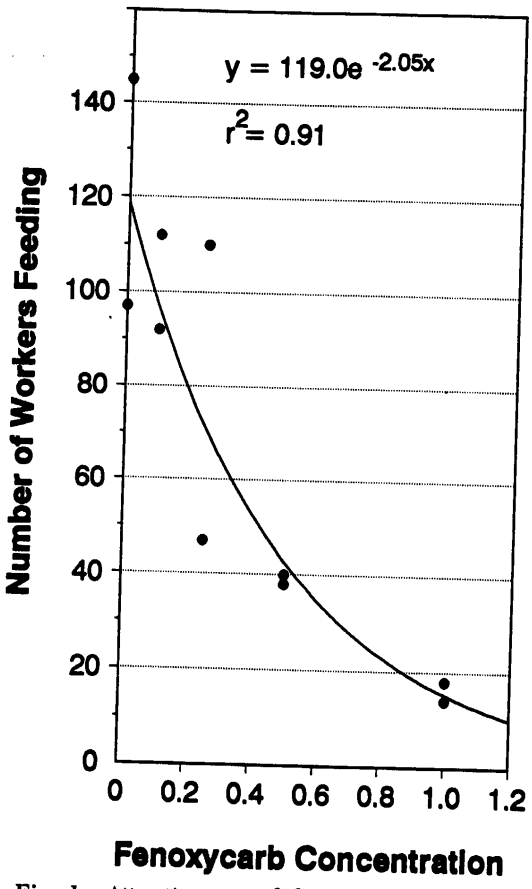

Fig. 1. Attractiveness of fenoxycarb to foraging Pharaoh ants. Fenoxycarb was formulated in peanut oil on a weight-to-weight basis.

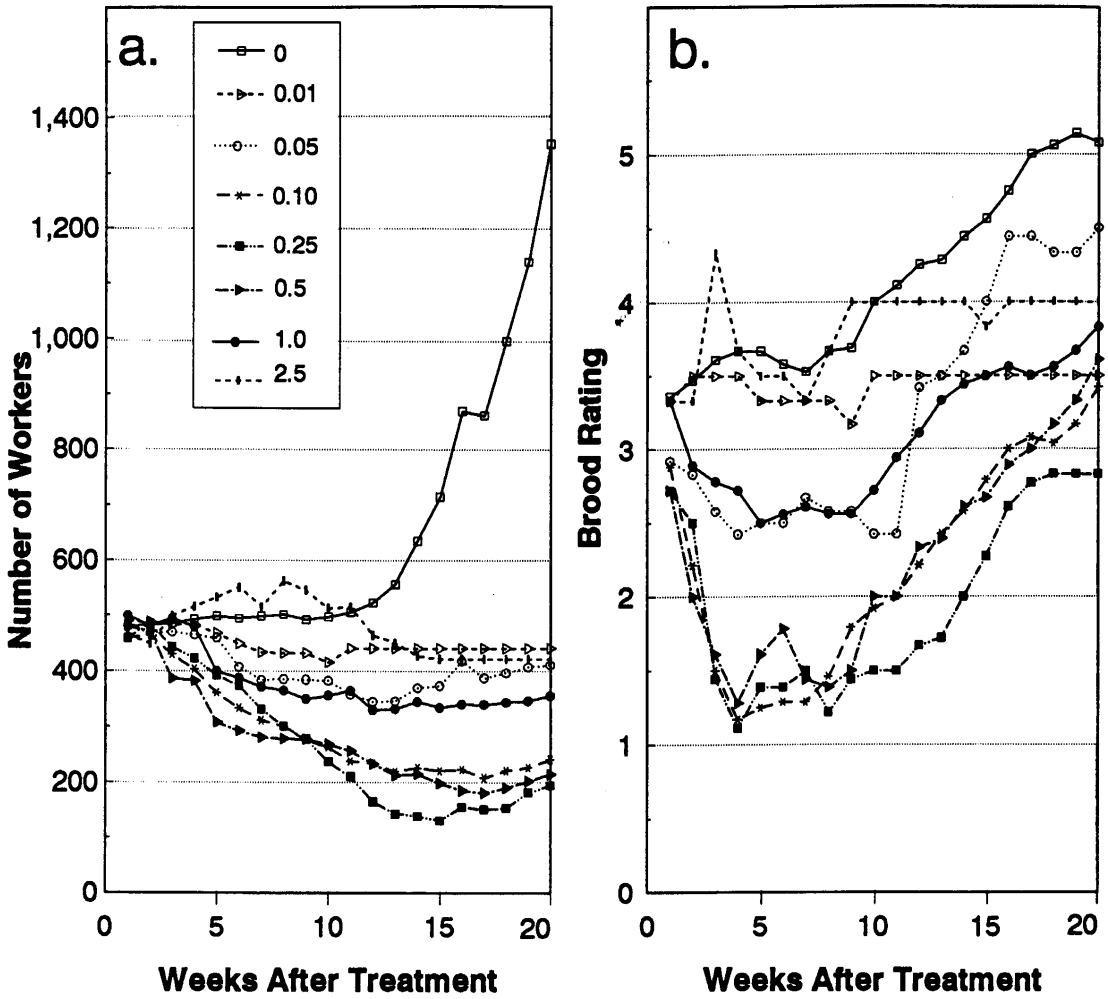

Fig. 2. Mean number of (a) Pharaoh ant workers and (b) brood rating for colonies treated with several concentrations of fenoxycarb (small-colony evaluations and one baiting).

onies exposed to the 0.1 and 0.25% concentrations took significantly longer to produce reproductives than the control. The fenoxycarb concentrations of 0.5 and 1.0% were not significantly different from 0.25% (Table 2).

Concentrations higher than 1.0% (2.5 [Fig. 2] and 5%) were not effective, probably because of repellency of the chemical (Fig. 1). The ants fed very little on the solutions above 1%. For example, in test 3, the ants consumed 56.7 ± 11.02% (mean ± SE) of the control bait and 0.83 ± 0.83% of the 2.5 and 5% fenoxycarb baits. The number of workers and brood in colonies treated with >1% fenoxycarb were not usually different from the controls.

Also, the concentrations below 0.1% (0.05 and 0.01%) did not cause any long-term effect; however, a few of the colonies treated with 0.05%

Table 2. First appearance of winged reproductives in colonies treated with each concentration of fenoxycarb (small-colony evaluation with one baiting)

% Concn	First appearance of winged reproductives (weeks after treatment), mean ± SE[a]
0	4.9 ± 0.2c
0.01	4.7 ± 0.3c
0.05	6.7 ± 1.1bc
0.1	12.6 ± 1.4ab
0.25	14.3 ± 2.2a
0.5	10.2 ± 1.2abc
1.0	9.9 ± 1.7abc
2.5	6.3 ± 0.3bc
5.0	5.7 ± 0.3bc

[a] Means followed by different letters are significantly different using GLM and Ryan-Einot-Gabriel-Welsch Q test for means separation ($F = 7.03$; df = 8, 63; $P < 0.0001$; SAS Institute [1988]).

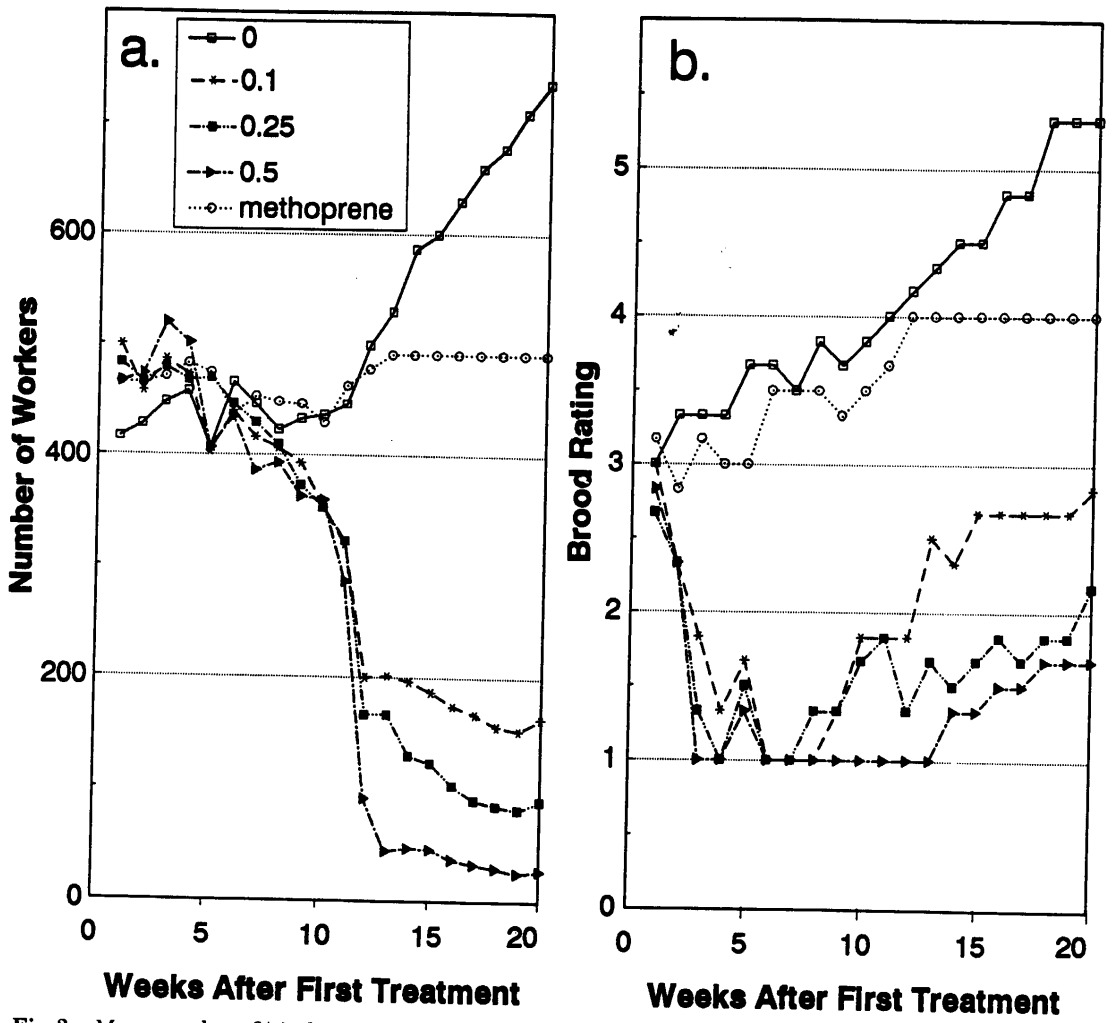

Fig. 3. Mean number of (a) Pharaoh ant workers and (b) brood rating for colonies treated with methoprene and several concentrations of fenoxycarb (small-colony evaluations and two baitings).

concentrations showed some slight reductions in brood levels. The colonies, however, quickly recovered from the effects and were soon similar in size and development to the controls. Intermediate castes were produced at lower concentrations (0.25, 0.1, and 0.05%). Individuals were considered an intermediate caste if they were larger than the usually monomorphic worker yet smaller than the reproductives.

Small-Colony Evaluations (Two Baitings). Colonies treated with two baitings (test 7) of 0.1, 0.25, or 0.5% showed significant reductions in worker number by week 12 ($F = 102.4$; df = 4, 10; $P < 0.0015$) and continued this way until termination of the experiment (Fig. 3a). New workers were not being produced in the fenoxycarb treatments to replace those workers dying of old age. Colonies treated with methoprene did not decrease worker numbers and did not differ significantly from the control. Brood rating decreased significantly by 4 wk ($F = 11.7$; df = 4, 10; $P < 0.0065$) for all fenoxycarb treatments (Fig. 3b), but by 12 wk ($F = 6.7$; df = 4, 10; $P < 0.0065$), 0.1% was no longer significantly different from the control. All colonies returned to normal except one colony at 0.5%. Methoprene did not differ significantly from the control when measuring brood rating.

Analysis of the variable, first appearance of winged reproductives (Table 3), indicated that neither 0.1 and 0.25% fenoxycarb nor methoprene significantly delayed the production of sexuals. However, the 0.5% fenoxycarb treatment caused a significant delay in the onset of winged reproductives. All three colonies treated with 0.5% fenoxycarb failed to produce sexuals through the last reading date; one 0.25% colony did also. The amount of active ingredient presented to small colonies was insufficient to cause permanent cessation of egg production (high enough titres of fenoxycarb were not maintained) because all of the colonies eventually recovered.

Table 3. First appearance of winged reproductives for colonies treated with methoprene and each concentration of fenoxycarb (small-colony evaluation with two baitings)

% Concn	First appearance of winged reproductives (weeks after treatment), mean ± SE[a]
Fenoxycarb	
0	4.3 ± 0.3b
0.1	8.3 ± 3.9b
0.25	13.3 ± 8.4ab[b]
0.5	29.3 ± 0.7a[c]
Methoprene	6.0 ± 1.7b

[a] Means followed by different letters are significantly different using GLM and Ryan-Einot-Gabriel-Welsch Q test for means separation ($F = 5.77$; df = 4, 10; $P < 0.01$; SAS Institute [1988]).

[b] One colony had not produced winged reproductives by the last reading; therefore, this final reading date was assigned as the time winged reproductives were produced.

[c] None of these colonies produced winged reproductives by the last reading; therefore, the final reading date for each colony was assigned as the time winged reproductives were produced.

Large-Colony Evaluations (Two and Four Baitings). In test 8 (two baitings), all fenoxycarb concentrations (0.1, 0.25, 0.5, and 1%) and methoprene caused a significant reduction in worker number with a decrease <5,000 workers at 10 wk ($F = 11.25$; df = 5, 12; $P < 0.0003$) (Fig. 4a). The brood rating gave similar results with the greatest decline occurring within the first 5 wk from a rating of 8–10+ down to 2–4 (Fig. 4b); however, the 0.1% treatment was not as effective as the other fenoxycarb concentrations based on brood rating. Colonies treated with 0.1% were only significantly different from the control for 2 wk (4 and 5 wk) ($F = 12.57$; df = 5, 12; $P < 0.0001$ and $F = 18.52$; df = 5,12; $P < 0.0001$). The treatment with 0.25% fenoxycarb was the most effective, completely reducing the brood rating in all colonies to zero by 20 wk. Two baitings against large colonies were insufficient to cause permanent brood reduction in all colonies treated with methoprene and 0.1, 0.5, and 1% fenoxycarb. In

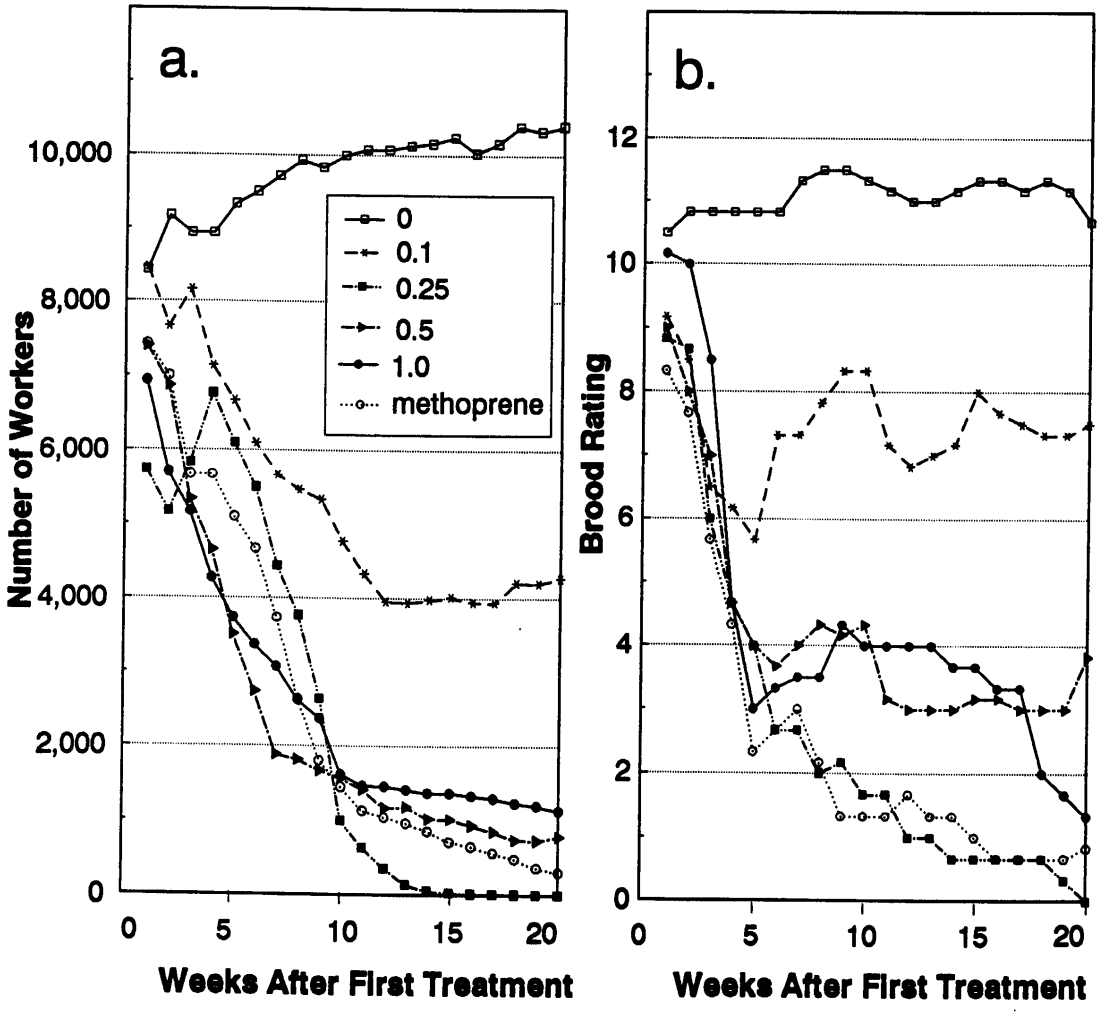

Fig. 4. Mean number of (a) Pharaoh ant workers and (b) brood rating for colonies treated with methoprene and several concentrations of fenoxycarb (large-colony evaluations and two baitings).

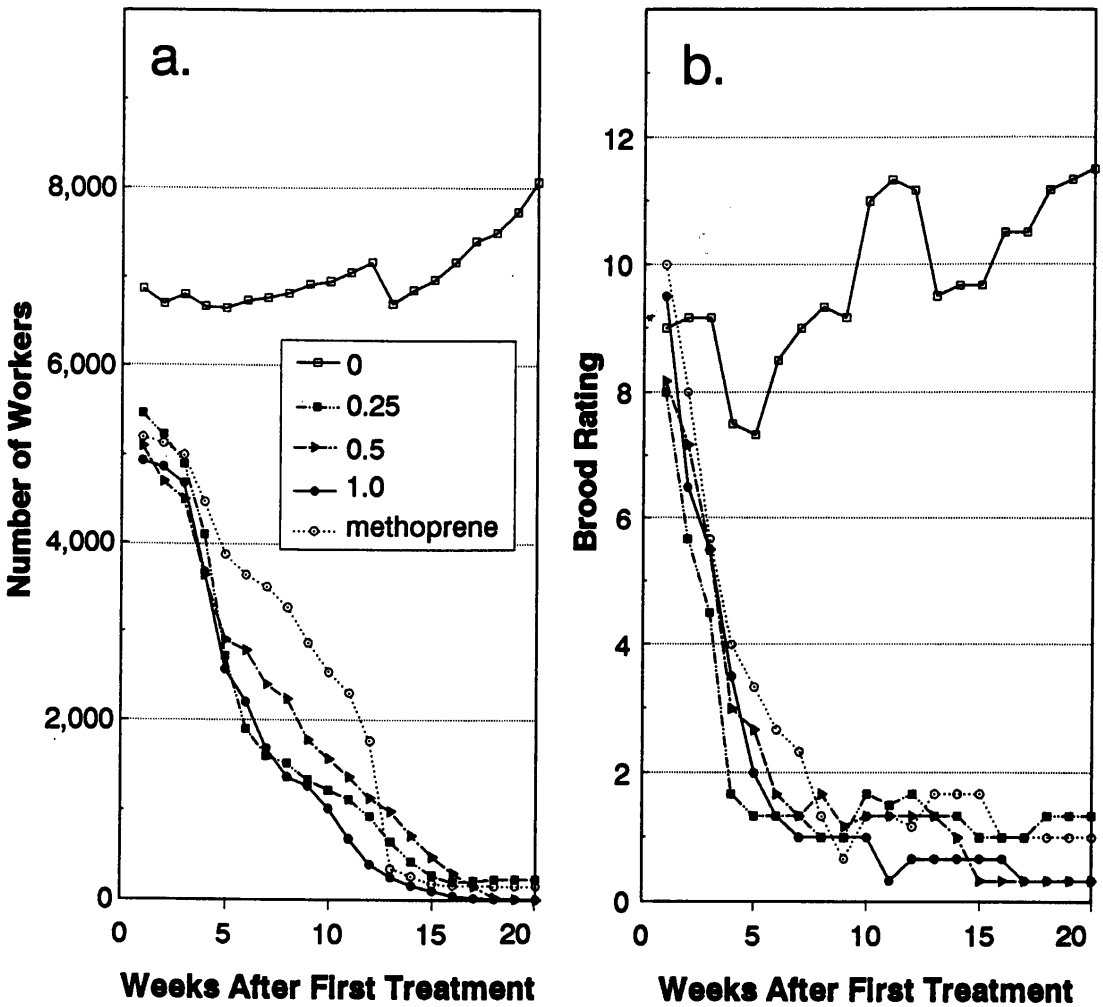

Fig. 5. Mean number of (a) Pharaoh ant workers and (b) brood ratings for colonies treated with methoprene and several concentrations of fenoxycarb (large-colony evaluations and four baitings).

each of these treatments, at least one of the colonies returned to normal.

Methoprene was more effective against large colonies than small colonies even though it did not cause permanent brood reduction or complete elimination of workers in either case. Both small and large colonies were starved before they were given the two baitings of methoprene. The inconsistent effects may be explained by bait consumption; 99% of the bait was consumed in the small colonies, but there was always bait remaining in the large colonies. This may indicate that there was an insufficient amount of bait given to the small colonies.

In test 9 (four baitings), after 6 wk, all fenoxycarb concentrations (0.25, 0.5, and 1%) contained significantly fewer workers than the control (F = 4.73; df = 4, 10; $P < 0.0211$) and remained so throughout the experiment (Fig. 5a). Methoprene-treated colonies were not significantly different from the control until 8 wk. More than 99% worker reduction had occurred by 20 wk in the 0.5 and 1% fenoxycarb treatments.

Brood rating (Fig. 5b) was significantly reduced in all fenoxycarb and methoprene colonies from 5 wk (F = 7.35; df = 4, 10; $P < 0.005$) until termination of the experiment. The greatest rate of decline in brood levels occurred during the first 5 wk. No significant differences between the three concentrations of fenoxycarb and methoprene occurred at the end of the experiment.

In test 9, all colonies were dead by 24 wk and 28 wk in the 0.5 and 1% fenoxycarb treatments, respectively. Time to total colony death ranged from 11 to 24 wk in the 0.5% fenoxycarb treatment and 15 to 28 wk in the 1% fenoxycarb treatment. Two of the 0.25% fenoxycarb-treated colonies were dead by 17 wk; however, one colony of the 0.25% fenoxycarb treatment returned to normal. Two methoprene-treated colonies were dead by 19 wk, but one colony returned to normal.

The overall effects of fenoxycarb on Pharaoh ants in laboratory colonies were a dramatic reduction in brood, the appearance of intermediate castes which resembled small queens or large workers in the lower concentrations (≤0.25), and a decline in the worker force because of attrition. The older workers were dying and new ones were not replacing them. In those colonies where the workers were completely eliminated, mortality occurred between 11 and 28 wk. This is similar to Edwards' (1986) studies using Pharorid, where workers were eliminated 20–25 wk after treatment. The decline in brood levels may be a result of direct toxicity, disruption of development, and reduction or cessation of egg production by the colony queens. This decline in brood levels is similar to the response of the fire ant, *S. invicta,* treated with fenoxycarb (Banks et al. 1988).

These results have shown that fenoxycarb is as effective as the commercially available bait, Pharorid. Although these experiments indicated which concentrations are acceptable to foraging workers and which are effective in controlling the Pharaoh ant, further studies are needed to correlate the amount of fenoxycarb needed to control a colony in relation to worker numbers.

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