

Retrieval of Granular Bait by the Argentine Ant (Hymenoptera: Formicidae): Effect of Clumped Versus Scattered Dispersion Patterns

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ABSTRACT Argentine ants, *Linepithema humile* (Mayr), use mass recruitment foraging, with clumped prey items being retrieved more efficiently than dispersed prey. However, in prior field experiments, granular baits, whether dispensed in containers or broadly scattered, had a similar impact on Argentine ant populations. In laboratory experiments, granular insecticide bait was encountered faster by Argentine ant workers and more granules were initially returned to the colony when the granules were scattered versus clumped. After 2 h, granules from both dispersion patterns were retrieved equally. Our results suggest that Argentine ant colonies adjust their foraging patterns to resources of different quality (prey versus bait). Also, foraging activity patterns for bait in the laboratory are consistent with prior field results demonstrating no efficacy advantages to discrete granular bait placements.

KEY WORDS *Linepithema humile*, Argentine ant, foraging, granular bait

BAITS ARE AN IMPORTANT component of urban pest ant management programs. They are fairly target specific, contain relatively little active ingredient, and can be presented in stations to substantially reduce exposure to nontarget organisms. Furthermore, they capitalize on the social behavior of ants, whereby, scout ants recruit nestmates to a newly discovered bait and toxicant is subsequently shared within the colony. The primary bait formulations available to pest management professionals and consumers are liquids, discrete solid matrices (including gels), and granules; the choice of form being frequently dependent on species dietary requirements, with little attention given to the foraging habits of the target ant.

Ants employ two primary foraging strategies: solitary foraging and mass recruitment (Hölldobler and Wilson 1990). In solitary foraging species, food, located by an individual worker, is returned to the colony only by that individual. This strategy, used mainly by species with small colonies, maximizes the number of workers actively searching for food, particularly food items that are always small and widely distributed in time and space. Mass recruitment foraging strategies are common in ants, particularly among species with large colonies (Beckers et al. 1989). In mass recruitment, foraging workers that locate food return to the nest and subsequently direct other workers to the discovered food, frequently with the aid of trail pheromones. This system is thought to be effective

where food items are large or clumped in space, so that a worker encountering the food could carry only a small portion of it, but many recruits could quickly reach, defend, and retrieve the food source (e.g., Pasteels et al. 1987; de Biseau et al. 1997).

The Argentine ant, *Linepithema humile*, employs mass recruitment foraging. It is a worldwide invasive species that disrupts biological control programs in agriculture (Markin 1970) and infests human residences (Klotz et al. 2000). In many regions where Argentine ants have been introduced, they have displaced native ant species through their superior competitive ability; they reach exceptionally high density because they lack aggression between adjacent colonies, discover resources quickly, and successfully defend them against competing species (Human and Gordon 1996, Holway 1999). In previous research (Roulston and Silverman 2002), we demonstrated that Argentine ants, consistent with theoretical predictions, returned similar sized prey items to the colony faster when those items were clumped rather than dispersed. From an insect control perspective, this predicts that toxic baits should be more effective at controlling ant colonies when the baits are clumped. Two studies, Krushelnycky and Reimer (1998) and Klotz et al. (2000), however, reported no differences in Argentine ant population reductions when hydramethylnon granules were scattered within the ants' foraging domain versus placed in piles or bait dispensers. Consequently, we investigated retrieval rates of clumped versus dispersed insecticide granules by Argentine ants in the laboratory to determine whether shifts in foraging strategy might be resource-depen-

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Table 1. Retrieval of clumped versus dispersed hydramethylnon bait granules by Argentine ant workers

	Clumped			Dispersed			<i>H</i> ^a	<i>P</i>
	<i>N</i>	Mean ± SD	Median	<i>N</i>	Mean ± SD	Median		
First granule moved (min)	12	33.1 ± 4.9	35	13	18.0 ± 4.4	10	7.96	0.005 ^b
First granule returned (min)	12	43.8 ± 5.0	50	13	24.0 ± 4.5	25	9.87	0.002 ^b
No. moved in 1 h	12	2.5 ± 2.5	2	13	5.7 ± 2.7	6	7.24	0.007 ^b
No. moved in 2 h	12	5.0 ± 4.2	3	13	7.0 ± 2.8	7	0.99	0.320
No. returned to nest in 1 h	12	1.5 ± 1.4	1	13	4.3 ± 2.7	3	9.03	0.003 ^b
No. returned to nest in 2 h	12	3.7 ± 3.5	2	13	5.8 ± 2.7	5	2.65	0.103

^a Adjusted for ties.

^b Significant difference between medians (Kruskal-Wallis test).

dent. We also examined the impact of granule distribution on Argentine ant worker survival.

Materials and Methods

Experimental colonies consisting of 300 workers were created from one laboratory colony of Argentine ants collected from Winston-Salem, NC. A total of 12–13 treatment colonies and 4 control colonies were used. Nests were comprised of clear plastic screw-top vials (6 cm diameter by 2.5 cm height) covered with red Plexiglas and containing a water source. Each nest was placed in a plastic, fluon-coated tray (13 by 18 cm). After 24 h, nests were removed from their tray and placed in the center of a 1.3 by 1.3 m foraging arena. The floor of the arena was covered with polyurethane and divided into 3,600 2 by 2 cm numbered grid squares. Ants could move through the arena, but the arena contained no food. After an additional 24 h (48 h starvation), 10 coarse (≈ 2 mm diameter) hydramethylnon (1%) bait granules (MAXFORCE ant bait; Clorox Co., Oakland, CA) were placed in the arena in one of two distributions: 10 granules within one randomly chosen grid square, or one granule within each of 10 randomly chosen grid squares. Ten granules were chosen for this experiment because they caused $\approx 50\%$ worker ant mortality in a prior dose mortality study (T.H.R., unpublished data). Ants were allowed to forage for 2 h. Every 10 min the number and position of ants in the arena, the number of granules still in their original position, and the number of baits still in the arena (not yet returned to the nest) were recorded. After 2 h, the nest and all the ants were returned to their original plastic tray. Any bait granules returned to the nest during the experiment were left in the nest. Granules left in the arena were discarded. After an additional 24-h starvation period, colonies were given vials of 25% sucrose solution and artificial diet (Silverman and Roulston 2001) and left undisturbed for an additional 4 d. At the end of that 4-d period, the nests were taken apart, and the number of live and dead ants inside was counted. Controls were left in their plastic tray.

The effect of treatment on the initial and maximum number of ants in the foraging arena was determined with the general linear model analysis of variance (ANOVA) procedure (Minitab 2000). The effect of treatment on time to granular retrieval and number of granules retrieved was determined using the Kruskal-

Wallis test (Minitab 2000). A two-way general linear model ANOVA was performed on percent worker survival following an arcsine transformation with granule treatment and time as main effects.

Results and Discussion

Before the placement of granules, there was no difference in the number of ants exploring the arenas selected to receive either bait distribution pattern: clumped, 26.3 ± 14.46 (mean ± SD) ants; scattered, 29.3 ± 14.81 ants ($df = 1$, $F = 0.25$, $P = 0.621$). There were also no differences in the maximum number of foragers in either of the treatments during the experiments: clumped, 41.8 ± 17.33 ants; scattered, 44.0 ± 16.64 ants ($df = 1$, $F = 0.10$, $P = 0.758$). Although the number of workers available to retrieve granules did not differ between treatments, the first granule encountered was moved from its initial position and returned to the nest faster when the granules were scattered in the arena (Table 1). This response is not unexpected because a randomly moving ant would encounter one of several dispersed objects, on average, more quickly than it would encounter one clump of objects, because small dispersed objects have a greater surface area than the same objects packed tightly. Therefore, although discovery of dispersed granules should occur earlier, we expected that recruitment after discovery of the clumped granules should lead to more clumped granules being moved. Instead, even by the end of the second hour, there was no difference in the number of granules moved and returned to the nest for either distribution pattern (Table 1). In contrast, clumps of similar sized prey (first-instar cockroach nymphs) were retrieved more quickly by Argentine ants than scattered prey (Roulston and Silverman 2002), which supports models showing that a mass recruitment strategy is most effective when resources are clumped (Johnson et al. 1987, Jaffe and Deneubourg 1992, Anderson 2001). When prey size and resource patch size differed, more resources were returned to the colony from small prey than from large prey, indicating that food-handling ability can predominate over retrieval advantages predicted by patch size alone (Roulston and Silverman 2002). A similar response was observed in the rate that red imported fire ants, *Solenopsis invicta* Buren, recruited to soybean oil. This rate depended on how the oil was delivered, with more oil retrieved from corn-

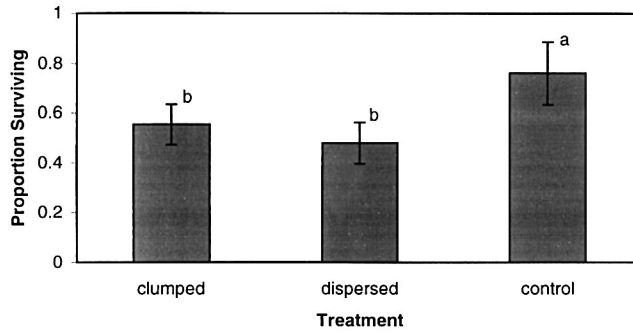


Fig. 1. Proportion (\pm SEM) of surviving *L. humile* workers exposed to different distributions of granular hydramethylnon bait. Bars with different letters indicate significant differences between treatments ($P < 0.05$; ANOVA).

cob grits than from a cotton wick, presumably because of a greater efficiency of processing oil-laden granules returned to the nest (Kidd et al. 1985). Despite their similar size (≈ 2 mm diameter), it seems that Argentine ants handle hydramethylnon bait granules differently than small prey, and thus the quality or type of resource can influence the pattern of ant foraging behavior. For example, when the resources are the same, *Aphaenogaster cockerelli* (Andre) (Hymenoptera: Formicidae) workers forage solitarily and collect more dispersed food than clumped food (Davidson 1977, Hölldobler et al. 1978). However, clumped "protein" (tuna) was collected more efficiently than dispersed seeds (Sanders and Gordon 2002); a response that is consistent with these ants showing a stronger recruitment response to "protein" than to seed resources (Hölldobler et al. 1978). The bait granules used in our study consisted, in part, of dried silkworm pupae and sugar, and this composition may have been of insufficient nutritional quality and/or moisture content relative to a freshly killed cockroach nymph to promote mass recruitment.

Whereas the granules killed significantly more Argentine ant workers than the control ($df = 2$, $F = 11.23$, $P = 0.001$), there was no difference in the proportions of workers alive between granule distribution patterns (Fig. 1). This would be expected based on the similar number of granules (toxicant load) returned to the nest. Ant mortality was correlated with the number of granules returned to the nest ($r = 0.671$, $P = 0.001$). Although granular baits placed in stations have an advantage over broadcast delivery by minimizing toxicant exposure to nontarget organisms and protecting bait from environmental factors that promote degradation (e.g., moisture, UV light), our laboratory results demonstrate that retrieval rates of clumped bait granules, through Argentine ant mass recruitment, was initially less than and subsequently equal to, retrieval of dispersed granules. The similar field population reduction levels reported by Klotz et al. (2000) for scattered versus containerized hydramethylnon granules may also reflect an insignificant level of recruitment to the containerized bait.

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