AN OPTIMISED SULFLURAMID BAIT FORMULATION FOR CONTROL OF BOTH PHARAOH'S ANTS *MONOMORIUM PHARAONIS* (L.) (HYMENOPTERA: FORMICIDAE) AND GERMAN COCKROACHES *BLATTELLA GERMANICA* (L.) (DICTYOPTERA: BLATTELLIDAE)

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Abstract— Containerised insecticide bait products offer considerable advantages for control of urban crawling insect pests. However the differences in insecticide susceptibility and food preference between some pest species have resulted in a diversity of commercial bait products, each targeted at specific insects. However the broad and generally similar food preferences of the two major urban pest insects; the German cockroach *Blattella germanica*, and the Pharaoh's ant *Monomorium pharaonis*, has prompted the development of a sulfluramid (Alstar^{R}) broader spectrum bait targeted at both these pests.

Laboratory tests were carried out with sulfluramid 0.5% and 1.0% bait in comparison with commercially available hydramethylnon 0.9% bait, against entire Pharaoh's ant colonies. Results indicated that worker ants consumed sulfluramid baits very readily, and mortality appeared between 1 and 7d after introduction of the bait, depending on the availability of alternative food. Intoxication of the worker ants was rapidly followed by the death of the brood within the nests. Complete kill of the nests was achieved by 28 to 35 days after baiting. Large scale field tests against Pharaoh's ants in apartment blocks and other buildings in Czech Republic showed that sulfluramid baits resulted in a rapid initial reduction in ant numbers, with final elimination of the ants being achieved within 7 to 240 days of baiting, depending on the availability of alternative food sources. Hydramethylnon baits showed a broadly similar efficacy.

Against German cockroaches, laboratory tests with sulfluramid 1.0% baits showed the onset of knockdown after 1d exposure to the bait, with compete mortality being obtained within 3d. In the same test, hydramethylnon 2.04% achieved complete mortality 7d after exposure to the bait. Field trials in infested apartment blocks showed that both sulfluramid 1.0% and hydramethylnon 1.6% baits achieved and maintained greater than 80% reduction in cockroach numbers over 120d after baiting. During this trial, numbers of cockroaches in untreated apartments showed a 44% seasonal increase in numbers.

These data indicate that a single optimised sulfluramid bait product may be used successfully to control both Pharaoh's ant and German cockroach infestations.

INTRODUCTION

German cockroaches and Pharaoh's ants are two of the most ubiquitous urban pest insects. Their synanthropic habits, their choice of micro-habitat, and their dietary habits result in them presenting a serious potential health hazard to urban dwellers.

Broad spectrum residual insecticides have been used for many years to control crawling urban insects. Since the early '80s however, specific containerised bait insecticides containing various active ingredients such as sulfluramid, hydramethylnon, and abamectin, have been developed for control of ants and cockroaches. Sulfluramid was originally discovered during a programme to identify novel compounds for the control of imported red fire ants (Vander Meer *et al*, 1985), and has since been developed for the control of other ant species (Reid & Klotz, 1992). Against cockroaches, sulfluramid's high activity is well documented (Appel & Abd-Elghafar, 1990; Reid *et al*, 1990). Containerised baits in general offer a number of advantages over conventional residual spray or dust treatments. The containment of the active ingredient in a bait station reduces the potential for environmental contamination, and for contact with the insecticide by operators, or by people living or working in the treated environment. It also enables the insecticide baits to be removed when pests are eliminated. In terms of efficacy, the protected nature of containerised bait insecticides largely protects the insecticide from the process of attrition and degradation that curtail the activity of insecticides applied as residual films.

Target species often differ in their intrinsic susceptibility to a particular active ingredient, and in their innate food preference. This has hitherto resulted in the development of a range of slightly differing bait products to achieve control of various pest species of cockroaches and ants. However a broad-spectrum insecticide bait is considered to offer advantages to both householder and

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professional user. It retains some of the flexibility of the conventional broad spectrum residual insecticides in terms of controlling a range of target species, yet offers the efficacy, convenience, safety and environmental advantages of the containerised insecticide baits.

Polyphagy is a characteristic, indeed possibly a pre-requisite, of the most successful urban insects. With this is mind, this paper presents key results of a programme to develop a single optimised bait formulation based on sulfluramid, that is both palatable and effective on the principal urban cockroach and ant pest species; *Blattella germanica* and *Monomorium pharaonis*.

MATERIALS AND METHODS

STAGE 1 – Different bait bases
Different active ingredient concentrations
No alternative food

Test 1 – Laboratory tests on Pharaoh's ants

Colonies of Pharaoh's ants were obtained for testing by placing small nest boxes (100×80×20mm) in the main stock colony, until they became occupied by a sub-colony. These sub-colonies contained many hundreds of ants comprising all life-stages ie immatures, queens and workers. Each sub-colony was then placed in individual stainless steel trays (330×230 50mm), with the inside edges covered with polytetrafluoroethylene suspension, to prevent ants escaping. Colonies were maintained in subdued red light at 27°C and 70% RH for several weeks to allow for colony establishment and growth. Over this time they were supplied with a standard diet (liver-powder, honey and peanut butter; 1:1:1 w/w) and water (from a small plastic tub with a wick) *ad libitum*.

The treatments offered were:

Active Ingredient	*Conc.*	*Bait base*
Sulfluramid	0.5%	Experimental bait base A
Sulfluramid	0.5%	Experimental bait base B
Hydramethylnon	0.95%	Maxforce^{R} Pharaoh's Ant Killer.
Untreated control	–	Standard laboratory diet

Three replicate colonies were offered each treatment under test for a period of two weeks. Over this time the standard laboratory diet was withdrawn. At the end of the two week period, the baits were withdrawn and the standard diet replaced.

Bait consumption was measured by weighing the baits before and after the two week exposure period. In addition, identical baits that were held under similar conditions, but with no exposure to ants, were also weighed, in order to allow compensation for any background weight changes.

Test 2 – Laboratory tests on German cockroaches

Batches of 30 adult male fully susceptible 2–3 week old German cockroaches were confined in glass tanks (300×200×200mm). The inside rims of the tanks were smeared with a petroleum jelly/paraffin mixture to prevent escape. All tanks were provided with a harbourage, and water *ad libitum*, and were maintained at 27°C and 45%RH. The cockroaches in the untreated control tanks were supplied with standard cockroach diet, but none was supplied to the cockroaches exposed to the insecticide baits.

One weighed bait station was placed in each tank, and was re-weighed after 14 days. Equivalent baits were also held in the test room without exposure to insecticides, so that corrections could be made for any background changes in bait weight.

Treatments offered were:

Active Ingredient	*Conc.*	*Bait base*
Sulfluramid	1.0%	Experimental bait base
Hydramethylnon	2.04%	Maxforce^{R} commercial gel bait
Untreated	–	Standard diet

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Knockdown and kill of cockroaches was recorded at intervals up to 14d after the introduction of the baits.

STAGE 2 – Same bait base
Different active ingredient concentration
Alternative food present

Test 3 – Laboratory Test on Pharaoh's ants

Small colonies of Pharaoh's ants, each consisting of 2 to 4 queens, 150 to 350 workers, and quantities of immature stages, were established in small wooden nest boxes with internal dimensions of 30×15×3mm. The nest space was covered with a microscope slide, which in turn was covered with a metal strip to keep the interior dark. The nests were transferred to a 150mm diameter petri dish, and provided *ad libitum* with the standard laboratory diet of hard-boiled egg yolk, crushed adult houseflies, and water.

Treatments offered were:

Active Ingredient	*Conc.*	*Bait base*
Sulfluramid	0.5%	Alstar[R] commercial bait station
Hydramethylnon	0.9%	Maxforce[R] Pharaoh's Ant Killer bait station
Untreated control		

One bait station was added to each petri dish, with the standard ant diet remaining in the dish as a competitive food source. The untreated control colonies were supplied with the standard diet only.

The impact of the treatments was assessed at intervals after treatment by temporarily removing the metal cover to each nest, and examining the nest through the microscope slide using a binocular stereo-microscope. Numbers of females, males, workers and third instar larvae were estimated.

Test 4 – Field Test on Pharaoh's ants

Field tests against infestations of Pharaoh's ants were carried out in Czech Republic, by the Institute of Public Health, Prague.

Infested apartment blocks of medium to high quality, together with other buildings, were located in the towns of Olomouc, Plzen, and Praha. A total of about 260 apartments, in 9 apartment blocks were selected, together with infestations in other buildings such as offices, restaurants and laboratories. The apartments were centrally heated, and typically consisted of a kitchen, living room, 1 to 3 bedrooms, and bathroom, covering an area of 40 to 70m^2.

The trial was started in the autumn, the optimum time for Pharaoh's ant treatments, as the central heating systems are then turned on and the resulting uniform warmth in the buildings encouraged greater movement and foraging of the ants. The ant infestations were assessed using glass monitoring tubes (150×15mm) containing a few grams of hard-boiled hens egg yolk. The assessments were done 2 or 3 times before treatment (-39 to -7d), and after treatment on the days indicated in Table 6. At each assessment interval about half of the total number of apartments were randomly selected for monitoring. Two monitoring tubes were placed overnight per selected apartment, collected and stoppered the following day, and returned to the laboratory for examination. The proportion of positive tubes (ie those with 1 or more ants), and the number of workers per positive tube, were recorded.

Treatments offered were:

Active Ingredient	*Conc.*	*Bait base and rate*
Sulfluramid	0.5%	Alstar[R] commercial bait stations applied at 1 per 10m^2.
Hydramethylnon	0.95%	Maxforce[R] Pharaoh's Ant Killer baits were placed at 1 per 10m^2.

The bait stations were placed in each apartment at the area dosage rate. Typically 2 or 3 were placed in the kitchen, and the remainder in the bathroom and WC. Other rooms were sometimes treated if ants were active there. One round of baiting was carried out.

Sulfluramid baits were applied to 161 apartments in 6 blocks, and hydramethylnon to 61 apartments in 2 blocks. Two infested apartment blocks containing a total of 120 apartments, were used as untreated controls.

All commercial and householder treatments were suspended at experimental sites during the trial.

Test 5 – Field tests against German cockroaches

Field trials were carried out in large low-income apartment blocks in Anglet, south-west France. Relatively poor hygienic condition occurred in many apartments, and a widespread infestation of German cockroaches existed. All apartments were of virtually identical design, comprising kitchen, living room, 2 bedrooms, bathroom and WC, with a total area of c. 60m^2. Trials were carried out during June to November, a time when the cockroaches tend to naturally increase in number, at least initially, in response to a seasonal increase in temperature.

Apartments were screened initially by placing 6 sticky traps ("Mr Sticky") at fixed sites (under kitchen sink, behind or beneath stove, under fridge, in cabinets), and a further 4 traps at other locations which the technician suspected to be infested. Traps were examined after 24h, and apartments with a catch of greater than 16 cockroaches were included in the trial. Acceptable apartments were trapped one more time prior to treatment, so that the pre-treatment baseline catch was based on the mean of two pre-treatment trapping rounds (-14d and -7d).

Selected apartments were excluded from the on-going commercial treatment programme, and occupants were asked to suspend their own insecticide treatments for the duration of the trial.

Treatments offered were:

Active Ingredient	*Conc.*	*Bait base and rate*
Sulfluramid	1.0%	Alstar^R bait stations were applied at 2–3 per 10m^2.
Hydramethylnon	1.6%	Maxforce^R bait stations were placed at 2–3 per 10m^2.
Untreated control		

Eight apartments were allocated at random to the treatments, with the exception of unusually heavily infested apartments which were distributed equally between treatments. Bait stations were applied at the rate of 12 bait stations per apartment, to areas which the trapping had shown to be heavily infested. Bait stations were placed horizontally, but against vertical surfaces. Locations typically baited included; under the stove, under the fridge, under the sink, in cupboards, and near the coffee machine.

After treatment, apartments were trapped at intervals, using the same trap locations as used in the pre-treatment trap rounds. Traps were again left in position overnight, collected, and returned to the laboratory for examination.

STAGE 3 – Same bait base
Comparison of two active ingredient concentrations
Alternative food present

Test 6 – Laboratory Test on Pharaoh's ants

This test was carried out using exactly the same protocol as Test 3 above. The objective was to establish whether the 1% bait was as effective as the 0.5%. Treatments were as follows:

Treatments offered were:

Active Ingredient	*Conc.*	*Bait base and rate*
Sulfluramid	0.5%	Alstar^R bait station
Sulfluramid	1.0%	Alstar^R bait station
Untreated control		

RESULTS

Test 1 – Laboratory tests on Pharaoh's ants

Bait consumption

Consumption of all insecticide baits was much reduced compared to the untreated standard diet (Table 1). Greater quantities of the sulfluramid baits were eaten compared to the Maxforce^{R} bait, which may have been a reflection of the slightly slower mortality caused by the sulfluramid baits.

Worker mortality

Estimates of worker mortality indicated that consumption of the insecticide baits resulted in a rapid mortality of ants (Table 2). The largely synchronised death of the colony indicated the extent to which the baits had been distributed amongst individuals within the colony. Most dead ants were found in the nest box.

Test 2 – Laboratory tests on German cockroaches

Bait consumption

Consumption data in this no-choice test (Table 3) indicated that despite the sulfluramid bait causing a more rapid onset of knockdown than hydramethylnon (Table 4), consumption of the sulfluramid bait was nonetheless greater. Despite this test being carried out using a non-optimised sulfluramid bait base, the higher consumption data indicate the relatively high palatability of the base plus insecticide.

Table 1. Bait consumption by *M. pharaonis*

Treatment	Mean Bait Consumption g (SE)
Control	2.20 (+/- 0.12)
Sulfluramid A	0.27 (+/- 0.06)
Sulfluramid B	0.42 (+/- 0.15)
Hydramethylnon	0.10 (+/- 0.04)

Table 2. Estimated percentage mortality of *M. pharaonis* workers

	Days after Treatment							
Treatment	0	1	2	3	7	14	21	28
Control	0	0	0	5	10	10	10	10
Sulfluramid A (0.5%)	0	65	85	95	99	100	100	100
Sulfluramid B (0.5%)	0	60	75	90	99	99	100	100
Hydramethylnon (0.9%)	0	70	98	99	99	99	99	100

Table 3. Bait consumption by *B. germanica*

Treatment	Mean Bait Consumption g (SE)
Control	0.64 (+/- 0.03)
Sulfluramid (1.0%)	0.20 (+/- 0.05)
Hydramethylnon (2.04%)	0.06 (+/- 0.05)

By 24 h after initial exposure to the baits, the majority of those cockroaches exposed to sulfluramid had been knocked down, with the mortality being complete by 3d after exposure. The effects of hydramethylnon were more delayed, with no effect at 24h, and complete mortality not being recorded until the 7d assessment (Table 4).

Test 3 – Laboratory Test on Pharaoh's ants

All colonies exposed to sulfluramid baits were totally killed within 4 weeks exposure, while all colonies exposed to hydramethylnon baits were killed within 6 weeks (Table 5). Exposure to the sulfluramid bait was characterised by the onset of slow, jerky movement of the workers after about 3 days, until eventually the ants ceased moving altogether, except for their antennae. The onset of jerky movement coincided with a cessation of normal behaviour, such as caring for the brood. Intoxicated queens did not show the jerky movements. Symptoms of intoxication in ants exposed to hydramethylnon were broadly similar.

Test 4 – Field Test on Pharaoh's ants

In the untreated apartment blocks the proportion of positive traps varied from 58 to 79%, with ant numbers per trap ranging from 35 to 47, over the 406 days of the trial. There were no trends in these ant numbers, and it was concluded that changes in ant numbers in the treated apartments could be confidently attributed to the treatments applied.

Monitoring of sulfluramid treated sites showed that ant counts were ultimately reduced to zero at every site. Monitoring continued for up to 407 days after baiting, with no re-appearance of ants at any site, indicating that ants appeared to have been eradicated within the treated areas (Tables 6 & 7).

At all sulfluramid treated sites, ant numbers showed a marked mean percent reduction by the 8 day assessment, ranging from 43 to 100%. The time taken for ant catches to reach zero at sulfluramid treated sites appeared to be determined by the availability of alternative food sources for the ants, not to the level of pre-treatment infestation. This elimination time ranged from less than 8 days in one office building where there was minimal alternative food available, to 32 to 120 days in the restaurant and in 2 apartment blocks, to within 240 days in 4 apartment blocks.

In hydramethylnon treated buildings ant numbers also showed a substantial reduction over the first week of the test. Elimination of ants was achieved for the two treated apartment blocks within 75 and 116 days, and no reappearance was recorded over the course of the trial.

Table 4. Mean % KD and mortality of *B. germanica* males exposed to baits

	Days after treatment		
	1	3	7
Treatment	KD / Mort.	KD / Mort.	KD / Mort.
Untreated	0 / 0	0 / 0	0 / 0
Sulfluramid (1.0%)	93 / 0	0 / 100	0 / 100
Hydramethylnon (2.04%)	0 / 0	10 / 90	0 / 100

Table 5. Mortality of worker *M. pharaonis*

		Days after treatment							
Treatment	% a.i. conc.	0	3	7	14	21	28	35	42
untreated	–	0	–	-33	–	−53	–	−100	−133
sulfluramid	0.5	0	25	88	94	99	100	–	–
hydramethylnon	0.9	0	–	86	–	97	–	97	100

Table 6. Percentage of monitoring tubes positive for *M. pharaonis* in apartment blocks.

	Sulfluramid (6 blocks)	Hydramethylnon (2 blocks)
Pre-treatment mean ant catch per positive tube	49	38
Days after treatment		
pre	62	53
8	35	30
16	34	18
32	20	–
36	–	20
64	17	–
75	–	2
116	–	0
120	10	–
150	–	–
176	–	0
240	0	0
351	0	–
407	0	–

Table 7. Percentage of monitoring tubes positive for *M. pharaonis* following treatment with sulfluramid in other building types.

	Restaurant (1 site)	Laboratories (2 sites)	Offices (1 site)
Pre-treatment mean ant catch per positive tube	275	135	93.2
Days after treatment			
pre	53	76	49.4
8	36	7	0
16	22	–	0
32	8	9	–
64	3	0	0
120	0	–	0
150	0	0	0
240	0	–	–

Test 5 – Field tests against German cockroaches

Mean percent reduction within columns followed by the same letter were not significantly different (p = 0.05; Wilcoxon signed rank test). Untreated apartments were not included in the statistical analysis owing to insufficient replication.

The population of cockroaches in the untreated apartments showed the expected seasonal increase in numbers over the course of the trial, reaching a maximum of 44% increase relative to the pre-treatment numbers at the 60d assessment. This created a relatively severe challenge for the products over this period. The sulfluramid bait reduced cockroach numbers by over 70% at the 14d assessment, and maintained greater than 80% reduction up to the end of the trial at 120d after treatment. There was no significant difference between the sulfluramid and hydramethylnon treatments at any time during the trial (Table 8). These mean figures conceal variation between apartments in which eradication of cockroaches was achieved early on in the trial, and those in which cockroaches remained in small numbers until the end of the trial.

Test 6 – Laboratory tests on Pharaoh's ants

Results of this comparison of 0.5% and 1.0% sulfluramid in the same bait base indicated that the higher concentration bait still exhibited a delayed onset of mortality, with no dead ants being recorded until the 7d assessment (Table 9). The 1.0% bait retained this slow action throughout the test, and achieved a 100% mortality of the worker ants at the same time as the 0.5% bait, at 35d after introduction of the baits.

DISCUSSION

The information presented in this paper illustrates the convergent development of a sulfluramid bait product, designed to be effective against both German cockroaches and Pharaoh's ants. Successful development of such a product has been achieved through selecting one bait base and insecticide concentration palatable and effective to both species.

Although their specific nutritional food requirements are likely to differ, information on the food preferences of German cockroaches (Cornwell, 1968), and of the Pharaoh's ant (Edwards & Abraham, 1990) indicate that the actual food materials consumed by the two species have much in common. The sulfluramid cockroach and ant bait used in Stages 2 and 3 of the study reported here, was designed to take advantage of the dietary overlap of these two key species. Although specific phagostimulants have been identified for the German cockroach, (Tsuji, 1966; Wileyto & Boush,

Table 8. Mean % reduction of *B. germanica* populations in apartments after bait treatment

Treatment	*n*	Mean cockroach nos pre-treatment	Days after treatment				
			14	30	60	90	120
Untreated	3	25	-12	-28	-44	-19	9
Sulfluramid (1.0%)	8	46	71a	86a	90a	81a	88a
Hydramethylnon (1.6%)	8	52	76a	90a	90a	93a	97a

Table 9. Percent mortality of worker *M. pharaonis* in laboratory choice test

Treatment	Days after treatment							
	0	3	7	10	14	21	28	35
untreated (1 nest)	0	0	-12	-12	-25	-25	-25	-25
sulfluramid 0.5% (5 nests)	0	0	44	57	87	95	99	100
sulfluramid 1.0% (6 nests)	0	0	40	44	65	93	94	100

1983), over-dependence on them was avoided in the final bait base, owing to indications that use of specific phagostimulants in insecticide baits may select for strains exhibiting behavioural resistance to such baits (Silverman & Bieman, 1993).

The decisive results and factors determining the progression of the project through Stages 1 to 3 are outlined below:

Stage 1

These basic laboratory studies essentially confirmed earlier evaluation of sulfluramid against ants and cockroaches. Although the tests reported here used experimental bait bases, the palatability and efficacy of the bait base plus sulfluramid to both species was clear. The speed of action against both species in these no-choice tests was faster than that subsequently seen in choice tests. This slightly slower activity in choice tests may relate to a combination of reduced intake of insecticide, together with a dilution of the insecticide by the non-insecticidal food material.

Stage 2

In this Stage, evaluation of sulfluramid in one standardised bait matrix, although at different active ingredient concentrations was carried out. The results showed that in laboratory choice tests, and in field tests, the new standard bait base was a palatable and effective base for sulfluramid for use against both Pharaoh's ants and German cockroaches.

Stage 3

Having established in Stage 2 that sulfluramid baits at 0.5% and 1.0% were effective against ants and cockroaches respectively, the next objective was to select one active ingredient concentration that was active and palatable against both species. Published results on other ant species (Reid and Klotz, 1992) indicated that sulfluramid was active against these social insects at a relatively broad range of concentrations. This indicated the possibility of some flexibility in bait concentration against the Pharaoh's ants. Against German cockroaches however, results of field tests indicated that reducing the sulfluramid concentration much below 1.0% gave reduced efficacy (FMC internal report). Clearly then at this final stage of the programme, the indications were that the 1.0% bait was more likely to be effective against Pharaoh's ants, than the 0.5% was going to be against German cockroaches. Results of Test 6 indicated in fact that this higher concentration bait could control Pharaoh's ants effectively.

In conclusion, the tests described here indicate that it is possible to develop a single bait product, in this case sulfluramid 1.0% bait, for successful use against both Pharaoh's ants and German cockroaches. Such a product is believed to offer not only high levels of efficacy against either or both target species, but also improved flexibility to the user and supplier.

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