LABORATORY and FIELD EFFICACY of NOVIFLUMURON FORMULATIONS against the GERMAN COCKROACH

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Abstract Insecticidal activities of noviflumuron formulated as dust, gel, and suspension concentrate (SC) were evaluated against the German cockroach, *Blattella germanica* (L.), in the laboratory and in apartments. In laboratory studies conducted in large cockroach arenas (1 m^2 boxes), population reductions averaged 99.9 ± 0.07, 97.7 ± 0.2 and 65.6 ± 16.7% for the dust, gel, and SC, respectively, after 16 weeks of exposure. For flufenoxuron dust, population reductions averaged 98.1 ± 0.2%. There were no significant differences between noviflumuron formulations compared to flufenoxuron. There were significant differences between the population sizes in the noviflumuron treatments compared to the untreated control. Cockroach populations not exposed to toxic baits increased in size by more than 1365.5 ± 69.9%. In a 2-year study conducted in apartments, noviflumuron dust and gel baits gave residual control of German cockroach populations. There were no significant differences between the performances of noviflumuron baits compared to the Maxforce® gel bait, and Avert® 310 dust bait.

Key Words noviflumuron, chitin synthesis inhibitor, German cockroach, residual

INTRODUCTION

Environmental and safety concerns associated with the use of neurotoxic insecticides for managing German cockroach, *Blattella germanica* (L.), infestations in human dwellings have necessitated the search for biorational chemistries. Biorational compounds are specific to the target pests, do not have adverse effects on non-target organisms, and usually are environmentally friendlier (Legaspi et al., 1999). Examples of biorational compounds are the Chitin Synthesis Inhibitors (CSI). Chitin synthesis inhibitors are active against only those organisms that synthesize chitins. As a result, these compounds are safer alternatives for managing German cockroach infestations in human dwellings compared to many of the currently used nerve poisons. Examples of CSI currently used for German cockroach control includes diflubenzuron, flufenoxuron, lufenuron, etc.

Noviflumuron, N-[[[3,5-dichloro-2-fluoro-4-(1,1,2,3,3,3-hexafluoropropoxy)phenyl] amino]carbonyl]-2,6-difluorobenzamide, is a new chemistry currently being developed by Dow AgroSciences, Indianapolis, Indiana, USA, for the structural pest control market. It has been classified as a CSI because of its mode of action. Preliminary data suggest it is more active against the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), than hexaflumuron, the current active ingredient in the Sentricon® Termite Colony Elimination System (Sheets and Karr, 2001). In this paper, we report the results of our investigations on the laboratory and field efficacy of this novel compound against the German cockroach.

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MATERIALS and METHODS

Laboratory Studies

The efficacy of dust, gel, and suspension concentrate (SC) formulations of noviflumuron was evaluated and compared to flufenoxuron dust against populations of a laboratory-reared, insecticide susceptible strain of *B. germanica.* There was also an untreated control treatment where cockroaches were not exposed to any toxic bait but provided with food *ad libitum.* The German cockroach strain used in these studies is the 'Johnson Wax' (JWAX) strain. This strain has been maintained in culture at the center for Urban and Industrial Pest Management, Purdue University, West Lafayette, Indiana, since 1984 on a standard laboratory diet of Wayne™ Rodent Blox (Continental Grain, Chicago, IL, USA) at 27^0 C, 70% RH and 12:12 h [L:D] photoperiod. The JWAX strain was isolated from a field-collected population before the introduction of synthetic organic insecticides (Koehler and Patterson, 1986).

Studies were conducted in a 11 × 14.5 m room with a controlled environment (27^{0}C, 70% RH and 12:12 h [L:D] photoperiod). Test insects were released into 1m^2 boxes and allowed 3 d to acclimate before treatments were applied. Populations were provided with abundant food and water so as not to restrain growth. Water, provided in cotton stoppered 25 ml vials, and food (Wayne™ Rodent Blox) were positioned in opposite corners of the boxes. After the acclimation period, food was removed from all boxes except for the cockroach populations exposed to the SC treatment and the untreated control. All treatments except the SC were evaluated at a rate of 0.5%. The SC formulation was evaluated at 0.2%. For the dust and gel treatments, we provided 12 g of gel and 6 g of dust initially and these were replenished as soon as exhausted. The SC formulation was sprayed onto masonite panels (15.24 cm × 15.24 cm) using a spray tower apparatus (Spraying System Tee-Jet SS8001E, Dayton Electric Manufacturing Company, Chicago, IL, USA) with a flat fan stainless steel nozzle. The spray equipment was calibrated to deliver 25 mg/m^2 of formulated material at a rate of 1 gallon/1000 sq. ft. horizontal surface at a constant pressure of 60 psi. Two sprayed panels were placed at opposite corners of the arenas.

Treatments were replicated three times; each replicate was conducted with 500 insects consisting of 250 small nymphs (2nd and 3^d instars), 125 large nymphs (4th and 5^h instars), 65 males and 60 non-gravid females. Tests ran for 16 weeks after treatments were introduced. The number of living cockroaches were counted weekly by treatment and classified by age and sex. Dead cockroaches were removed from the arenas every week.

Field Studies

A 2-year study was conducted to evaluate the efficacy of noviflumuron dust and gel baits against field populations of *B. germanica* in multi-family housing apartments, located in Fort Wayne and Muncie, Indiana. Prior to the beginning of all studies, the housing authorities were advised to terminate all insecticide applications at least 4-6 wks in advance. Studies were initiated by establishing the pre-treatment cockroach population densities in each apartment in order to determine those apartments with sizable cockroach populations for inclusion in our studies. Cockroach densities were sampled in the kitchens and bathrooms of test apartments by placing one Lo-Line® sticky trap (10 × 19 cm, AgriSense-BCS Limited, South Wales, UK) in the following areas: 1) the cabinetry under the kitchen sink, 2) the cabinetry above the kitchen sink, 3) under the stove, 4) below the refrigerator, 5) the utility room (area around water heater and furnace), and 6) on the floor behind the toilet seat. Traps were placed one day, and retrieved 24 h later, so that traps were in place overnight. On retrieving the traps, the number of cockroaches caught was counted and recorded by trap. Trap catches were recorded as number of males, females, gravid females, large nymphs (instars 4 - 6), and small nymphs (instars 1 - 3). A minimum of 12 cockroaches caught in six traps (i.e., an average of 2 cockroaches/trap) was required for any apartment to be selected as a test apartment. Pre-treatment sampling data were used to divide test apartments into high,

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medium, and low densities, and treatments were assigned to these apartments in such a way as to ensure that there was some sort of balance in the average pre-treatment population densities by treatment. Treatments were applied to the same general area where sampling traps were placed during pre-treatment samplings (see above).

In the first year of studies conducted in 1997, we evaluated the efficacy of noviflumuron dust and gel baits at 0.5%. The standard treatment was Avert® [Prescription Treatment® (PT) 310] dust bait (active ingredient (a.i.) is 0.05% abamectin B1; Whitmire Micro-Gen Research Laboratories, Inc., St. Louis, MO, USA). Approximately 15 g of bait materials were applied in each apartment and post-treatment population density monitoring was conducted at 2, 4, 8, 12, and 16 weeks.

In 1998, we also evaluated noviflumuron dust and gel baits at 0.5% and compared the efficacy of these treatments to Avert® dust bait (PT 310), Cynoff® Water Soluble Bags (WSB) insecticide (35.6% cypermethrin, FMC Corporation, Philadelphia, PA, USA) and Maxforce® FC Roach bait stations (a.i. = 0.05% fipronil; Maxforce Insect Control Systems, Oakland, CA, USA). Approximately 15 g of dust and/or gel formulations (noviflumuron, Avert®) were applied in each apartment. Twelve Maxforce® FC bait stations were placed in each test apartment; 2 stations in each sampling 'zone' (see above). For the pyrethroid spray treatment (Cynoff®), we applied approximately 200 ml of a 2% solution as a 'crack and crevice' treatment with a 1-gallon B & G sprayer. Formulated product was sprayed to the point of run-off to all harborage areas in the sampling 'zone'. Post-treatment population density monitoring was conducted at 2, 4, 8, 12, 18, and 24 wks. Treatments were re-applied after the 12 wk post-treatment population density sampling was concluded.

Data Analyses

For the laboratory studies, the mean number of living cockroaches was calculated by treatment by week (PROC MEANS, SAS Institute, 2000). Analysis of variance (PROC ANOVA) was used to compare the effect of treatments on cockroach population densities as appropriate for a completely randomized design. Means were separated with Tukeys test at a = 0.05. The variable of interest in the field trials was trap catch reduction/residual control of cockroach populations by treatment over time. Pre- and post-treatment population densities were estimated for test apartments from the total number of cockroaches caught on the six traps. Trap catch reduction (%) was calculated by test apartment at each post-treatment sampling interval with the formula:

$$(\text{pre-treatment count}) - (\text{post-treatment count at wk X}) / (\text{pre-treatment count}) \times 100$$

where X is the post-treatment sampling interval.

Trap catch reduction were calculated by treatment with PROC MEANS. These data were then transformed using the formula: ø = arcsin, where ø is transformed % reduction, and *P* is percentage converted into proportion. Analysis of variance was then used to compare the post-treatment trap catch reduction data by treatment by week. In all cases, Tukey test was used for mean separation at a = 0.05. For practical evaluations of the efficacy of treatments, a satisfactory level of population reduction was set at 70% *a priori*, based on our experience with tenant's level of satisfaction.

RESULTS and DISCUSSION

Laboratory Studies

Without exposure to toxic baits, German cockroach populations consisting of an initial 500 insects increased, on the average, to 6827.7 ± 349.7 after 16 weeks. Conversely, similar populations exposed to the noviflumuron formulations suffered significant decline in number over time

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Table 1. Comparative reduction in laboratory populations of the German cockroach exposed to noviflumuron formulations

	Total number of cockroaches alive by treatment by week (Mean ± SE)						
	Noviflumuron	Noviflumuron	Noviflumuron	Flufenoxuron	Untreated	ANOVA statistics	
Week	dust	gel	SC	dust	control	*F*	*p*
0	500	500	500	500	500		
1	475.3 ± 4.7ab	433.7 ± 0.3abc	334.3 ± 34.9c	393.7 ± 6.7bc	522.7 ± 41.6a	8.77	0.0026
2	241.0 ± 5.0a	285.0 ± 55.3a	166.0 ± 0.0a	220.7 ± 6.4a	452.0 ± 0.0a	4.26	0.0568
3	157.0 ± 25.9b	173.3 ± 7.8b	423.3 ± 181.1ab	159.0 ± 9.3b	1137.7 ± 346.2a	5.80	0.0111
4	312.0 ± 76.4b	451.0 ± 56.2b	397.7 ± 120.1b	355.7 ± 21.7b	1150.7 ± 38.4a	23.97	<0.0001
5	165.7 ± 25.2b	246.3 ± 19.9b	315.7 ± 88.9b	173.0 ± 11.6b	1612.7 ± 182.5a	45.89	<0.0001
6	117.3 ± 5.5b	134.3 ± 9.7b	149.7 ± 5.7b	125.7 ± 5.2b	2381.7 ± 475.3a	22.00	<0.0001
7	117.3 ± 4.7b	100.7 ± 9.8b	131.0 ± 4.4b	110.7 ± 4.7b	2234.0 ± 0.0a	8656.7	<0.0001
8	100.0 ± 6.6b	110.0 ± 1.5b	116.7 ± 4.3b	99.3 ± 1.7b	4836.0 ± 1083.0a	15.54	0.0003
9	88.7 ± 8.3b	104.7 ± 4.4b	115.3 ± 6.4b	84.3 ± 0.9b	5529.3 ± 1260.3a	18.57	0.0001
10	74.7 ± 8.8b	87.0 ± 2.7b	101.3 ± 6.9b	60.0 ± 5.6b	5283.3 ± 863.7a	36.28	<0.0001
11	34.3 ± 12.4b	76.0 ± 2.5b	178.0 ± 85.6b	51.3 ± 3.7b	5662.7 ± 690.3a	64.30	<0.0001
12	10.7 ± 5.7c	58.7 ± 3.7b	116.3 ± 12.5d	42.3 ± 2.2bc	5391.0 ± 0.0a	42502.4	<0.0001
13	3.3 ± 1.2b	46.0 ± 3.0b	78.3 ± 8.4b	28.0 ± 1.7b	6146.3 ± 273.4a	498.53	<0.0001
14	2.7 ± 1.3b	23.3 ± 1.2b	70.3 ± 3.7b	21.0 ± 2.0b	7067.0 ± 445.7a	249.33	<0.0001
15	1.7 ± 0.9b	14.3 ± 2.3b	83.3 ± 14.3b	13.7 ± 0.9b	7495.0 ± 206.6a	1299.9	<0.0001
16	0.7 ± 0.3b	11.7 ± 0.9b	172.0 ± 84.3b	9.3 ± 0.9b	6827.7 ± 349.7a	355.31	<0.0001

Means in rows followed by the same letter(s) are not significantly different according to Tukey's test at $\alpha = 0.05$ (SAS Institute, 2000).

Table 2a. Comparative efficacy of noviflumuron dust and gel baits against populations of the German cockroach in multi-family housing apartments, 1997

		Pre-treatment counts	Post-treatment % reduction in trap catches (Mean ± SE)				
Treatment	n	(Mean ± SE)	02 wk	04 wk	08 wk	12 wk	16 wk
Noviflumuron dust bait	10	36.3 ± 10.0a	56.1 ± 9.8a	74.2 ± 7.0a	94.7 ± 2.8a	96.9 ± 1.2a	96.5 ± 1.7a
Noviflumuron gel bait	8	26.9 ± 5.1a	34.9 ± 10.7a	74.3 ± 7.8a	86.0 ± 3.1ab	86.6 ± 5.1a	92.5 ± 4.3a
Avert® PT 310 dust bait	9	21.6 ± 12.0a	57.7 ± 11.1a	67.2 ± 11.6a	70.0 ± 10.9b	45.0 ± 4.8b	47.2 ± 13.3b
F		0.61	0.78	0.50	4.5	9.8	10.4
P		0.5536	0.47	0.61	0.02	0.0008	0.0006

Means in columns followed by the same letter(s) are not significantly different according to Tukey's test at $\alpha = 0.05$ (SAS Institute, 2000). *F* and *p* statistics were generated from analysis of variance of transformed percent trap catch reduction data.

Table 2b. Comparative efficacy of noviflumuron dust and gel baits against populations of the German cockroach in multi-family housing apartments, 1998

		Pre-treatment counts	Post-treatment % trap catch reduction (Mean ± SE)					
Treatment	n	(Mean ± SE)	02 wk	04 wk	08 wk	2 wk	8 wk	4 wk
Noviflumuron dust	7	36.3 ± 10.0a	43.9 ± 3.9a	67.9 ± 6.7a	82.4 ± 9.7ab	88.2 ± 8.5a	96.0 ± 3.3a	98.4 ± 1.3a
Noviflumuron gel	9	26.9 ± 5.1a	57.5 ± 12.0a	68.8 ± 6.9a	90.9 ± 4.3a	87.9 ± 8.2a	92.3 ± 4.1a	89.8 ± 4.8ab
Avert® PT 310 dust	8	22.1 ± 8.2a	57.2 ± 12.5a	58.3 ± 11.0a	77.6 ± 11.9ab	90.2 ± 4.4a	78.5 ± 13.6a	71.8 ± 13.7ab
Cynoff® WSB	8	26.9 ± 5.1a	57.1 ± 13.2a	43.2 ± 15.1a	48.4 ± 14.8b	56.9 ± 19.3a	46.7 ± 27.0a	49.6 ± 18.5b
Maxforce® FC	9	16.4 ± 5.5a	63.9 ± 12.9a	70.1 ± 10.2a	84.2 ± 5.8ab	85.8 ± 6.9a	83.9 ± 6.9a	89.6 ± 5.7ab
F		0.87	0.25	1.23	1.03	1.60	2.31	3.74
p		0.4888	0.9067	0.3159	0.4030	0.1984	0.0849	0.0174

Means in columns followed by the same letter(s) are not significantly different according to Tukey's test at $\alpha = 0.05$ (SAS Institute, 2000). F and P statistics were generated from analysis of variance of transformed percent trap catch reduction data.

(see Table 1). Population reductions averaged 99.9 ± 0.07, 97.7 ± 0.2, and 65.6 ± 16.7%, respectively, for cockroach populations exposed to the dust, gel, and SC formulations. In general, there were no significant differences in the population decline recorded for the cockroach populations exposed to the noviflumuron formulations. But population reduction was much higher for the dust and gel formulations compared to the SC formulation after 16 weeks of exposure. The reason for the comparatively poor performance of the SC formulation might be due to the fact that this treatment was applied as a 'one–time' treatment, while the dust and the gel baits were replenished as soon as they were exhausted. For flufenoxuron, reduction in populations averaged 98.1 ± 0.2%. There were no significant differences between the performances of noviflumuron compared to flufenoxuron. Cockroach populations exposed to the noviflumuron formulations suffered significant population decline compared to cockroach populations not exposed to toxic baits. From the foregoing, it is apparent that the noviflumuron has potential insecticidal activities against adult and nymphal cockroach populations in the laboratory.

Field Studies

Like the laboratory studies, the dust and gel formulations of noviflumuron were very effective for the residual control of German cockroach populations in multi-family housing apartments (Tables 2a, 2b). In addition, the level of residual control was very consistent because satisfactory performances were recorded for each of the two field trials (Tables 2a, 2b). In the 1997 study, trap catch reduction averaged from between 56.1 to 96.9% for the dust, and between 34.9 and 92.5% for the gel formulation of noviflumuron. Trap catch reduction for the Avert® dust bait, the standard treatment in this study, averaged between 47.2 and 70.0% (Table 2a). There were no significant differences between the performances of these treatments in the first 4 wk following treatment application, but significant differences were found thereafter. The noviflumuron formulations had significantly higher trap catch reduction compared to Avert® at wks 8, 12, and 16. The reason for these differences in performance in the later stages of the study might be due to the non-availability the Avert® dust bait to the cockroach populations probably due to contamination and/or complete removal of the bait.

In the 1998 study, the noviflumuron dust and gel baits were as effective as the standard treatments because we did not detect any significant differences in trap catch reductions among these treatments (Table 2b). On the other hand, the noviflumuron baits had significantly higher trap reductions, on the average, compared to Cynoff®. In contrast to the 1997 study, all treatments were re-applied 12 wk after first treatment and this probably explained the reason for the lack of significant differences in trap catch reductions recorded for the noviflumuron baits compared to the Avert® dust bait.

From the foregoing, it is apparent that noviflumuron has potent insecticidal activities against the German cockroach. In laboratory studies, cockroach populations exposed to the noviflumuron formulations suffered significantly higher population decline compared to the untreated control population. In addition, there were no significant differences between the performances of the noviflumuron formulations compared to flufenoxuron. Flufenoxuron is currently the most active chitin synthesis inhibitor against the German cockroach (Reid et al., 1992). Data generated from studies in low-income housing apartments have also shown that noviflumuron is an effective residual control agent against field cockroach populations.

In conclusion, noviflumuron has potent insecticidal activities against German cockroach populations in both laboratory and field trials.

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