Research Article

Received: 9 February 2008 Revised: 24 June 2008 Accepted: 25 June 2008 Published online in Wiley Interscience: 18 December 2008

(www.interscience.wiley.com) DOI 10.1002/ps.1685

Field evaluations of insecticide treatment regimens for control of the common bed bug, *Cimex lectularius* (L.)†

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Abstract

BACKGROUND: Because bedbugs, *Cimex lectularius L.*, have not been a problem in the USA for over 40 years, few insecticide products are labeled for their control. Most products that are labeled for bedbugs are pyrethroids. However, recent studies indicate that field-collected bedbugs may be resistant to pyrethroids. There are also non-pyrethroid products labeled for bedbugs, but, like the pyrethroids, none of these products has been evaluated for field efficacy. This study evaluated the efficacy of two insecticide treatment regimens for bedbugs in multi-unit housing. Both of the treatments included multiple products currently being used by the pest management industry.

RESULTS: The 'traditional' treatment consisted of applications of pyrethroid products and an insect growth regulator. The 'novel' treatment consisted of applications of non-pyrethroid products. The traditional treatment significantly reduced the number of bedbugs from 39.8 ± 10.1 per unit prior to treatment to 2.2 ± 1.0 at the end of the test period ($P = 0.02$; 95% reduction). The number of live bedbugs in the 'novel' treatment was also significantly reduced from 71.4 ± 25.3 bedbugs per unit to 10.2 ± 4.4 after 8 weeks (86% population reduction).

CONCLUSIONS: Although both treatment regimens reduced bedbug numbers, the fact that bedbugs were not eliminated after multiple applications suggests that the insecticides, applied at the current label rates, were inadequate. These results suggest that a more integrated approach to bedbug control is necessary in multi-unit housing situations.

Keywords: bedbugs; *Cimex lectularius*; multi-unit apartments; insecticide treatment; pyrethroids, chlorfenapyr

1 INTRODUCTION

The common bedbug, *Cimex lectularius* L., is currently reclaiming its status as a major household pest across North America. The number of reported infestations in single family homes, hotel rooms and multi-unit housing has increased 10–100-fold every year since 1990.[1,2] Bedbugs are typically introduced into homes in the luggage of travelers, by the purchase of infested (used) furniture or refurbished mattresses, or on the clothing of workers, either migrant or stationary, that are employed or housed in infested locations.[3–6] In addition to the phoretic transport of bedbugs by human activities, bedbugs have also been documented moving on their own from one apartment or hotel room to another via wall voids or electrical conduits in multi-unit facilities.[6]

Bedbugs are highly cryptic and can hide almost anywhere,[7] including the cracks and crevices in furniture, behind picture frames and light switches, under wallpaper, in door and window frames, behind baseboards and headboards and in bedding.[6,8,9] Because bedbugs prefer dark locations[10] with little air flow[11] and minimal disturbance,[12] their harborages are not evenly distributed throughout the host's dwelling.[6] Harborages are most frequently located in the dark recesses of the host's box springs, bed frame or in the mattress seams. In these locations the bedbugs can hide all day, yet be in close proximity to the host at night. While dark cracks and crevices are the preferred harborages, in heavily infested dwellings bedbug aggregations can often be found out in the open on the walls and ceiling.

Because of their cryptic nature, live bedbugs can be very difficult to detect when the infestation is small. Currently, there is no commercial monitoring device available for bedbug detection,[4] so the initial indication of bedbug presence is usually the host's reaction to the bites. Additional evidence may include blood spots on the bedding where a fed bedbug has been crushed,[13] black fecal stains on the mattress or wall[5] or the presence of bedbug exuvia.[9] Typically, evidence of a bedbug infestation (other than the bites) does not become visible until the infestation has been present for several months. Therefore, unless a homeowner or a pest management professional has had experience in dealing with bedbugs, it can be difficult to locate bedbugs and their harborages to control the infestation.[13]

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† This article was published online on 18 December 2008. An error was subsequently identified in the title. This notice is included in the online and print versions to indicate that both have been corrected [9 January 2009].

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Owing to the social stigma associated with bedbugs, the hospitality and housing industries often refuse to discuss bedbug infestations for fear of bad publicity or litigation.[14] Apartment tenants may also be reluctant to inform their housing management company of an infestation for fear of financial penalties or eviction. As a result, residents will often try to eliminate the infestation by themselves,[14] using over-the-counter spray insecticides, home remedies and even cockroach baits. However, the residents usually fail to control the bedbug problem, so allowing the infestation to continue.

Historically, people in the United States have treated their bedbug problems with a variety of toxicants, but these toxicants provided only marginal relief until the introduction of dichloro-diphenyl-trichloroethane (DDT) in 1939.[15] Although DDT was very successful at eliminating bedbug infestations, bedbug resistance to DDT was documented within 8 years of its initial use.[16] However, the liberal use of DDT and malathion practically eliminated bedbugs in the United States by the 1960s,[6] with only a few infestations continuing to persist where sanitation conditions were exceedingly poor. Over the next several decades, scattered populations in the United States, and those in other nations, developed resistance to a host of chemicals used for bedbug control. These chemicals included methoxychlor, dieldrin, aldrin,[17,18] carbaryl, endrin, gamma-BHC,[19] sodium fluoride,[20] malathion and other organophosphates, benzene hexachloride and other chlorinated cyclodienes.[6] Most of these older chemistries are no longer registered with the US Environmental Protection Agency and are not available for bedbug remediation.

Because bedbugs have not been a problem in the USA for over 40 years, few of the currently registered insecticide products are labeled for bedbug control. The majority of those that are labeled are either natural pyrethrins or synthetic pyrethroids. Although the effects of these pyrethroids on wild bedbug populations have not been studied extensively, there is laboratory evidence to suggest that these emerging bedbug populations have developed resistance to some of these products[14] (Moore and Miller, unpublished data). In addition to the pyrethroids, there are several other non-pyrethroid products that are currently being used alone or in combination with other insecticides for bedbug control in the field. Like the pyrethroids, some of these novel products have been evaluated in the laboratory,[21] but none has been evaluated for field efficacy. The purpose of this study was to evaluate the field efficacy of two different insecticide product regimens for control of bedbugs in multi-unit housing. Both of these treatment regimens include products that are currently labeled for bedbugs and are in common usage by the pest management industry to control bedbug populations in hotels, apartments and single family homes.

2 METHODS AND MATERIALS

2.1 Field site

Evaluations of bedbug treatments were conducted from January to March 2006 in Buckingham Village, a low-income housing facility located in Arlington, VA. The facility consists of two-story brick buildings containing 8–16 apartment units built on a slab foundation. The housing facility was built between 1937 and 1953 and has been under numerous pest control contracts. The current pest control contract requires that each apartment unit be treated on a quarterly basis for general household pests. Quarterly treatment consists of a baseboard, crack and crevice application of lambda-cyhalothrin (0.3 g L^{-1}; Demand CS, Syngenta, Greensboro, NC), hydroprene (0.7 g L^{-1}; Gentrol Concentrate, Wellmark International, Schaumburg, IL) and fipronil (0.1 g L^{-1}; Maxforce FC cockroach gel bait, Bayer Environmental Science, Montvale, NJ). When the facility receives a bedbug complaint, the pest management company typically provides a supplementary treatment of lambda-cyhalothrin (0.3 g L^{-1}) applied in combination with deltamethrin (0.6 g L^{-1}; Suspend SC, Bayer Environmental Science, Montvale, NJ) and hydroprene (0.7 g L^{-1}).

The residents of Buckingham Village were primarily Hispanic day-laborers. Typically, a single resident was the leaseholder for the apartment, while the other tenants rented from the leaseholder at a daily or weekly rate. This arrangement allowed tenants to move themselves and their belongings from one apartment to another every few days. The overcrowded conditions in the housing facility and the frequent movement of the residents contributed to the bedbug problems. Because the tenants were often not at home during normal working hours, and because they were largely Spanish speaking, the authors were not able to provide residents with any bedbug prevention information or sanitation advice during the course of this study. However, tenants in bedbug-infested apartments frequently applied their own bedbug control measures. For example, boric acid was observed along the baseboards and inside bed frames and other furniture. Masking tape, duct tape and caulk were also used along the baseboards, wall heaters, electrical outlets and switch plates to contain bedbugs inside the walls. Over-the-counter pyrethroid products and bleach diluted in water were also frequently applied on furniture and bedding to kill bedbugs.

2.2 Apartment selection

During the initial inspection of the housing facility (January 2006), it was observed that the intensity of bedbug infestations varied from one apartment to the next. However, all apartment units had signs of bedbug infestation. To quantify the pretreatment bedbug infestation levels, individual apartments were visually inspected. The visual inspection was conducted in a systematic fashion with two trained, certified pest management personnel (PMP) inspecting, counting and comparing their counts taken from specific locations within each room of the apartment. The PMP began their inspection by counting the live bedbugs present on the baseboards, walls and ceiling. Clothes, wall hangings and other possessions were moved away from the baseboards and walls to allow for the inspection. However, piles of clothing and the personal items were not inspected. Each piece of furniture within the room was also inspected by removing the cushions, drawers or bedding, and then inverting the furniture so that all seams and cracks could be inspected and counted by both inspectors. Empty suitcases were inspected when available, but duffle bags, backpacks and suitcases containing the owner's personal belongings were not inspected.

During the initial inspection, kitchens and bathrooms were found to be infested with German cockroaches, and no bedbugs were found in these rooms. Therefore, the kitchens and bathrooms were excluded from any treatment or further bedbug counts. Areas used for sleeping (i.e. bedrooms, living room and dining area) in each apartment were inspected for bedbugs. Within each 'sleeping room', the number of bedbugs (all instars and adults) on the walls, baseboards, ceilings, bedding and other furniture was recorded. Apartments in which more than ten live bedbugs were found in 'sleeping rooms' were selected for participation in the study. Fifteen apartment units in total were selected and randomly assigned to receive one of two insecticide treatment regimens or to serve as a control.

2.3 Treatment regimens

Five apartments were assigned to receive one of two bedbug treatment regimens consisting of the combined application of several insecticide products. One treatment combination consisted primarily of insecticides that have had bedbugs on the product label for many years. This treatment regimen was designated the 'traditional treatment'. The second treatment combination consisted primarily of newer products that were new to the bedbug label, were EPA exempt or had only a site label for crawling insect pests. This treatment regimen was designated the 'novel treatment'.

2.3.1 *Traditional treatment*

The products selected for use in the traditional treatment were β-cyfluthrin 18 g L^{-1} SC (Tempo SC Ultra; Bayer CropScience LP, Montvale, NJ) at 0.5 g AI L^{-1}, deltamethrin 47.5 g L^{-1} SC (Suspend SC; Bayer CropScience LP, Montvale, NJ) at 0.6 g AI L^{-1} and hydroprene 3.6 g L^{-1} AE (Gentrol Aerosol; Wellmark International, Schaumburg, IL). All products were applied at the highest concentration of active ingredient allowed by the insecticide label. Tempo SC Ultra was diluted in a pump sprayer (1 gal Prime Line 2000, B&G Equipment Co., Jackson, GA) and applied to baseboards, ceiling/wall junctions and cracks and crevices where bedbugs were harboring. Suspend SC was also diluted in a pump sprayer and applied to mattresses and inside box springs. Gentrol Aerosol was applied around the baseboards, cracks and crevices, and as a border around bed frames or box springs. After the initial treatment, each apartment was re-treated at 2 week intervals (maintenance treatments) with all of the products listed above for the duration of the 8 week test.

2.3.2 *Novel treatment*

The products selected for use in the novel treatment were chlorfenapyr 214.5 g L^{-1} EC (Phantom; BASF Corporation Research Triangle Park, NC) at 5 g AI L^{-1}, Steri-Fab (60.39% isopropyl alcohol; Noble Pines Products Co., Yonkers, NY), NIC 325 (dust formulation of 99.5% limestone, AMC-Texas LLC, Fort Collins, CO) and hydoprene 3.6 g L^{-1} AE (Gentrol Aerosol; Wellmark International, Schaumburg, IL). Phantom was diluted in a pump sprayer (1 gal Prime Line 2000, B&G Equipment Co., Jackson, GA) and applied to baseboards, ceiling/wall junctions and cracks and crevices where bedbugs were harboring. Steri-Fab was used only once during the initial treatment and was applied directly on bedbugs harboring along the tufts and seams of mattresses and box springs. NIC 325 was used in subsequent mattress treatments and was applied on the seams and tufts of mattresses. NIC 325 was also applied in the seams and wood framing of the box springs. The application of Gentrol Aerosol completed the novel treatment. Gentrol was applied as described for the traditional treatment. After the initial application was completed, each apartment was re-treated with Phantom, Gentrol and NIC 325 every 2 weeks for the duration of the test.

2.3.3 *Treatment and monitoring schedule*

Treatments were applied by PMP from Innovative Pest Management Co. and by David Moore of Virginia Tech, a certified technician. Both traditional and novel treatments were applied every 2 weeks for 8 weeks. The first treatment application during the initial visit was intended to kill as many bedbugs as possible. Both the initial treatment and subsequent maintenance treatments allowed the PMP to use as much product as they determined was necessary to control bedbug populations.

Visual counts of live bedbugs were conducted as described above for the apartment selection. The number of bedbugs was recorded for each apartment unit (including controls) prior to the initial treatment (Table 1). The numbers of live bedbugs (all instars and adults, no eggs) and their specific locations within the apartments (along the ceiling, walls, baseboards, cracks and crevices, mattresses and box springs, couches, nightstands and chairs) were recorded. Subsequent bedbug counts were made on days 3, 5, 7, 14, 28, 42 and 56. All bedbug counts were taken immediately before re-treatment applications were made.

It should be noted that the inspections did not include many of the residents' personal items, although these items may have harbored bedbugs (piles of laundry, stuffed animals and, in one apartment, a packed closet that the resident asked be left closed). The authors were unable to treat these items, so it had to be accepted that some portion of the bedbug population would be left to re-infest the treated locations. However, every effort was made to keep the inspections thorough and consistent from month to month, repeatedly inspecting all those areas where bedbugs had been recorded at the beginning of the test so that accurate assessments could be made of the bedbug populations harbored within those locations.

All apartments units were treated 'as is'. No modifications were made to individual apartments in preparation for the insecticide applications. Housing residents were not required to move objects away from the walls or to clean their units at any time during the test.

2.3.4 *Amount of pesticide applied*

Treatment products were weighed in the application equipment before and after each application to determine the amount of product (g) applied in each apartment unit. The total product applied was calculated for both the traditional and novel treatments and then divided by the number of apartment units

Table 1. Number of live bedbugs (all life stages) recorded in each apartment unit by location

Treatment combination ($n = 5$)	Bedbug location	Pretreatment number of live bedbugs		Day 3 number of live bedbugs		Day 56 number of live bedbugs		% Reduction
		Mean (± SE)	Range	Mean (± SE)	Range	Mean (± SE)	Range	
Traditional	Mattress	1.8 (±1.8)	0–9	0.4 (±0.4)	0–2	0.0 (±0.0)	0–0	100
	Wall	36.4 (±10.6)	7–64	4.6 (±1.9)	1–10	2.2 (±0.9)	0–4	94
	Couch	1.6 (±1.6)	0–8	0.6 (±0.6)	0–3	0.0 (±0.0)	0–0	100
Novel	Mattress	24 (±17.8)	0–94	3.6 (±2.5)	0–13	1.8 (±1.8)	0–13	93
	Wall	45.4 (±27.2)	7–150	18.4 (±7.4)	4–46	8.4 (±7.4)	0–17	82

(5) to determine the average number of grams applied per product per apartment (Table 2).

2.4 Statistical analysis

Visual counts were recorded by treatment (traditional, novel and control) for each test day. The efficacy of a particular treatment, either novel or traditional, was determined using repeated measures ANOVA.[22] The intent of this analysis was to compare the number of live bedbugs on a particular test day with the number recorded on all previous test days. The expectation was that the treatment combination(s) would result in a significant reduction in the mean number of live bedbugs by the end of the test period. Another feature of the repeated measures analysis was the inclusion of the baseline population measurements as a covariant. Since the apartment units had different levels of bedbug infestations prior to treatment, the untreated population means were adjusted to improve the homogeneity of the variances and the normality of the data. Differences between treatments (novel, traditional or control) were determined using the Tukey–Kramer test. Values of $P \leq 0.05$ were used to indicate significance.[22]

3 RESULTS

3.1 Traditional treatment

Prior to the application of the traditional treatment regimen, the mean number of bedbugs observed in each apartment unit was 39.8 ± 10.1 (Fig. 1). By day 3, the mean number of live bedbugs had dropped to 5.6 ± 1.6. The mean number of bedbugs recorded between day 7 and day 28 ranged from 5.2 ± 1.7 to 10.6 ± 3.5 (mean $\pm$ SE). However, bedbug counts declined to 2.6 ± 1.3 by day 42 and were further reduced to an average of 2.2 ± 1.0 by the test termination date. In the traditional treatment apartments, bedbugs had been recorded on the walls, couches and mattresses (Table 1). By the end of the test, there was a 100% reduction in the number of bedbugs on the walls and couches and a 94% reduction in the number of bedbugs on the mattresses. Overall, the traditional treatment combination reduced the number of live bedbugs by an average of 95% over the 8 week test period. The repeated measures analysis determined that the traditional treatment did significantly reduce the number of bedbugs from the pretreatment infestation levels (df = 6, $F = 2.79$, $P = 0.02$).

3.2 Novel treatment

The average number of live bedbugs in apartment units selected for the novel treatment combination was 71.4 ± 25.3 prior to the first application (Fig. 1). On day 3, the mean number of bedbugs recorded had decreased to 24.0 ± 8.4. However, by day 14 the mean number of bedbugs had increased to 31.8 ± 10.1, prior to the second treatment application. Bedbug numbers declined again after the second application, with 16.2 ± 5.9 bedbugs recorded on day 28. The number of live bedbugs decreased further over the following weeks, and a mean of only 10.2 ± 4.4 live bedbugs was observed on day 56. In the apartments receiving the novel treatment, bedbugs were only observed on mattresses and the walls (Table 1). At the termination of the test there was a 93% reduction in the mean number of bedbugs counted on the mattresses and an 82% reduction in bedbugs on the walls. Overall, the novel treatment combination resulted in an 86% reduction in the number of bedbugs per unit at the end of the test. The repeated measures analysis determined that the novel treatment also significantly reduced the number of bedbugs from the pretreatment infestation levels (df = 6, $F = 2.68$, $P = 0.02$).

3.3 Control units

The number of live bedbugs in the control units varied considerably from one monitoring period to the next owing to the authors' inability to gain consistent access to apartment units (Fig. 1). At the initiation of the test, the mean number of bedbugs observed per apartment unit ($n = 5$) was 56.8 ± 17.2. On day 3, access could be gained only to one heavily infested unit (113 bedbugs). The mean number of bedbugs recorded in four control apartment units on day 5 was 37.7 ± 12.3. On day 5, access was denied to the heavily infested apartment unit that had been inspected on day 3, lowering the overall mean number of bedbugs recorded. On day 7, access was again allowed to the heavily infested unit, but access was denied to the other four control apartment units. Therefore, the number of bedbugs recorded on day 7 was 165. On day 14 it was discovered that residents had thrown away a heavily infested bed frame, reducing the overall mean for control units to 18.3 ± 2.7 bedbugs. On day 28, the authors were able to gain access to all five control units, and the mean number of bedbugs was 26.6 ± 6.6. On day 42 there was access to all five apartment units, but one resident was in the process of moving during the inspection. A mean number of 20.6 ± 6.0 bedbugs were recorded on day 42. On the final day of the test, the mean number of bedbugs recorded was 19.7 ± 14.0; however, access was allowed only to three control apartment units. Although the

Table 2. Mean amount of formulated insecticide product and active ingredient applied in each apartment unit

Treatment regimen	Product (concentration applied)	Mean amount applied per unit over the entire test period (mL) (± SE)	Mean amount applied per unit per test day (mL) (± SE)	Active ingredient applied per unit over entire test period (g) (± SE)
Traditional (*n*= **5**)	Deltamethrin (0.6 g AI L^{-1})	1564 (±198.4)	711 (±49.6)	0.94 (±0.12)
	β-Cyfluthrin (0.5 g AI L^{-1})	2893 (±69.6)	723 (±17.5)	1.45 (±0.04)
	Gentrol Aerosol (3.6 g hydroprene L^{-1})	566 (±10.4)	141 (±2.6)	2.04 (±0.04)
	Total	**5023 mL**	**1576 mL**	**4.43 mg**
Novel (*n*= **5**)	Steri-Fab	1077 (±301.0)	1077 (±310)	–
	NIC 325	91 (±0.6)	31 (±0.2)	–
	Chlorfenapyr (5 g AI L^{-1})	3593 (±74.3)	898 (±18.6)	17.96 (±0.09)
	Gentrol Aerosol (3.6 g hydroprene L^{-1})	441 (±5.9)	110 (±1.5)	1.58 (±0.02)
	Total	**5202 mL**	**2115 mL**	**19.54 mg**

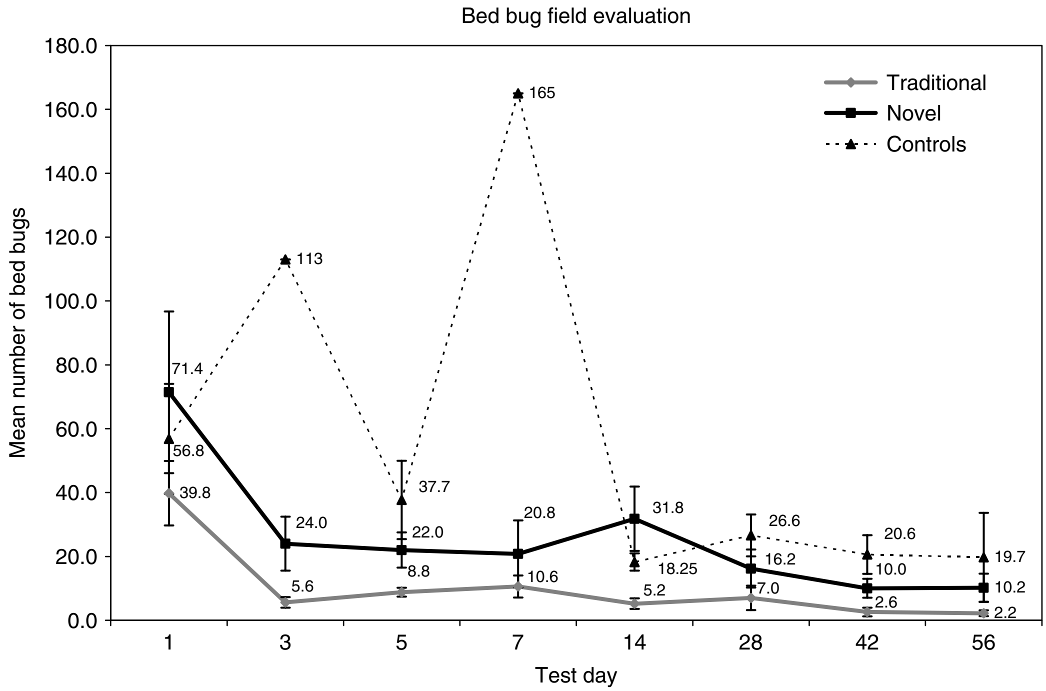

Figure 1. Mean number of live bedbugs (all active life stages, no eggs) recorded from visual counts taken in apartments. All visual counts were recorded on the day of treatment, immediately prior to the application.

analysis indicated that the number of bedbugs in the control units had also been reduced during the test period (df $= 6$, $F = 3.71$, $P = 0.003$), it had to be concluded that any reduction observed was due to tenant behavior and not to any natural reduction in bedbug numbers.

3.4 Comparison of treatment efficacy

The ANOVA indicated that there was a significant treatment effect (df $= 2$, $F = 15.9$, $P = 0.004$) and a significant time effect (df $= 6$, $F = 5.8$, $P < 0.001$) on the bedbug numbers. There was also a significant treatment–time interaction (df $= 12$, $F = 1.9$, $P = 0.05$). The Tukey–Kramer test indicated that the reductions in mean bedbug numbers in both the traditional and novel treatments were significantly greater than those of the control units (df $= 12$, $t = -5.7$ and -3.5 respectively, $P = 0.0003$ and 0.01 respectively). The traditional and novel treatment combinations were not significantly different from each other at the $\alpha = 0.05$ level, but the two treatment combinations were significantly different from each other at the $\alpha = 0.10$ level (df $= 12$, $t = -2.4$, $P = 0.08$).

3.5 Product applied

The mean amounts of formulated products applied for each treatment are listed in Table 2. The total amount of product applied in the traditional treatment was 5023 mL (>5 L) per apartment unit. However, this amount was not significantly different from the total amount of product in the novel treatment, which was 5202 mL per unit (df $= 1$, F $= 0.07$, $P = 0.79$). There was significantly more active ingredient (19.5 g) applied in the novel treatment apartments than in the traditional treatment apartments (4.4 g) during the test period (df $= 1$, $F = 34.71$, $P = 0.0004$).

4 DISCUSSION AND CONCLUSIONS

In a survey of pest management companies conducted in 2005, Gangloff-Kaufmann *et al.*[23] reported that 96–98.2% of respondents found bedbugs most frequently harboring on mattresses and in box springs. Baseboards were also identified as a common place to find bedbugs (94.1%). When respondents were asked if they treated these locations, 75.1% of companies reported that they treated mattresses, 87.3% reported that they treated the box springs and over 90% of the companies routinely made baseboard, crack and crevice applications.

It was very interesting to compare field experience with the Gangloff-Kaufmann survey results because, while the present infestation locations generally concurred with those identified in the survey, the ability to treat the 'beds' and to some degree the baseboards, cracks and crevices was often hindered by the conditions of the apartments. The test apartment units used in this study were very similar in size and floor plan. The tenants were typically male day-laborers and lived in large numbers (6–9). The tenants would sleep in the bedrooms, living room and dining area, depending on how many were occupying the unit. Some of the apartments had multiple beds in different rooms, while others did not have 'beds' at all. Tenants slept on stacked pieces of cardboard or wadded-up clothing, while others slept directly on the floor. Because bedding varied considerably from apartment to apartment, there were few 'mattresses' to treat. None of the products available in either treatment regimen was labeled for application to these unique sleeping surfaces. Therefore, the ability to treat all 'beds' was limited.

The amount of personal belongings also varied from one apartment to the next. Some of the test apartments had almost no furniture or personal items, yet other units were extremely cluttered. Cluttered apartment units typically had piles of clothing in corners, obscuring the baseboards. Clothing and other belongings would also be piled inside closets, making proper inspection difficult and crack and crevice treatment impossible owing to the potential contamination of personal belongings.

In spite of the difficult conditions, the results of this field test indicated that both the traditional and novel treatment combinations significantly reduced bedbug populations. While the traditional treatment was not necessarily superior ($P = 0.08$), the absolute reduction in the number of bedbugs (95%) to a mean of 2.2 recorded individuals per apartment not only reduced the presence of bedbugs but also reduced the future infestation potential. While the novel treatment produced an 86% reduction, a mean of 10.2 bedbugs was still observed in each apartment at the end of the test, which greatly increased the likelihood of rapid re-infestation. It should be noted that bedbug eggs were not quantified in either treatment, and there was certainly potential for unrecorded bedbugs still to be present in both treatments.

In both the traditional and novel treatments, the greatest decrease in the number of live bedbugs occurred after the initial treatment. The success of both treatment combinations during the first two counting periods (days 1–3) was a little surprising. This is because, when these bedbugs were tested in the laboratory, high levels of resistance to dry pyrethroid residues were observed, especially to deltamethrin residues (LT_{50} value for deltamethrin 458 h, resistance ratio 450; Moore and Miller, unpublished data). However, subsequent laboratory evaluations have shown that the LT_{50} value can be greatly reduced when the bedbugs are sprayed directly with the wet formulation (LT_{50} value for deltamethrin 99.6 h; Miller and McCoy, unpublished data). Therefore, it is suspected that the direct application of the pyrethroids to the bedbugs in these field evaluations may have increased their efficacy (Miller and McCoy, unpublished data).

In the traditional treatment, the highest proportion of bedbugs was found on the ceiling/wall junction, while additional population foci were located on the beds and other furniture. Direct application of pyrethroid insecticides to the bedbug bodies as they aggregated in these locations most likely resulted in the large reduction observed on day 3. However, during the course of the test, it was observed that some of the bedbugs persisted in these locations even after several treatments. At the end of the 8 week test period, bedbugs were still recorded in three of the five pyrethroid-treated units (3–4 bedbugs per apartment), indicating that, although the treatments did work, multiple applications and considerable time were needed to control the population.

In the novel treatment, the highest proportion of bedbugs was located on actual mattresses and box springs. Additional bedbug aggregations were located on the walls and popcorn ceiling. The direct application of Steri-Fab on the bodies of bedbugs as they aggregated on bed seams resulted in the large population reduction observed on day 3. For example, in one apartment unit, 94 bedbugs were recorded on the bed prior to treatment. After the application of Steri-Fab, the number of bedbugs on the bed was reduced to 13 (day 3). Direct application of chlorfenapyr (Phantom) to the walls of infested apartments also resulted in a 61% reduction in bedbug numbers by day 3. The quick knockdown activity of chlorfenapyr in the field was surprising because laboratory assays indicated that it was extremely slow acting (LT_{50}: 10 days 9 h).[21] However, the authors believe that the direct application of the wet material to the bedbug bodies may have enhanced the cuticular penetration of the insecticide formulation. After the initial bedbug reduction, populations in the novel treatment remained the same (average of 22 per apartment) from day 3 to day 7. It is suggested that one of the reasons for this lag in activity was the fact that Steri-Fab has no residual activity. Therefore, bedbugs on the mattresses that were not killed from the initial application simply survived through to the next counting period. A second reason for the lag in activity may be that the bedbugs are not susceptible to dry residual deposits of chlorfenapyr.[21] Chlorfenapyr is a pro-insecticide and typically has to be ingested and metabolized to produce lethal effects.[24] Therefore, once the application was dry, the residual activity was reduced. Regardless of the reason, this lag in bedbug mortality between days 3 and 7 allowed time for the surviving bedbugs to mate and reproduce. Not surprisingly, an increase in bedbug numbers was observed on day 14. On day 14, a second application of chlorfenapyr was applied, reducing the number of remaining bedbugs on the walls and popcorn ceiling. NIC 325 was also applied to the mattresses as a residual dust application. Bedbugs treated with NIC 325 were still active 2 weeks after the application (day 28), although they were covered with dust. However, by the end of the 8 week test period, bedbugs were only found on the bed in one apartment unit (nine bedbugs), indicating that NIC 325 did control bedbugs, although it took a long time.

Because of the slow activity of hydroprene and the fact that it was always applied in combination with either a pyrethroid or chlorfenapyr in the present treatment regimens, it was not possible to identify any specific effect that hydroprene had on the bedbugs in either treatment. The greatest decrease in the test populations occurred immediately after the first treatment, so hydroprene most likely did not contribute to this decrease owing to its slow-acting nature. It is not known whether the product had an effect on bedbug fertility.

Resident cooperation issues in control apartment units confounded the authors' analysis of treatment efficacy. Not surprisingly, resident cooperation declined when they realized that the research personnel were simply counting their bedbugs and making no effort to control them. Also, the control residents frequently threw out infested belongings, drastically reducing bedbug numbers in the control units (e.g. a wooden bed frame was thrown out, reducing the mean number of bedbugs in the control unit by almost 90%). However, the most troublesome aspect of resident cooperation was that they denied researchers access. If residents were at home, they frequently would not allow researchers in to conduct inspections. Therefore, inspections could only be made when residents were away and management provided access. This lack of resident cooperation limited the ability to monitor the control populations, so, while the efficacy of the two treatment regimens can be reasonably assessed by comparing the bedbug reductions within and between treatments, comparison with controls has very limited value.

Even with the large amount of product (>5000 mL) applied in the traditional and novel treatments, complete elimination of visible live bedbugs did not occur. Multiple products and multiple applications were necessary to achieve the reduction in bedbug numbers observed in this test. Yet neither treatment eliminated the (visible) bedbug infestations. The fact that bedbugs were not eliminated after multiple treatments indicates the extreme difficulty that can be expected when attempting to eliminate these pests using the formulations currently available. If the pyrethroid products were changed to increase the maximum percentage of active ingredient in the formulation, and if the products were allowed to be applied on additional surfaces, it might be possible to control bedbug infestations using insecticide products alone. However, under the current pesticide labels, bedbug control in multi-unit situations such as the one described in this study will require a more integrated approach. In addition to insecticide applications, complete eradication would require building-wide sanitation efforts, bedbug prevention education and on-going resident cooperation in the bedbug management effort.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to Dr Richard Kramer, Josh Kramer, Joseph Ray and Jules Antonsen of Innovative Pest Management (Brookeville, MD) for their help in the location, inspection and treatments of the test apartments. They also thank Dr Susanne Aref of the Virginia Tech Department of Statistics (Statistical Consulting Service) for her analysis of the time series data, and Bayer Environmental Sciences for partial support of this research project.

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