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Susceptibility of the bedbug, *Cimex lectularius*, to selected insecticides and various treated surfaces

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Abstract. Adult bedbugs, *Cimex lectularius*, were exposed for 24 h (25°C) to filter paper treated with various dilutions of the technical grade of nine insecticides dissolved in acetone to determine the concentration–response relationships. The order of toxicity, from most to least based on the LC_{50}'s was: dichlorvos, pirimiphos methyl, lambda-cyhalothrin, bendiocarb, permethrin, malathion, carbaryl, tetrachlorvinphos, and fenvalerate.

The residual toxicities of commercial formulations of six of the chemicals diluted with water and applied to wood, cardboard, cloth and galvanized metal, were determined by exposing adult bedbugs at 3, 7 and 12 weeks after treatment. The formulation of bendiocarb (FICAM® 76% W) had little residual activity on all surfaces at 12 weeks after treatment. The formulation of carbaryl (SEVIN® 21.5% L) was toxic to bedbugs on all surfaces at 12 weeks after treatment, but required high concentrations on wood, cardboard, and cloth. The formulation of pirimiphos methyl (ACTELLIC® 57% EC) had no residual activity on any of the surfaces at 12 weeks after treatment. The formulation of tetrachlorovinphos (RABON® 50% W) had residual activity for 12 weeks on all surfaces except metal. The formulation of permethrin (ATROBAN® 11% EC) had residual activity on only metal and wood while the formulation of lambda-cyhalothrin (KARATE® 13.1% EC) had residual activity 12 weeks on all surfaces.

Key words. *Cimex lectularius*, Hemiptera, Cimicidae, bedbug control, insecticides.

Introduction

The common bedbug, *Cimex lectularius* L., is not only a pest of humans but is also an important pest of poultry (Axtell & Arends, 1990; Lindsay *et al.*, 1989; Newberry & Jansen, 1986; Newberry *et al.*, 1991; Rosen *et al.*, 1987; Usinger, 1966). Bedbugs are pests of hens and roosters used to provide hatching eggs for broiler production. Each side (one-third) of a broiler-breeder house typically has a wooden slatted platform over which the feeders and waters are hung. These wooden slats provide excellent harbourage for bed bugs. Other harbourages are galvanized metal nest boxes, cloth curtains on the sides of the house, and cardboard boxes used to transport the eggs. Few data have been published on the toxicities of insecticides against bedbugs and the duration of effectiveness of chemicals on different types of surfaces (Dremova & Tsetlin, 1989; Newberry, 1991) and, consequently, there is inadequate information on bedbug control in poultry houses (Axtell & Arends, 1990). Therefore, concentration–response data were obtained for nine insecticides and data on the residual activity of commercial formulations of six of the insecticides applied to five different types of surfaces likely to be in poultry houses.

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Materials and Methods

The bedbugs used in these tests were from colonies established about 1 year earlier from specimens collected in a broiler-breeder chicken house in North Carolina, U.S.A. The laboratory colony was maintained in 6-litre containers and provided a bloodmeal twice a week by placing a restrained 3-week-old chick in the container. Active partially engorged adult bedbugs (sex not determined) were removed randomly from the culture 2 days after feeding and used in the tests.

The concentration–response data were collected by exposing adult bedbugs to residues of several concentrations of each chemical (technical grade dissolved in acetone) on filter paper (No. 2, 11 cm diameter, Whatman International Ltd, Maidstone, England) in a 10 cm diameter inverted petri dish. The filter paper was treated with 1.2 ml of the dilutions, a sufficient volume to totally wet the paper with no runoff. Dilution concentrations were expressed in parts per million (ppm) of active ingredient (AI) on a weight/volume basis. Six dilutions, producing mortality between 5% and 95% after 24 h exposure (25°C), were used for each insecticide. A replicate consisted of treated filter paper with ten bedbugs and there were four replicates per dilution on four different days. Mortality was determined after 24 h by counting the bedbugs which did not move when the dish was tapped. The concentration–response data were analysed by the log-probit procedure using POLO-PC software (LeOra Software, Berkeley, Calif.) (Russell *et al.*, 1977).

The percentage active ingredient of the technical grade insecticides (and source) were: 98.2% dichlorvos (Fermenta, Kansas City, Mo.), 90.8% pirimiphos methyl Pitman-Moore, Kansas City, Mo.), 84.1% lambda-cyhalothrin (Pitman-Moore), 97.9% bendiocarb (Nor-Am Chemical Co., Wilmington, Del.), 92.0% permethrin (Pitman-Moore), 98.0% malathion (Chem Service, West Chester, Pa.), 99.0% carbaryl (Rhone-Poulenc, Research Triangle Park, N.C.), 99.0% tetrachlorvinphos (Fermenta), and 98.0% fenvalerate (Fermenta).

The residual toxicities to bedbugs of commercial formulations of six of the insecticides were determined on five different surfaces after exposure to environmental conditions in a poultry house. The surfaces were: aged galvanized metal (cut from a used nest box), pine plywood (aged outdoors for 1 year), corrugated cardboard (Stone Container Corp., Lexington, N.C., U.S.A.), cotton cloth (100% cotton), and polyester–cotton blend cloth (35% cotton and 65% polyester). The surfaces were treated with water dilutions (w/v) of the formulations at concentrations, expressed as ppm of active ingredient (AI), that were expected to produce about 90% mortality of the bedbugs after 24 h exposure. Each surface (a square 10 × 10 cm) was treated with 1.67 ml of each dilution applied with a pipette and spread evenly over the surface with a small brush and allowed to dry for 3 h. This volume was sufficient to totally wet the surface with no run off and simulated typical spray applications used in treating poultry houses.

Ten adult bedbugs were placed on the treated surface and held in place by an inverted bottom of a petri dish (9 cm diameter) at 23–25°C. There were three replicates of each type of surface for each dilution of each chemical. Mortality was monitored initially (day 0) and 24, 48 and 72 h after exposure, but nearly all mortality occurred after 24 h and those data were used. The residual effectiveness was determined by repeating the above procedure at 3, 7 and 12 weeks post-treatment. Between tests the treated surfaces were aged by hanging the squares from a wire about 2 m above the floor in an environmentally-controlled caged-layer poultry house (23–27°C, 14:10 L:D).

The insecticides, trade names, formulations, and sources (in parentheses) used in the residual tests were: bendiocarb (FICAM® 76% W, Nor-Am Chemical Co., Wilmington, Del.), carbaryl (SEVIN® 21.5% L, Dragon Corp., Roanoke, Va.), pirimiphos methyl (ACTELLIC® 57% EC, ICI Americas Inc., Wilmington, Del.), tetrachlorvinphos (RABON® 50% W, SDS Biotech Corp., Painesville, Ohio), permethrin (ATROBAN® 11% EC, Coopers Animal Health Inc., Kansas City, Mo.), and lambda-cyhalothrin (KARATE® 13.1% EC, ICI Americas Inc., Wilmington, Del.).

Results and Discussion

Based on mortality data collected after 24 h exposure in the dose–response experiment (Table 1), the bedbugs were most susceptible to dichlorvos, pirimiphos methyl and bendiocarb, all of which had LC_{50}'s and LC_{90}'s less than 100 ppm. Permethrin, malathion, lambda-cyhalothrin, carbaryl and tetrachlorvinphos were less toxic, with their LC_{90}'s between 200 and 500 ppm, although the LC_{50} of lambda-cyhalothrin was <100 ppm. With this testing method, fenvalerate exhibited very low toxicity after 24 h exposure. Even after exposure for 48 and 72 h, fenvalerate exhibited lower toxicity than the other compounds (Table 1). Dremova & Tsetlin (1989) used a topical application method and reported the order (from most to least) of toxicities to be: fenvalerate, permethrin, pirimiphos methyl, carbaryl, diclorvos, and bendiocarb. The finding that fenvalerate was highly toxic to bedbugs by topical application according to Dremova & Tsetlin (1989) and very low in toxicity in our tests using treated filter paper, suggests that the method of exposure is critical in evaluating insecticides.

In the residual tests of formulated chemicals (Table 2), bendiocarb (FICAM®) and pirimiphos methyl (ACTELLIC®) were initially toxic to bedbugs on all surfaces (test concentrations of 600 ppm or less) but they had short residual lives on most of the surfaces. Only ACTELLIC® was more toxic on wood than on metal which is inconsistent with the absorbency of the materials. Carbaryl (SEVIN®) and tetrachlorvinphos (RABON®) retained substantial toxicities on all surfaces, except metal. However, relatively high concentrations of carbaryl and tetrachlorvinphos were required to produce 90% mortality initially (1000–8000 ppm, except on metal which was 500 ppm for both chemicals). In the case of carbaryl on wood, 8000 ppm only produced 36.7% mortality initially. Permethrin (ATROBAN®) was initially active at low concentrations (20–100 ppm) but only exhibited residual activity on metal and wood. Lambda-cyhalothrin (KARATE®) was active at low concentrations (5–400 ppm) on all surfaces and exhibited relatively long-lasting residual activity, with the shortest residual life on metal.

These results illustrate the need for additional data beyond that provided by concentration–response exper-

Table 1. Concentration–response of the bedbug, *Cimex lectularius*, exposed for 24 h (25°C) to insecticide-treated filter paper. LC_{50} and LC_{90} in ppm with 95% confidence intervals based on log-probit analysis.

Insecticide	LC_{50} (95% CL)	LC_{90} (95% CL)
Dichlorvos	2.9 (2.5–3.3)	5.7 (4.8–7.5)
Pirimiphos methyl	13.5 (10.0–17.2)	29.8 (21.9–65.3)
Lambda-cyhalothrin	22.2 (3.0–44.6)	357.7 (167.9–3565.6)
Bendiocarb	47.1 (40.7–53.9)	95.9 (80.4–124.6)
Permethrin	71.4 (49.2–91.9)	201.7 (141.1–517.3)
Malathion	92.0 (79.1–105.8)	245.0 (190.2–388.0)
Carbaryl	166.3 (131.4–198.6)	364.0 (292.8–531.7)
Tetrachlorvinphos	252.0 (210.2–298.5)	472.7 (381.9–702.3)
Fenvalerate	2734.2 (1604–5418)	41,792.0 (16,029–257,260)
Fenvalerate, 48 h	654.4 (332–1241)	9951.2 (4190–49,159)
Fenvalerate, 72 h	169.7 (53–369)	2323.9 (944–14,864)

Table 2. Per cent mortality of bedbugs, *Cimex lectularius*, exposed for 24 h to residues of commercial formulated insecticides on five different surfaces aged 0–12 weeks after treatment.

		Mean per cent mortality at weeks after treatment			
Insecticide, tradename and formulation	Surface and treatment (ppm AI)	0	3	7	12
Bendiocarb, FICAM® 76% W	Metal (100)	90.0	10.0	0.0	12.0
	Wood (600)	96.7	86.7	23.3	3.3
	Cardboard (600)	100.0	27.2	0.0	0.0
	Cotton cloth (600)	96.7	46.7	3.3	0.0
	Cotton/polyester (200)	83.3	0.0	0.0	0.0
Carbaryl, SEVIN® 21.5% L	Metal (500)	80.0	63.3	26.7	6.7
	Wood (8000)	36.7	50.0	16.7	20.0
	Cardboard (4000)	76.7	66.7	70.0	50.0
	Cotton cloth (4000)	40.0	43.3	33.3	43.3
	Cotton/polyester (4000)	50.0	63.3	20.0	43.3
Pirimiphos methyl, ACTELLIC® 57% EC	Metal (60)	100.0	33.3	0.0	0.0
	Wood (20)	83.3	0.0	0.0	0.0
	Cardboard (200)	80.0	0.0	0.0	0.0
	Cotton cloth (200)	73.3	86.7	6.7	0.0
	Cotton/polyester (60)	96.7	0.0	0.0	0.0
Tetrachlorovinphos, RABON® 50% W	Metal (500)	86.7	63.3	0.0	0.0
	Wood (2000)	63.3	80.0	30.0	93.3
	Cardboard (1000)	100.0	100.0	43.3	60.0
	Cotton cloth (2000)	80.0	43.3	16.7	20.0
	Cotton/polyester (2000)	73.3	90.0	30.0	46.7
Permethrin, ATROBAN® 11% EC	Metal (20)	90.0	13.3	36.6	50.0
	Wood (50)	73.3	93.3	86.7	46.7
	Cardboard (50)	90.0	40.0	40.0	0.0
	Cotton cloth (100)	80.0	0.0	0.0	0.0
	Cotton/polyester (80)	80.0	0.0	6.6	3.3
Lambda-cyhalothrin, KARATE® 13.1% EC	Metal (5)	95.0	46.6	63.3	10.0
	Wood (20)	90.0	66.7	70.0	53.3
	Cardboard (20)	90.0	80.0	70.0	63.3
	Cotton cloth (200)	83.3	73.3	80.0	76.7
	Cotton/polyester (100)	93.3	13.3	73.3	73.3

iments using technical grade insecticide applied to some standard surface such as filter paper, for proper evaluation of the effectiveness of surface treatments for bedbug control. The formulation and the nature of the surface greatly affect the efficacy of the insecticide. Nevertheless, dosage–response data using a standard treated surface, such as filter paper, provides a method for detecting some (but not all) toxic chemicals and baseline data which may be useful in evaluating differences in insecticide susceptibilities (Feroz, 1968).

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