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Residual Susceptibility of *Plodia interpunctella* to Deltamethrin Dust: Effects of Concentration and Time of Exposure

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Abstract—Wandering phase fifth instar *Plodia interpunctella* (Hübner) were exposed at ten weekly intervals for 6, 12 and 24 h or 1 week to 0.05% deltamethrin dust at application rates of 38, 47 and 56 mg per 0.016 m². The percentages of pupating larvae and adult emergence at all three rates were greatest at the 6-h exposure and least at the 1-week exposure, but there was no consistent decrease in pupation or emergence as the exposure was increased from 6 to 24 h. Pupation and emergence decreased with increasing application rate of deltamethrin dust at each weekly bioassay, and the percentage of emerged adults was usually less than the percentage of larvae that pupated. At the conclusion of the test (9 weeks), curve-fit adult emergence data for larvae exposed for 1 week to deltamethrin dust at application rates of 38, 47 and 56 mg per 0.016 m² were calculated by linear regression to be 26.6%, 20.5% and 17.3% respectively. For all other exposure times at each rate, adult emergence usually exceeded 20% after 2–4 weeks. Published by Elsevier Science Ltd

Key words—deltamethrin dust, exposure, *Plodia interpunctella*

INTRODUCTION

Plodia interpunctella (Hübner), the Indian meal moth, is a major pest of stored and processed food. Larvae can remain hidden until they reach the fifth instar, and are often unnoticed until they begin wandering in search of a pupation site. Dichlorvos aerosol systems have historically been used to control adult moths in the headspaces of warehouses in an attempt to limit infestations. However, impending restrictions on the use of dichlorvos in warehouses that contain bagged and processed commodities could limit the utilization of this chemical. Now that malathion has been removed from the post-harvest market, the only insecticide that is labeled in the U.S.A. as a treatment for flooring surfaces is the pyrethroid cyfluthrin. This insecticide is applied as a residual treatment to control insects crawling on the floors or walls of warehouses.

There are several insecticides registered as crack, crevice and spot treatments, and there could be extensions to expand the label for some of them. One possible candidate is a 0.05% active ingredient (AI) deltamethrin dust that is registered in the U.S.A. at an application rate of 222–333 mg per 0.094 m² (2–3 g per square yard). A previous test showed that the highest application rate would control adult *Tribolium castaneum* (Herbst), the red flour beetle, and adult *T. confusum* (du Val), the confused flour beetle, on concrete and tile panels for approximately 20 weeks (Arthur, 1997). The objectives of this study were to determine whether the range of application rates listed on the current deltamethrin dust label would control wandering phase fifth

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instar *P. interpunctella*, and to evaluate the toxicity of the dust when larvae were exposed for different time periods.

MATERIALS AND METHODS

A sample of 0.05% deltamethrin dust was obtained from AgrEvo Environmental (Montvale, NJ, U.S.A.). A standard 15 mm × 100 mm Petri dish was used as the test unit; the total internal surface area of this Petri dish (top, bottom and sides) is approximately 0.016 m^2 (0.17 ft^2). Therefore the equivalent amount of dust needed to treat a dish in proportion to the label range of 222–333 mg per 0.094 m^2 is 38–56 mg per Petri dish.

The treatment rates tested in this study were 38, 47 and 56 mg per 0.016 m^2, and an untreated control. Four dishes were treated at each of the three insecticide application rates by weighing the appropriate amount of dust into a Petri dish, covering the dish with the lid, taping the sides to minimize loss and hand-shaking the dish to distribute the dust. Four dishes at each application rate were needed to expose *P. interpunctella* in separate dishes for 6, 12 and 24 h or 1 week. Four untreated dishes were also included as the controls at each exposure time.

The *P. interpunctella* strain used in this study was a field strain that had been collected in June 1988 in Riley County, KS, U.S.A., and maintained on an enriched ground wheat larval diet in approximate rearing conditions of 27 ± 1°C, 60% r.h. One day after the Petri dishes had been treated with the insecticidal dust, ten mixed-sex fifth instars were placed into each dish (four rates of dust including the untreated control, four exposure times, 16 dishes). The average weight of larvae was 10.56 ± 1.54 mg. After each exposure time of 6, 12 and 24 h had been completed for each application rate, including the untreated controls, the larvae were removed from the dish containing the dust and placed in a new Petri dish lined with filter paper. A final set of larvae was exposed to the dust for 1 week (the approximate time required for pupation) before they were transferred to new dishes. The exposure dishes and transfer dishes were held in the laboratory at approximately 25°C, 60% r.h., 9 h light : 14 h dark. The dishes treated with the insecticidal dust alone were also stored in the laboratory under the same environmental conditions.

One week after the larvae had been exposed for 6, 12 and 24 h, the number of larvae that had pupated in each dish was recorded, together with the larvae that had been left in the dish for the 1-week exposure. Adult emergence was recorded after a second week, and the moths and transfer dishes were discarded. The exposure process was repeated at weekly intervals for 9 weeks by exposing new larvae in the same treated dishes for each of the exposure intervals. After the exposure interval had been completed, the larvae were transferred to new dishes and held as described above. After 9 weeks, the first block (replicate) was concluded and all treatment dishes were discarded. The bioassay procedures described for the first block were used for the second and third replicate blocks.

Pupation and adult emergence in the untreated controls averaged 97 ± 7.8% and 89 ± 15.2% respectively. Treatment data were corrected for control mortality using Abbott's formula (Abbott, 1925). Data for pupation and adult emergence (survival) were analyzed as a randomized complete block, with application rate as a whole-plot treatment, week as a split-plot treatment and exposure time as a repeated measure, using the general linear models (GLM) procedure of the statistical analysis system (SAS Institute, 1987). TableCurve software (Jandel Scientific, San Rafael, CA, U.S.A.) was used to generate linear regressions in which the treatment week was the independent variable and either pupation or adult emergence was the dependent variable for each application rate–exposure combination, and also to show that linear regression was appropriate because the lack of fit (Draper and Smith, 1981) for each equation was not significant ($P \geq 0.05$). The analyses also identified the pure error caused by variation in the data, and estimated R^2 as a percentage of the maximum attainable R^2.

RESULTS

The application rates, week and exposure time were significant ($P < 0.05$), but no associated interactions were significant ($P \geq 0.05$) in determining the percentage of pupating larvae. The percentage of pupating larvae gradually increased from weeks 0 to 10 for each exposure within a particular application rate, with considerable week to week fluctuation in the data (Fig. 1). The percentage of pupating larvae exposed to 38 mg deltamethrin per 0.016 m^2 was usually greatest after the 6-h exposure and least in the 1-week exposure for trials conducted at each weekly interval. However, the variation in the exposure times was such that the expected pattern of decreased pupation with increasing exposure occurred only on weeks 5, 6 and 9. Similar results occurred in the 47 and 56 mg treatments. In both of these treatments, pupation after 1 week of exposure was consistently less than pupation after 6 h of exposure, and the percentage of pupating larvae was often greater in the 24-h than in the 12-h exposure.

The linear regression equations that were fitted to the data indicated decreasing pupation at each exposure interval as the application rate was increased from 38 to 56 mg per 0.016 m^2, but there was no consistent relationship between the 6-, 12- and 24-h exposures (Fig. 2). The adjusted R^2 values (R^2 as a percentage of the maximum available) for the linear equations ranged from 0.36 to 0.89 at all three application rates (Table 1). The lowest pupation rate occurred in the 1-week exposures compared with the 6-, 12- and 24-h exposures. However, the data for the 1-week exposures at each application rate varied from week to week, and the R^2 values for these equations were lower than the R^2 values for the 6-, 12- and 24-h exposures.

The application rate, week and exposure time were significant ($P < 0.05$), but no associated interactions were significant for adult emergence ($P \geq 0.05$). The percentage of adult emergence decreased as the application rate increased at each individual exposure, except for 6 h, and the same patterns were observed as for the pupation rate (Fig. 3). Adult emergence was lower in the 1-week exposures than in the 6-, 12- and 24-h exposures, and was usually less than the percentage of pupating larvae. Adult emergence after 1 week of exposure in the 56 mg treatment was below 20% until week 9.

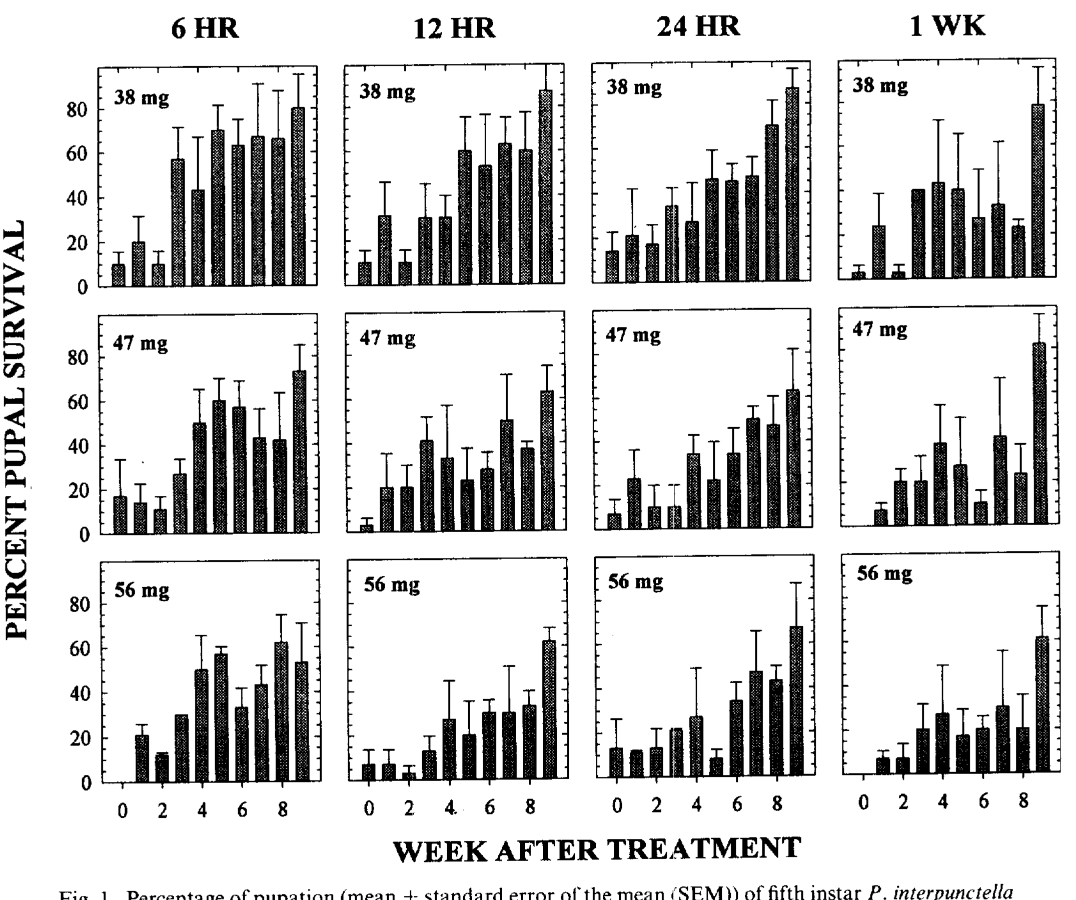

Fig. 1. Percentage of pupation (mean ± standard error of the mean (SEM)) of fifth instar *P. interpunctella* exposed for ten weekly intervals at 6, 12 and 24 h or 1 week to 38, 47 and 56 mg of deltamethrin dust per 0.016 m^2.

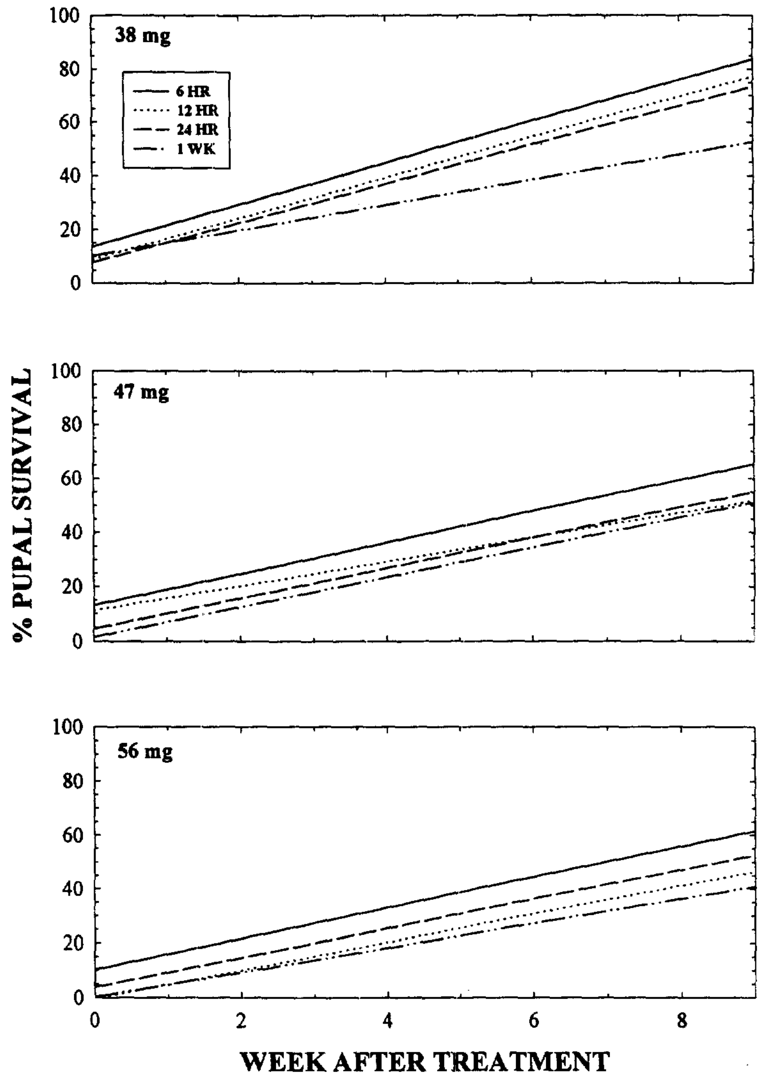

Fig. 2. Plotted linear regression equations for percentage of pupation of *P. interpunctella* at each application rate (mg per 0.016 m^2) and exposure interval.

Table 1. Linear equations, $y = a + bx$, where y is the percentage of pupal survival and x is the week from 0 to 9, for fifth instar *P. interpunctella* exposed for four time intervals (Exp) to three application rates of 0.05% (AI) deltamethrin dust

Application rate[†] (mg)	Exp	a	b	R^2[‡]	Max. R^2	% of max.
38	6 h	1.39 ± 0.81	0.77 ± 0.14	0.51	0.60	0.85
	12 h	0.88 ± 0.72	0.77 ± 0.12	0.56	0.64	0.87
	24 h	0.89 ± 0.65	0.69 ± 0.11	0.56	0.63	0.89
	1 week	0.96 ± 1.00	0.49 ± 0.17	0.22	0.61	0.36
47	6 h	1.47 ± 0.74	0.53 ± 0.12	0.37	0.53	0.70
	12 h	1.27 ± 0.71	0.41 ± 0.12	0.27	0.40	0.68
	24 h	0.78 ± 0.64	0.46 ± 0.12	0.36	0.52	0.69
	1 week	0.53 ± 0.43	0.43 ± 0.14	0.23	0.54	0.43
56	6 h	1.28 ± 0.58	0.49 ± 0.16	0.44	0.67	0.66
	12 h	0.00 ± 0.60	0.51 ± 0.16	0.45	0.53	0.85
	24 h	0.65 ± 0.74	0.46 ± 0.13	0.30	0.44	0.68
	1 week	0.16 ± 0.76	0.30 ± 0.13	0.15	0.40	0.38

[†]Amount of dust is per 0.016 m^2.
[‡]R^2 is determined by linear regression, maximum (max.) R^2 is the maximum attainable R^2 from the lack of fit test of Draper and Smith (1981) and the percentage R^2 is the percentage of the maximum.

The data for adult emergence were described by linear regression (Fig. 4). There was more variation in the data for adult emergence than in the corresponding data for pupation, as indicated by the lower adjusted R^2 values for the linear analyses for each concentration and exposure time (Table 2). The plotted adult emergence values after 1 week of exposure at the final week of the test (week 9) were 26.6%, 20.5% and 17.3% for the 38, 47 and 56 mg per 0.016 m^2 application rates respectively. In all other exposure times at each rate, adult emergence usually exceeded 20% after 2–4 weeks.

DISCUSSION

Insecticidal applications that control adult coleopteran pests of stored products may not prevent wandering phase *P. interpunctella* from pupating and eventually emerging as adults. Arthur (1989) showed that concentrations of 5, 10, 20 and 30 ppm of chlorpyrifos-methyl applied to inshell peanuts controlled *Tribolium castaneum* (Herbst), the red flour beetle, and *Oryzaephilus mercator* (Fauvel), the merchant grain beetle, for 10 months. However, when fifth instar *P. interpunctella* were exposed the day after the peanuts had been treated, the adult emergence values at the 5, 10, 20 and 30 ppm concentrations were 44.1%, 63.9%, 7.9% and 6.7% respectively. Adult emergence was at least 50% at all concentrations when larvae were exposed 60 days after treatment. In similar tests with cyfluthrin, application rates of 2 and 4 ppm on inshell peanuts controlled adult red flour beetles for 10 months, while concentrations of 10, 14, 18 and 22 ppm on peanuts did not prevent adult emergence when fifth instars were exposed (Arthur, 1995).

Several research studies imply equivalent control of various stored-product beetle species to either *P. interpunctella* or *Cadra* (*Ephestia*) *cautella* (Walker), the almond moth, but in these studies the lepidopteran species were exposed as eggs. Ardley (1976) reported that 4 ppm

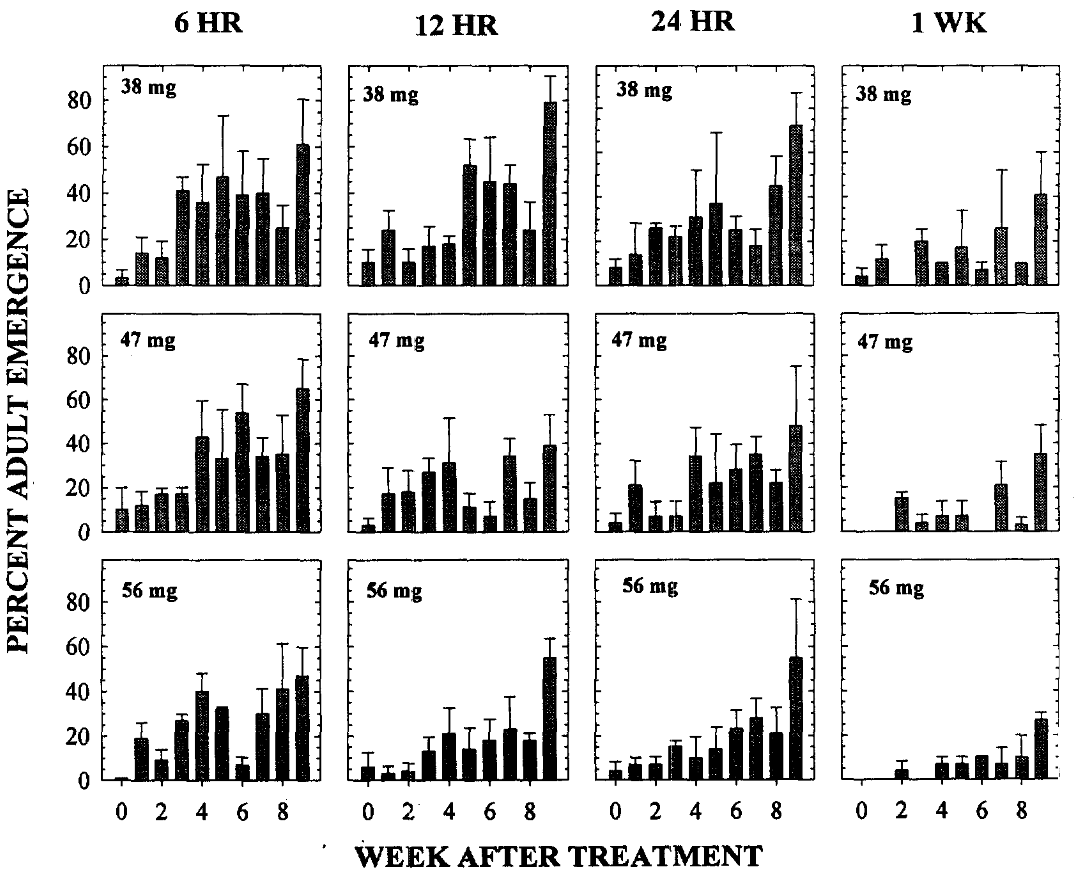

Fig. 3. Percentage of adult emergence (mean ± SEM) of fifth instar *P. interpunctella* exposed for ten weekly intervals at 6, 12 and 24 h or 1 week to 38, 47 or 56 mg of deltamethrin dust per 0.016 m^2.

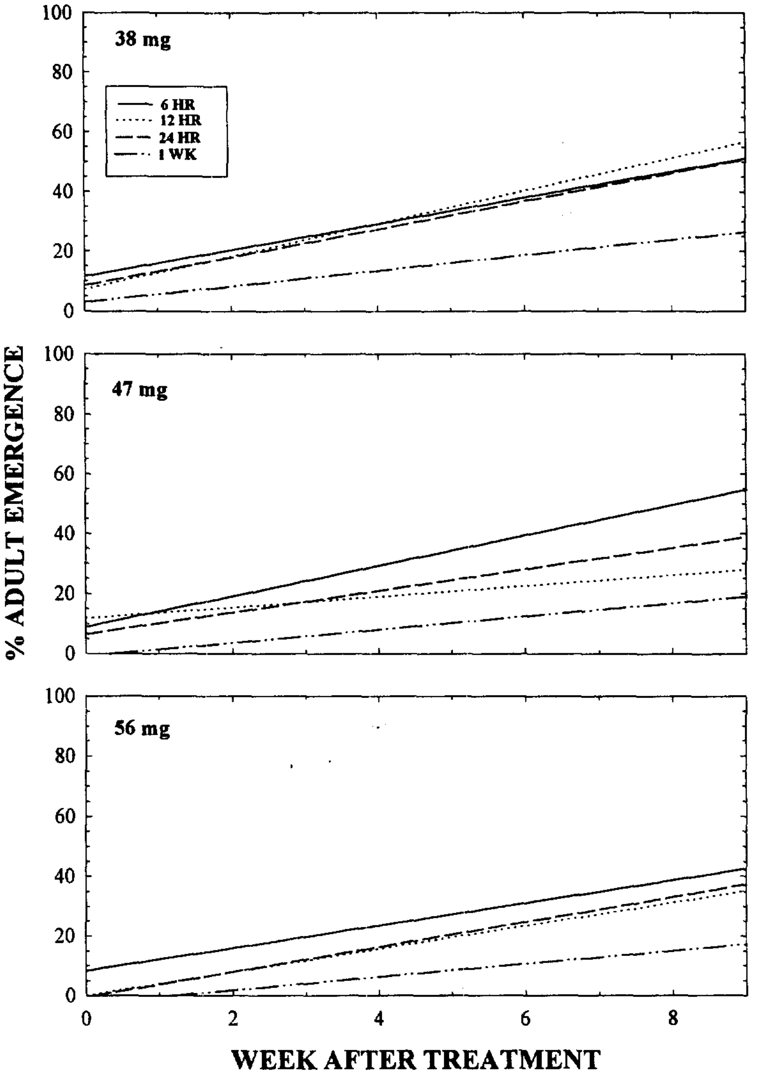

Fig. 4. Plotted linear regression equations for percentage of adult emergence of *P. interpunctella* at each application rate (mg per 0.016 m^2) and exposure interval.

Table 2. Linear equations, $y = a + bx$, where y is the percentage of adult emergence and x is the week from 0 to 9, for fifth instar *P. interpunctella* exposed for four time intervals (Exp) to three application rates of 0.05% (AI) deltamethrin dust

Application rate† (mg)	Exp	a	b	$R^{2‡}$	max. R^2	% of max. R^2
38	6 h	1.04 ± 0.79	0.49 ± 0.13	0.31	0.45	0.69
	12 h	0.93 ± 0.69	0.49 ± 0.12	0.36	0.65	0.55
	24 h	0.75 ± 0.51	0.51 ± 0.14	0.31	0.45	0.69
	1 week	0.07 ± 0.73	0.34 ± 0.12	0.20	0.35	0.57
47	6 h	1.20 ± 0.74	0.49 ± 0.13	0.25	0.42	0.59
	12 h	1.21 ± 0.74	0.17 ± 0.10	0.09	0.37	0.24
	24 h	0.89 ± 0.70	0.28 ± 0.12	0.15	0.32	0.48
	1 week	0.53 ± 0.43	0.43 ± 0.14	0.23	0.54	0.43
56	6 h	1.04 ± 0.58	0.31 ± 0.10	0.24	0.54	0.44
	12 h	0.05 ± 0.55	0.37 ± 0.10	0.34	0.51	0.67
	24 h	0.30 ± 0.60	0.30 ± 0.10	0.22	0.44	0.50
	1 week	−0.10 ± 0.29	0.16 ± 0.05	0.27	0.52	0.52

†Amount of dust is per 0.016 m^2.
‡R^2 is determined by linear regression, maximum (max.) R^2 is the maximum attainable R^2 from the lack of fit test of Draper and Smith (1981) and the percentage R^2 is the percentage of the maximum.

bioresmethrin + 20 ppm piperonyl butoxide on wheat controlled *Sitophilus granarius* (L.), *S. oryzae* (L.), *O. surinamensis* (L.), *P. interpunctella* and *C. cautella*. Bioassays were conducted by exposing adult beetles and moth eggs on treated wheat. Bengston *et al.* (1987) showed that 2 ppm cyfluthrin + 10 ppm piperonyl butoxide and 4 ppm cypermethrin + 10 ppm piperonyl butoxide controlled a variety of beetle species and *C. cautella* exposed on treated wheat. Beetles were exposed as adults, moths were exposed as eggs, and mortality was assessed after 3 and 26 days. An earlier test with fenitrothion was conducted in a similar manner (Bengston *et al.*, 1980). In a test which examined the effect of post-treatment temperature on pyrethroid toxicity, beetles were exposed on treated filter paper, whereas *P. interpunctella* and *C. cautella* were treated by topical application, and no relative toxicity comparisons between beetles and moths were expressed (Subramanyam and Cutkomp, 1987).

Studies in which moth eggs are exposed on treated commodities may not be relevant for exposure studies with insecticides that are applied to flooring surfaces. In contrast with aerosols, which are directed primarily against adult moths, surface treatments leave a residue that kills crawling insects, including late instar larval moths. As *P. interpunctella* increase in age and size, they may become less susceptible to insecticides, and concentrations that would kill early instars may not be effective against the wandering phase fifth instars.

The percentages of both pupation and adult emergence at each concentration increased as the week increased from 0 to 9, indicating a breakdown or reduced activity of deltamethrin dust. Pyrethroid insecticides degrade on exposure to ultraviolet light, and some degradation could have occurred from exposure to indoor lighting in the laboratory. However, the environmental conditions and resulting degradation patterns would probably be similar inside a large food storage facility, and the laboratory studies are a fair representation of actual field conditions.

Throughout the test, adult emergence at all three concentrations was usually lower for fifth instar *P. interpunctella* exposed to deltamethrin for 1 week as opposed to 6 h, but there was no pattern of increased mortality as the exposure time was increased from 6 h to either 12 or 24 h. This result could also be a function of the reduced insecticidal susceptibility of the fifth instars. In field situations, fifth instars could be exposed to treated surfaces for varying time periods, and control programs would be affected if increased exposure on these treated surfaces did not yield a corresponding increase in mortality.

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