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Differential Effectiveness of Deltamethrin Dust on Plywood, Concrete, and Tile Surfaces Against Three Stored-product Beetles

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Abstract—Plywood, concrete, and tile panels measuring 0.094 m² were treated with 0.05% deltamethrin dust at the rate of 3.54 g per m² and bioassayed each week for 21 weeks with *Tribolium confusum* (J. duVal), *Tribolium castaneum* (Herbst), and *Rhyzopertha dominica* (F.). Insects were exposed for 24 h, then either removed from the treated surface and held for 96 h (recovery study) or kept on the treated surface for an additional 96 h (residual study). Regression equations for *T. confusum* survival on plywood in the recovery study did not fit the data. Average survival at the 24- and 120-h mortality assessments was 56.8 ± 3.8% and 14.8 ± 2.8%. The LT_{95} on concrete, as determined by substituting a value of 5% survival (y) into the regression equation and solving for week (x), was 4.7 and 10.5 weeks for the 24- and 120-h assessments, indicating that mortality increased during the holding period. Toxicity was greatest on tile, with LT_{95}s of 9.7 and 10.8 weeks at 24 and 120 h, respectively. Survival of *T. confusum* on all three surfaces in the residual study was greater than in the recovery study. The LT_{95} for 24 and 120 h was 0.0 and 0.2 weeks for plywood, 3.2 and 4.3 weeks for concrete, and 6.0 and 6.4 weeks for tile. Both *T. castaneum* and *R. dominica* were controlled by the deltamethrin dust, and there were no significant differences among the three surfaces or between the two methods of exposure.

Key words—Tribolium confusum, Tribolium castaneum, Rhyzopertha dominica, deltamethrin, dust, treated surfaces

INTRODUCTION

Most large food storage facilities in the United States are not refrigerated or cooled to control insect pests. Several insecticides are used as crack and crevice treatments in these structures, but only the organophosphate insecticide malathion and the pyrethroid insecticide cyfluthrin are currently labeled as broadcast treatments on flooring surfaces. Malathion is not being supported for reregistration and has been deleted on most labels for indoor use. Cyfluthrin is available in emulsifiable concentrate (EC) and wettable powder (WP) formulations.

Floors of food warehouses are usually made of concrete. The residual efficacy of most organophosphate insecticides is often lower on concrete than on less alkaline surfaces (Cogburn, 1972; Watters, 1976; White, 1982; Williams *et al.*, 1983; Roper and Wright, 1985; Jain and Yadav, 1989). Comparison studies have shown that pyrethroid insecticides can be more effective on concrete surfaces than organophosphates (Williams *et al.*, 1983; Jain and Yadav, 1989), but their efficacy may be formulation-dependent. Cyfluthrin EC was less effective than the WP formulation against *Tribolium confusum* (J. duVal), the Confused flour beetle, and *T. castaneum* (Herbst), the Red flour beetle exposed on unsealed treated concrete (Arthur, 1994). Deltamethrin WP was more effective than deltamethrin EC on a variety of surfaces bioassayed with three *Callosobruchus* species

(Jain and Yadav, 1989). Parkin (1966) earlier had found WP formulations to be effective on porous surfaces.

Deltamethrin dust (0.05% AI) is labeled for indoor non-food uses at an application rate of 2.36–3.55 g per m^2, but its residual toxicity towards beetle pests of stored food is not known. The purpose of this study was to determine the residual efficacy of the dust applied at the maximum label rate of 3.55 g per m^2 to wood, concrete, and tile surfaces against *T. confusum*, *T. castaneum*, and *Rhyzopertha dominica* (F.), the Lesser grain borer. These species are serious pests of storage facilities in the United States.

MATERIALS AND METHODS

Five square 0.094 m^2 sections of plywood, concrete, or tile surfaces were used as test units in this study. The plywood surface was half-inch construction-grade plywood, the concrete was constructed by pouring ready-mix concrete into 0.094 m^2 forms, and the floor tile was standard non-waxed vinyl composite. Four panels of each type of surface were treated with deltamethrin dust and one panel was the untreated control. Deltamethrin 0.05% dust (DeltaDust, EPA registration #432-772) was obtained from AgrEvo Environmental (Montvale, NJ, USA). Individual treatments were prepared by weighing 333 mg of dust into each of twelve 20-ml vials capped with a screen lid. Four panels of each surface type were treated by shaking the vial to distribute the contents evenly over the surface. All treated and untreated panels were kept in an indoor laboratory at approximately 25°C.

One day after treatment (week 0) six 75 mm diameter by 25 mm tall open cylindrical glass rings were placed on each panel. Two rings were placed side by side on the top, middle, and lower portions of the panel. Ten 1–2 week-old adult *T. confusum*, *T. castaneum*, and *R. dominica* were placed in each of the two top, middle, and bottom rings, respectively. All insects were obtained from pesticide-free laboratory cultures. After 24 h, the insects were categorized as surviving (able to run upright), knocked down (lying on their backs but able to move), or dead + moribund (not moving or only reflexively twitching when prodded). The insects of each species in the left position of the two rings were removed and placed in Petri dishes lined with filter paper. These insects comprised the "recovery study". The other insects in the right positions were kept on the treated panels and comprised the "residual study". All insects were examined again 4 days later and were categorized as surviving, knocked down, or dead + moribund.

The bioassays were repeated as described above at weekly intervals for 21 weeks. Data for each species were summarized by multiplying the number of survivors at each assessment by 10 to obtain a percentage value, and averaging the four replicates. The test was analyzed by species with surface as a whole-plot treatment, method of exposure (recovery vs residual) as a sub-plot treatment, and time (24 versus 120 h) and week as repeated measures using the general linear model (GLM) procedure of the Statistical Analysis System (SAS Institute, 1987). When applicable, the non-linear model procedure (NLIN) of SAS was used to fitted non-linear equations for survival on each surface. Linear or quadratic equations were fitted using GLM when non-linear equations could not be calculated. A 95% effectiveness period (LT_{95}) for residual efficacy on each surface was determined by substituting a survival of 5% (y) into the regression equations and calculating the value for week (x).

RESULTS

Tribolium confusum

Surface, method of exposure, time, week, and all interactions except surface * exposure * week * time were significant ($P < 0.05$). The main and sub-plot effects (surface and method of exposure) were separated from the repeated measures time and week.

Recovery study. The percentage of *T. confusum* surviving after a 24-h exposure on plywood gradually increased from 20% at week 0 to 80–90% from weeks 5 to 9 (Fig. 1A). However, from weeks 11 to 15 only about 20% of the beetles survived (80% either knocked down or dead) after 24 h of exposure. After week 16, the percentage of survivors gradually increased, but because

of the wide fluctuations in survival throughout the test, regression lines could not be fitted to the data ($P \geq 0.05$). Average survival at 24 h was 56.8 ± 3.8%.

Toxicity was greater on concrete than on plywood (Fig. 1B). All individuals were either knocked down or dead after 24-h exposure until week 5. The number of survivors at each weekly bioassay tended to fluctuate from week 7 to week 16, then increased to about 70–80% for the remainder of the test. Survival data were described by quadratic regression where y = survival and x = bioassay week, and the LT_{95} was 4.7 weeks. The residual toxicity of deltamethrin dust was greater on tile than on plywood or concrete (Fig. 1C). The number of survivors on tile was below 20% from weeks 0 to 13 and gradually increased to about 90% by the end of the test (Fig. 1C). Variability in the survival data was described by quadratic regression (Fig. 1C) and the LT_{95} was 9.7 weeks.

Beetles removed from the treated panels at each weekly bioassay did not recover from exposure to the deltamethrin dust. Survival after 4 days in untreated Petri dishes (120 h after exposure) was usually less than that at 24 h and varied on all three surfaces (Fig. 2). Survival on plywood averaged 14.8 ± 2.8% and exceeded 40% only at weeks 7 and 9 (Fig. 2A), but was not consistent from week to week ($P \geq 0.05$). On concrete, approximately 50% of the beetles that survived at 24 h were either knocked down or dead after 120 h (Fig. 2B). Survival after 120 h was less than 20% for all weeks except for week 9 until week 17. The increase in survival was described by quadratic regression and the LT_{95} was 10.5 weeks. Survival patterns on tile were similar to those for concrete, with the LT_{95} being 10.8 weeks.

Residual study. *T. confusum* survival after a 24-h exposure at each weekly bioassay was usually greater in the residual study than in the recovery study. About 80% of the beetles on plywood survived after 24-h exposure (Fig. 3A) from weeks 5 to 21 with the exception of weeks 11, 16, and 17. Survival variability was described by a non-linear equation, and the 5% survival threshold was exceeded at the origin. The number of survivors after 24 h of exposure on concrete was approximately 20% or less until week 9, then gradually increased to 90% by week 15 (Fig. 3B). Survival on tile was less than 20% until week 12, then gradually increased to approximately 60 to 80% from weeks 14 to 21 (Fig. 3C). The LT_{95} from quadratic regression analyses was 3.2 and 6.0 weeks for concrete and tile, respectively.

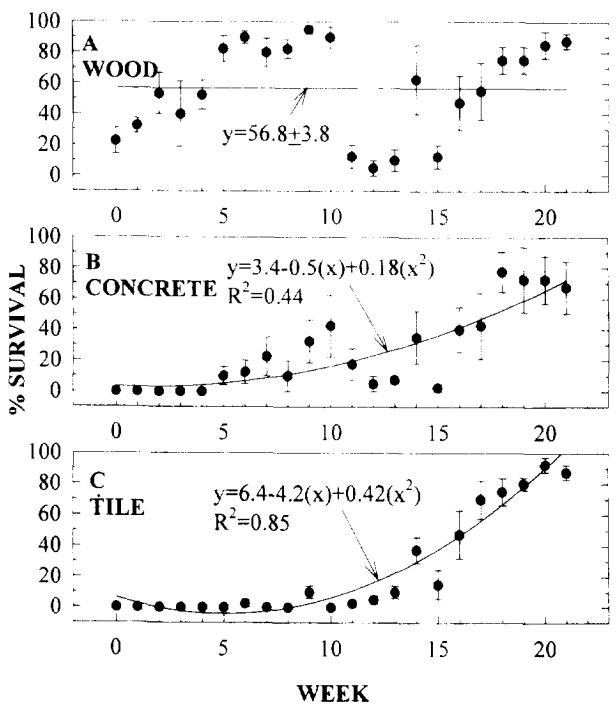

Fig. 1. Percentage survival (means ± SEM) at weekly bioassays of *T. confusum* exposed for 24 h on wood (A), concrete (B), and tile (C) panels treated with 0.05% deltamethrin dust at the rate of 3.54 g/m². Quadratic regression equations with y = percentage survival and x = week were fitted to the survival data for concrete and tile.

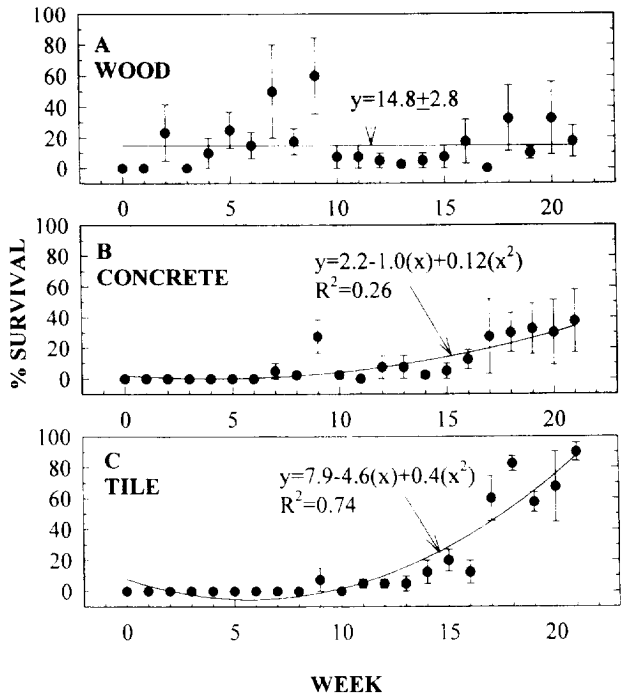

Fig. 2. Percentage survival (means ± SEM) at weekly bioassays of *T. confusum* 96 h after being removed from the original 24-h exposure period on wood (A), concrete (B), and tile (C) panels treated with 0.05% deltamethrin dust at the rate of 3.54 g/m^2. Quadratic regression equations with y = percentage survival and x = week were fitted to the survival data for concrete and tile.

An increase in the exposure from 24 to 120 h slightly increased knockdown and mortality. Recovery from knockdown during some weeks was evident, but the equations describing survival for 24 and 120 h exposures were similar on all three surfaces (Figs 3 and 4). The number of survivors on plywood increased from 10 to 20% at weeks 0–5 to nearly 100% by week 9 (Fig. 4A). Data were described by a non-linear equation, and the LT_{95} was 0.2 weeks. No beetles survived after a 120-h exposure on concrete from weeks 0 to 5, but survival gradually increased, except for a drop at weeks 10 and 12, until week 15 when it plateaued at approximately 90% (Fig. 4B). The LT_{95} was 4.3 weeks. On tile, no beetles survived the 120-h exposures from weeks 0 to 5, but survival increased to approximately 20% from weeks 6 to 11, 40% from weeks 13 to 16, and 60 to 80% from weeks 17 to 21 (Fig. 4C). The LT_{95} was 6.4 weeks.

Tribolium castaneum

Time, week, surface * time interaction, and week * time interaction were the only significant effects for *T. castaneum* survival ($P < 0.05$). Because there were no differences among the three surfaces and the two methods of exposure, these data were combined and separated by 24 and 120 h exposure for each week.

T. castaneum was more susceptible than *T. confusum* to the deltamethrin dust. Less than 10% of *T. castaneum* survived after a 24-h exposure until week 20 (Fig. 5A). Survival data were described partly by quadratic regression and the LT_{95} was 14.6 weeks. The percentage of survivors at 120 h was 5% or less at each bioassay for the entire test (Fig. 5B). Although a quadratic regression equation could be fitted to the data, the R^2 of the equation was only 0.02. Data were instead averaged for the entire 22 weeks (1.5 ± 0.03%).

Rhyzopertha dominica

R. dominica was extremely susceptible to deltamethrin dust. None survived after 24 h in the recovery study except for 10% in replicate 3, week 13 on plywood. None survived after the 4-day holding period in clean Petri dishes. Most *R. dominica* were knocked down or killed after several hours of exposure at each weekly bioassay in the residual study. The dust remained on the surfaces for much of the test, and there was no survival at either the 24- or 120-h exposure period.

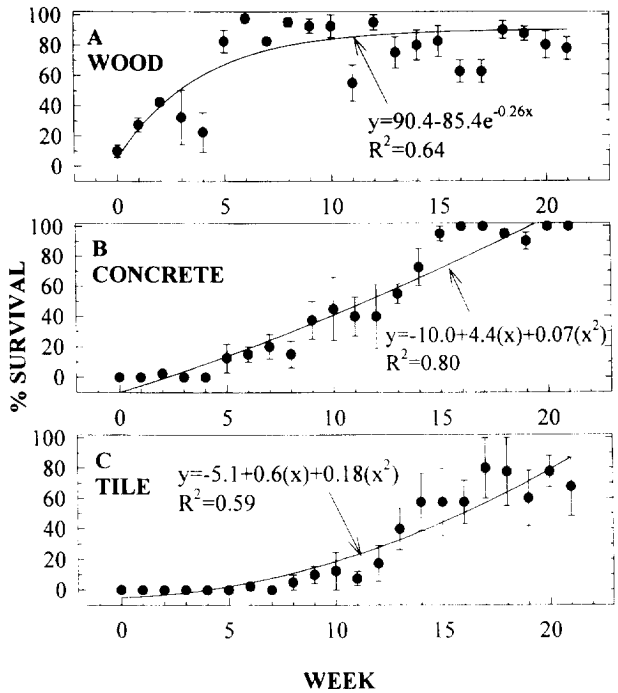

Fig. 3. Percentage survival (means ± SEM) at weekly bioassays of *T. confusum* exposed for 24 h on wood (A), concrete (B), and tile (C) panels treated with 0.05% deltamethrin dust at the rate of 3.54 g/m^2. Beetles were not removed after exposure. A non-linear equation was fitted to the survival data for wood and quadratic regression equations were fitted to the survival data for concrete and tile. For all equations, y = percentage survival and x = week.

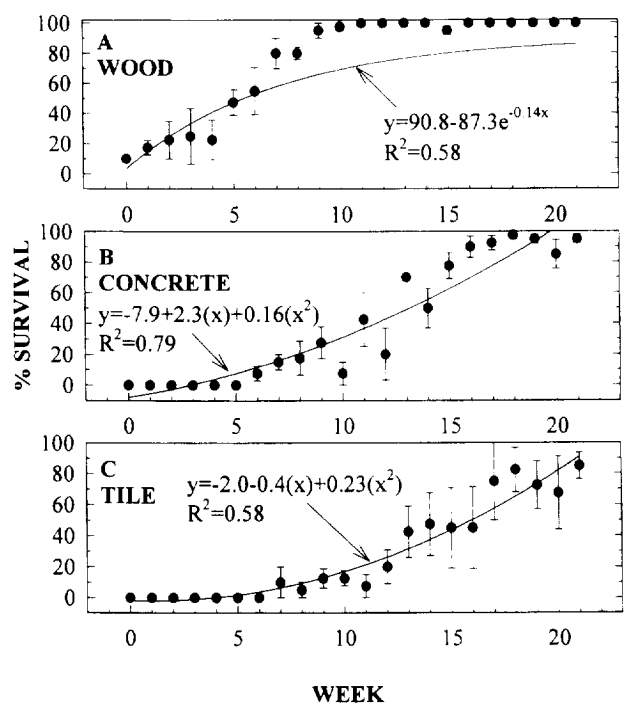

Fig. 4. Percentage survival (means ± SEM) at weekly bioassays of *T. confusum* exposed for an additional 96 h (120 h total) on wood (A), concrete (B), and tile (C) panels treated with 0.05% deltamethrin dust at the rate of 3.54 g/m^2. A non-linear equation was fitted to the survival data for wood and quadratic regression equations were fitted to the survival data for concrete and tile. For all equations, y = percentage survival and x = week.

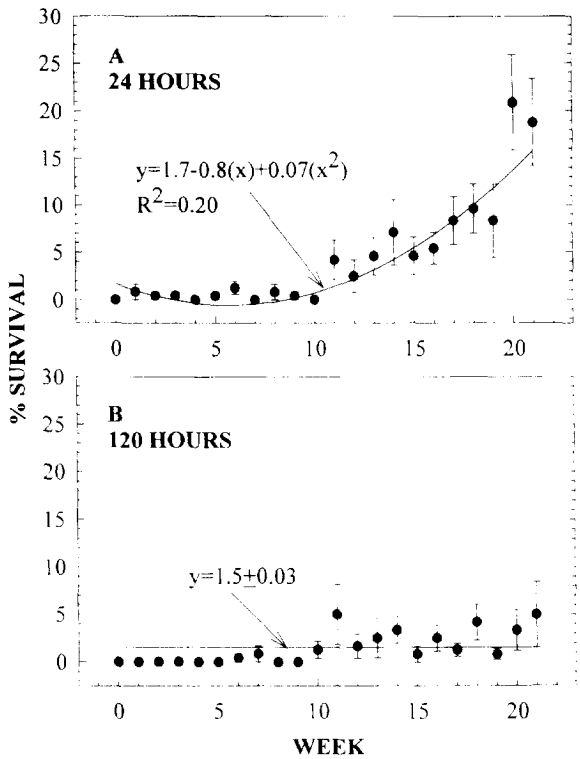

Fig. 5. Percentage survival (means ± SEM) at weekly bioassays of *T. castaneum* exposed for 24 (A) and 120 (B) h to 0.05% deltamethrin dust at the rate of 3.54 g m^2. No significant differences among surfaces or between exposure methods were detected. A quadratic regression with y = percentage survival and x = week was fitted to the survival data for 24 h.

DISCUSSION

More *T. confusum* survived after 24 and 120 h of continuous exposure to treated surfaces (residual) than after corresponding time periods for the recovery data. One possible cause for these results is that the beetles in the residual test moved about the containment ring and picked up the dust particles until they were knocked down. Theoretically, each individual beetle could pick up the dust for up to 120 h in the residual test as compared to 24 h in the recovery test. The continuous removal of the dust each week would make less dust available for the new insects exposed in subsequent weeks in both studies. In the residual test, the longer exposure period gave the beetles more time to move about and remove the dust from the treated surface.

These differences in the recovery and residual studies were not as noticeable for *T. castaneum* because deltamethrin was more toxic to *T. castaneum* than to *T. confusum*. At each weekly bioassay, nearly all *T. castaneum* were either quickly knocked down or killed after 24 h exposure in both tests, and there were few active individuals until the final weeks. Therefore, *T. castaneum* could not pick up the dust particles in the same manner as *T. confusum*.

Results indicate that 0.05% deltamethrin dust has potential as a residual treatment in food storage facilities. *T. castaneum* and *R. dominica* are highly susceptible to the dust; however, *T. confusum* may be more difficult to control. The current maximum label rate of 333 mg per 0.094 m^2 was not effective on plywood bioassayed with *T. confusum*. Most flooring surfaces in food warehouses are composed of concrete or tile, and application of deltamethrin dust at the current label rate would control *T. confusum* on these surfaces for approximately 4–7 weeks. This is especially important because many insecticides sprayed on concrete degrade in a few days and residual protection is often difficult to obtain. One precautionary note is that a dust formulation will give exposed insects an opportunity to remove the toxicant from the treated surface even if those insects are ultimately killed, which will affect residual control of new insects that subsequently come into contact with the treated surface.

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