Effect of Temperature on Residual Toxicity of Cyfluthrin Wettable Powder

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ABSTRACT Red flour beetles, *Tribolium castaneum* (Herbst), were exposed for 0.5, 1, and 2 h at 20, 25, 30, and 35°C on concrete treated with 100 mg/m^2 20% (AI) cyfluthrin wettable powder (WP) at biweekly intervals for 8 wk. Knockdown typically averaged 80–100% at all exposure intervals and temperatures until week 8, with no significant differences among temperatures. Although the overall *F*-test indicated a significant difference in survival among the 3 exposure intervals, the only significant difference detected was at week 4. After week 0, beetles exposed at 25, 30, and 35°C began to recover from knockdown, and by week 6 survival was at least 90%, with 1 exception. Survival of beetles exposed at 20°C was 0.0 and 7.5% for weeks 0 and 2, and <30% for weeks 4, 6, and 8. Beetles were able to tolerate exposure to cyfluthrin WP at successively lower temperatures as residues aged on the concrete.

KEY WORDS *Tribolium castaneum*, cyfluthrin, pyrethroids, treated surfaces, insecticides

THE TOXICITY OF most organophosphate insecticides applied as residual crack-and-crevice treatments to control insects in and around mills and processing plants is positively correlated with temperature (Johnson 1990). Many of these compounds are older chemicals that have been registered for years, and they may be subject to regulatory restraints based on interpretations of new legislation and requirements for reregistration. Currently, the only pyrethroid chemical that is labeled as both a crack-and-crevice and as a general surface treatment is cyfluthrin. The 20% (AI) wettable powder (WP) formulation can be applied at either 100 or 200 mg/m^2 (9.5 or 19.0 g/1,000 feet^2).

Pyrethroid toxicity is generally negatively correlated with temperature (Johnson 1990), but results often vary depending on chemical structure (Sparks et al. 1983), target species (Toth and Sparks 1988, 1990), insecticide (Sparks et al. 1982, Hinks 1985), and the temperature range (Grafius 1986). In several studies, cyfluthrin toxicity and residual efficacy were negatively correlated with temperature (Hinks 1985, Wadleigh et al. 1991, Braness et al. 1991), but in one field study involving several pyrethroids applied to control insects on cotton, cyfluthrin was the only insecticide that did not experience a reduction in efficacy during a particularly warm period in which daily high temperatures were above 37°C (Guillebeau et al. 1989).

The red flour beetle, *Tribolium castaneum* (Herbst), is a major pest of flour mills and indoor storage facilities. A 2-h exposure interval killed 90% of the beetles exposed at ≈22°C on concrete treated with 200 mg/m^2 cyfluthrin WP, but as the residues aged, longer exposure intervals were required to give equivalent mortality (Arthur 1998a). The high label rate of 200 mg/m^2 also gave greater residual efficacy than the low label rate of 100 mg/m^2.

Many large storage facilities are not climate controlled, and seasonal temperature variations could have an effect on residual efficacy of cyfluthrin applied to control insect pests such as the red flour beetle. Temperature–toxicity data for red flour beetles exposed to cyfluthrin would be beneficial for pest management programs; therefore, the objectives of this test were to determine the effect of temperature on knockdown and recovery of red flour beetles exposed on concrete treated with cyfluthrin WP, and to determine differential responses associated with aging of the residues.

Materials and Methods

Individual treatment arenas were prepared by mixing ≈3,200 g of ready-mix concrete with 1,600 ml of tap water to create a liquid slurry (Arthur 1998b), and filling each of 60 disposable plastic petri dishes (89 mm in diameter by 15 mm in height) to a depth of ≈7 mm. The concrete was then allowed to dry for 3 d. Four replicate solutions of cyfluthrin 20% (AI) WP were formulated at the low label rate of 100 mg/m^2. Each replicate solution was used to treat 12 dishes, and individual treatments were applied with a Badger 100 artist's = airbrush (Franklin Park, IL) to spray each petri dish at the label spray rate of 40 ml of formulated solution per square meter (0.25 ml per dish). The remaining 12 dishes served as untreated controls.

The dishes were allowed to dry for ≈5 h, then 10 unsexed adult red flour beetles (1–2 wk old) were put in each of the 48 treated and the 12 untreated dishes. Twelve treated and 3 untreated dishes were put in each of 4 plastic boxes (26 by 36.5 by 15 cm) with a waffle-type grid in the bottom, which contained 750 ml of saturated NaCl to maintain the humidity at ≈70% RH. The dishes were covered and stacked inside the boxes, and 1 box was then placed in each of 4 incubators set at 20, 25, 30, and 35°C. There were 4 treated replicates and an untreated control for each temperature.

After 0.5 h, 4 treated dishes and 1 control were removed from each incubator, and placed on a laboratory counter. After ≈1 h, the beetles were classified as moving or knocked down, placed in new petri dishes containing filter paper, and returned to the incubator. This procedure was repeated at 1 and 2 h. Beetles were held for 1 wk without food because Arthur (1998b) showed that survival of red flour beetles exposed to cyfluthrin increased when food was provided. After 1 wk, beetles were removed from the incubator, classified as moving, knocked down, or dead. Beetles were discarded after classification.

The treated dishes were held in the laboratory at ambient conditions (≈25°C, 60% RH) to mimic conditions typically encountered in a milling and processing facility. Residual bioassays were conducted every 2 wk, using the same exposure procedures. Beetles that were moving when the assessments were made after the 1-wk holding period were considered to have survived exposure. Data were analyzed using the general linear models procedure (SAS Institute 1987) with temperature and exposure interval as the main effects and week as a repeated measure, with the percentage of surviving beetles as the response variable. Control mortality was rare, so no corrections were made. Lack of fit tests (Draper and Smith 1981) were conducted using Table curve 2 d software (Jandel Scientific, San Rafael, CA) to determine the R^2 of the regression equation, the amount of variation that could be explained by any model fit to the data, given the variation in the data (maximum R^2), and the amount of variation explained by the regression equation (R^2 s adjusted as a percentage of the maximum).

Results

Knockdown was significant for main effects of temperature and exposure interval ($F = 3.3$; df = 3, 179; $P = 0.0205$ and $F = 54.1$; df = 2, 159; $P = 0.0001$, respectively) and the repeated measure week ($F = 50.2$; df = 4, 24; $P = 0.0001$). However, with the exception of week 0, 0.5-h exposure, none of the regressions for temperature as the dependent variable were significant ($P \geq 0.05$), and knockdown data for the 4 temperatures were combined. Knockdown generally increased as exposure interval increased at each of the biweekly bioassays (Fig. 1). Except for week 0, 0.5 h, at least 80% of the beetles was knocked down after being exposed at all 3 intervals until week 6, but at week 8 only 50–55% were knocked down after being exposed for 0.5 and 1 h.

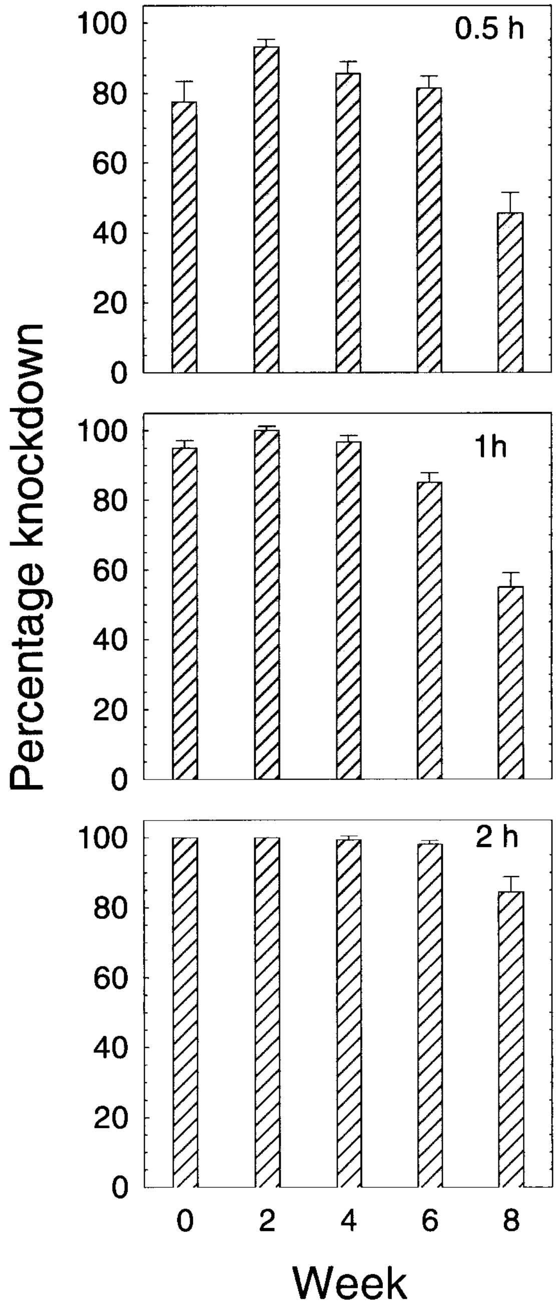

Fig. 1. Knockdown (mean ± SEM) of red flour beetles exposed for 0.5, 1, and 2 h on concrete treated with 100 mg of 20% (AI) cyfluthrin WP/m^2. Bioassays conducted at biweekly intervals for 8 wk.

Survival was significant for main effects of temperature and exposure interval ($F = 81.6$; df = 3, 179; $P = 0.0001$ and $F = 6.3$; df = 2, 159; $P = 0.0023$) and the repeated measure week ($F = 60.0$; df = 4, 24; $P =$

0.0001). However, although the overall *F*-test indicated a significant difference in survival among the 3 exposure intervals, the only significant difference ($P < 0.05$) within weeks occurred at week 4. There was no difference in survival with respect to exposure interval for the other 4 bioassays; therefore, data for exposure interval were combined.

Survival generally increased as temperature increased and as residues aged, indicating that as the residues aged, the beetles were able to tolerate exposure at successively lower temperatures. (Fig. 2 A-E). No beetles survived at week 0 when exposed at 20, 25, and 30°C (Fig. 2A), but approximately half survived exposure at 35°C. Although knockdown at weeks 2 and 4 was nearly 100% at all temperatures, beetles exposed at 25, 30, and 35°C began to recover and survive during the 1-wk holding period (Fig. 2 B and C). By week 6 (Fig. 2D), recovery and survival of beetles at 25, 30, or 35°C was at least 90%, and by week 8 (Fig. 2E), survival at these temperatures approached 100%. All regressions for temperature within week were significant ($P < 0.05$). Nonlinear equations were fit to the data for weeks 0 and 8 and sigmoidal equations were fit to the data for weeks 2, 4, and 6 (Table 1). The high values for the adjusted R^2s indicate the equations fit the data. The curve-fit plotted lines in Fig. 1 show a pattern of increased survival at 25, 30, and 35°C as the residues aged on the treated concrete.

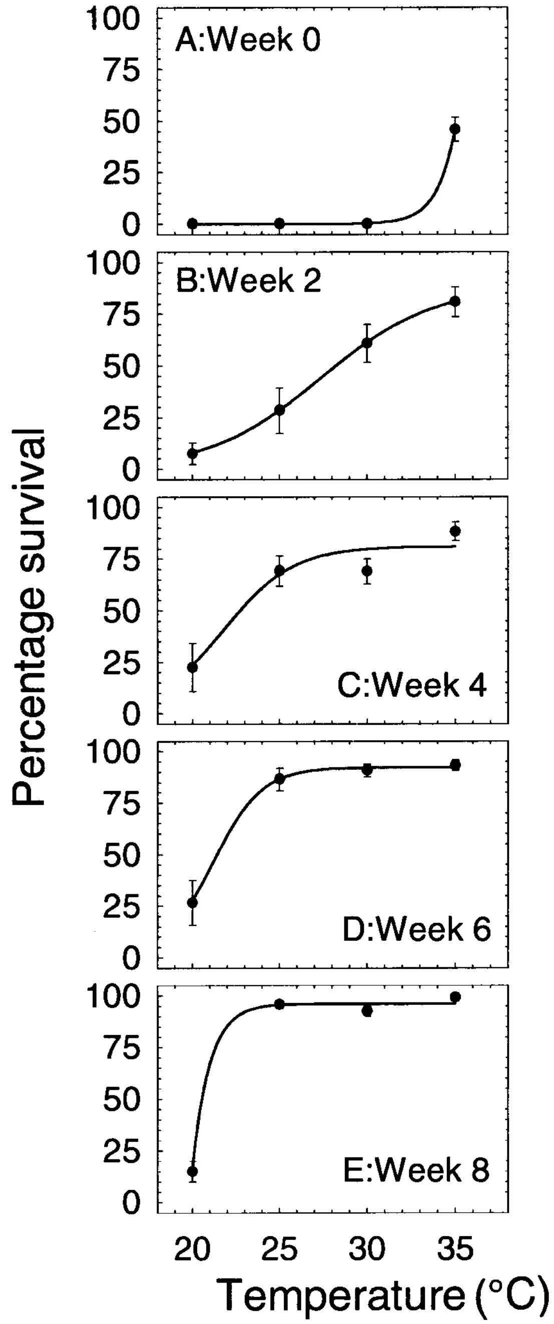

Fig. 2. Survival (mean ± SEM) of red flour beetles after exposure for 0.5–2 h at 20, 25, 30, and 35°C on concrete treated with 100 mg of 20% (AI) cyfluthrin WP/m^2. Fitted regression lines are from equations listed in Table 1.

Discussion

Several published studies in which various insect species were exposed by topical application to pyrethroid insecticides document reduced efficacy at temperatures exceeding 25°C. The LD_{50}s for fenvalerate, flucythrinate, and permethrin for tobacco budworm, *Heliothis virescens* (F.), larvae were 27, 138, and 13 times greater, respectively, at 27°C than at 16°C (Brown 1987), whereas LD_{50}s for 2 isomers of permethrin applied to 3rd-instar cabbage looper, *Trichoplusi ni* (Hübner), were almost 10 times greater at 26.7°C than at 15.6°C (Toth and Sparks 1988). Wadleigh et al. (1991) conducted studies with the German cockroach, *Blatella germanica* (L.), and found LD_{50}s for 10 pyrethroids to be twice as great at 26°C than at 19°C. Grafius (1986) also reported LD_{50}s for Colorado potato beetle, *Leptinotarsa decemlineata* (Say), doubled when temperature increased from 23 to 30°C. Additional research reporting decreasing toxicity of pyrethroids with increased temperatures is referenced by Toth and Sparks (1990).

Neutral and positive toxicity responses to pyrethroids with increasing temperature also has been reported, but the degree of response is often dependent on the individual species, the insecticide, and the method of application. Sparks et al. (1982) showed that as temperatures increased from 15.6 to 26.7 to 37.8°C, the LD_{50}s of permethrin increased for the cabbage looper; the fall armyworm, *Spodoptera frugiperda* (J. E. Smith); and the tobacco budworm, whereas LD_{50}s for fenvalerate decreased by ≈40% for both the fall armyworm and the tobacco budworm as temperatures decreased from 37.8 to 26.7°C. There was little difference in the LD_{50}s for deltamethrin against the cabbage looper and fall armyworm at 37.8 versus 26.7°C, but the LD_{50} for tobacco budworm was 35% lower at 37.8°C than at 26.7°C. A positive temperature coefficient also was reported

Table 1. Equations describing survival of red flour beetles exposed for 0.5–2 h at 20, 25, 30, or 35°C on concrete treated with 100 mg/m² 20% (AI) cyfluthrin wettable powder

Week	Equation parameters ± SEM			R^2	maximum R^2	% of maximum
	a	b	c			
0	—	$2.9 * 10^{-14} \pm 2.9 * 10^{-15}$		0.81	0.81	100
2	88.3 ± 17.7	27.4 ± 2.0	3.2 ± 1.4	0.51	0.51	100
4	81.0 ± 6.7	21.8 ± 1.0	2.0 ± 0.8	0.44	0.47	93.6
6	92.2 ± 4.5	21.2 ± 0.6	1.4 ± 0.6	0.63	0.63	100
8	96.0 ± 1.6	$3.9 * 10^{10} \pm 1.6 * 10^{9}$		0.92	0.93	98.9

Week 0, nonlinear equation $y = be^{x}$ with intercept of 0; weeks 2, 4, 6, sigmoid equations $y = a/(1 + \exp(-(x - b)c))$; week 8 nonlinear equation $y = a - be^{-x}$. For all equations, y = percentage survival, x = temperature.

for tralomethrin against the tobacco budworm (Sparks et al. 1983). Schouest and Miller (1988) measured toxicity of fenvalerate and permethrin to adult male pink bollworm, *Pectinophora gossypiella* (Saunders), by topical application, vial-discriminating dose, and sticky-trap exposures, and reported positive toxicity responses for both insecticides as temperature increased progressively from 21 to 26 to 32°C. Field trials with alphamethrin and deltamethrin applied to control clearwinged grasshoppers, *Camnula pellucida* (Scudder), and the twostriped grasshopper, *Melaonplus bivittatus* (Say), also report a positive response at increasing temperatures of 23, 27, and 31°C (Johnson 1990).

Several publications document the effectiveness of pyrethroid wettable powders applied on concrete to control stored product beetles, but these tests were conducted at a single exposure temperature of 27°C or less (Williams et al. 1983, Jain and Yadav 1989, Arthur 1994). In a previous test, nearly all of the red flour beetles exposed for 0.5 h on concrete treated with 100 mg/m2 cyfluthrin WP were still moving after completion of the exposure interval, but most of the beetles eventually died within a week in bioassays conducted at 0, 3, and 6 wk (Arthur 1998a). However, this test was conducted during the winter when the temperature inside the laboratory was ≈22°C. The results of the current study show that temperature may have enhanced knockdown of red flour beetles exposed on the treated concrete, compared with previous results (Arthur 1998a), but at temperatures >25°C, beetles recovered and there was little residual efficacy.

Red flour beetle recovery after exposure at different temperatures on plywood treated with 0.2, 0.5, and 1.0 g (AI)/m² of cypermethrin, fenvalerate, and permethrin also was described by Watters et al. (1983). Beetles were exposed for 5 h at temperatures of 10, 20, and 30°C, then removed and held at the exposure temperatures for 4 d in vials containing cracked wheat. Knockdown was 95–100% for bioassays conducted at 1, 3, 6, and 14 wk, but even with these high concentrations mortality never exceeded 90%. Toxicity of cypermethrin and fenvalerate was usually greater at 20°C than at 10 or 30°C, whereas permethrin toxicity increased as temperature increased.

The indoor environmental temperature could affect the efficacy of cyfluthrin wettable powder applied as a residual surface treatment inside flour mills, processing facilities, and food warehouses. Even if the beetles are knocked down at high temperatures, they can apparently recover. Toxicity of cyfluthrin wettable powder appears to be negatively correlated with temperature, and depending on the insect species, frequent applications may be necessary to eliminate infestations when temperatures within the target sites are between 25 and 35°C.

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