Cyfluthrin WP and EC Formulations to Control Malathion-Resistant Red Flour Beetles and Confused Flour Beetles (Coleoptera: Tenebrionidae): Effects of Paint on Residual Efficacy[1, 2]

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ABSTRACT Malathion-resistant red flour beetle and confused flour beetle field strains and a pesticide-susceptible laboratory strain of each species were exposed on unpainted and painted galvanized steel panels treated with cyfluthrin EC and WP formulations at label rates. Residues from both formulations applied to unpainted steel killed 99.8% of the insects after 1 h exposure for up to 235 d after treatment. Equivalent control on painted panels lasted approximately 3 wks and required 24 h exposure. Residual mortality on painted panels treated with cyfluthrin WP and EC quickly declined; tests with red flour beetles and confused flour beetles were discontinued after 116 and 123 d, respectively. All of the malathion-resistant strains were as susceptible as the laboratory strain to cyfluthrin, and there was no difference between the EC and WP formulations.

KEY WORDS Cyfluthrin, *Tribolium castaneum,* red flour beetle, *Tribolium confusum,* confused flour beetle, steel, paint.

The red flour beetle, *Tribolium castaneum* (Herbst), and the confused flour beetle, *Tribolium confusum* (DuVal), are cosmopolitan pests that can infest a variety of stored commodities and packaged foods. Warehouse infestations have historically been controlled by regular applications of malathion as a treatment to floors and walls. In recent years, field populations of red flour beetles in stored raw commodities and warehouses have developed resistance to malathion (Halliday et al. 1988, Subramanyam et al. 1989, Zettler and Cuperus 1990, Zettler 1991). Current levels of resistance are so severe that malathion surface applications at the label rate may not control many of the resistant strains (Arthur and Zettler 1991). Field populations of confused flour beetles are also developing resistance to malathion, but current resistance levels are not as severe as those in red flour beetle populations (Zettler 1991).

Malathion resistance may potentially affect insect control operations in dry-land warehouses operated by the U. S. Navy and in storages on individual ships. Both the red flour beetle and the confused flour beetle can infest dried

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[2] This paper reports the results of research only. Mention of a commercial or proprietary product does not constitute a recommendation by the U. S. Department of Agriculture.

food stored on Navy ships and cause severe losses when these ships are at sea. Most maintenance operations, including residual surface treatments for pest control, are conducted when the ship is in port. Regular maintenance also includes routine painting of the decks to reduce corrosion. There are insecticides that are being developed to replace malathion as a general surface treatment in stored product environments, but they may be unsuitable for pest management programs on Navy ships unless they give residual control on painted steel surfaces for at least three months.

One possible replacement for malathion in Naval shipboard storage facilities is the pyrethroid cyfluthrin (Tempo®). Labels for the EC and WP formulations have recently been extended to include the red flour beetle and confused flour beetle. However, there are no published reports concerning the residual efficacy of the EC and WP formulations as surface treatments for either the red flour beetle or the confused flour beetle. Efficacy data are necessary to include this insecticide in pest management programs for these species.

In addition, there are no published reports concerning the effect of paint on the residual efficacy of surface applications. Claborn et al. (1991) indicated that residues from a chlorpyrifos formulation applied to painted steel were less persistent that residues applied to unpainted steel. The objectives of this test were to determine: 1) residual efficacy of the Tempo formulations against malathion-resistant red flour beetle and confused flour beetle field strains, 2) residual efficacy between the two formulations, and 3) residual efficacy on painted and unpainted steel surfaces.

Materials and Methods

Sixteen, 0.09 m^2 # 22 gauge galvanized steel panels were used as exposure surfaces. Insecticide spray solutions were formulated from either a Tempo 2 EC (908 g per 3784 ml) or a Tempo 2 WP formulation. The maximum label rate for the EC formulation is 16 ml per 92.9 m^2 in 3.784 liters of water, or 0.016 ml per 0.092 m^2 in 3.8 ml water (3.84 mg [AI]). The maximum label rate for the WP formulation is 19 g per 92.9 m^2 in 3.784 liters of water, or 0.019 g per 0.092 m^2 in 3.8 ml water (3.80 mg [AI]).

Eight panels were primed with zinc chromate and painted with a grey enamel paint commonly used on U. S. Navy ships; eight panels were left unpainted. After the painted panels dried for 48 h, three painted panels and three unpainted panels were treated with the EC formulation at the maximum label rates using a delivery system equipped with a Teejet nozzle #650033. The nozzle was held approximately 0.3 m above the surface of the panel so that the insecticide spray would be distributed on the entire surface. Three painted panels and three unpainted panels were treated in the same manner with the WP formulation. One painted panel and one unpainted panel treated with 3.8 ml distilled water were included as controls for each formulation. After the panels were sprayed, they were stored on a laboratory counter (25 ± 1°C, 60 ± 2% RH) and held for approximately eight months. Red flour beetle strains tested were collected from field sites in Kentucky (KY), Utah (UT), Iowa (IA), and 2 sites in Oklahoma (OK1, OK2). Confused flour beetle strains tested were collected from sites in Colorado (CO), Missouri (MO), Tennessee (TN), Texas (TX), and New York (NY). All field strains and an insecticide-susceptible strain of each species maintained at the laboratory (SAVLAB) were cultured on a flour media mixture in a controlled environment (28 ± 1°C, 60 ± 2% RH, 14:10 h light-dark). Ten individuals from each of the five red flour beetle field strains, five confused flour beetle field strains, and the two laboratory strains were randomly exposed on the panels at selected intervals during storage. Each group of 10 was held in place on the panel with a 75 mm dia 25 mm high glass ring. Tests were conducted by exposing the red flour beetle strains at 7, 18, 31, 55, 76, 116, 145, 193 and 247 d after application and assessing knockdown and mortality after 1, 6 and 24 h. Confused flour beetle strains were exposed at 12, 25, 40, 61, 83, 123, 157, 201 and 255 d after application; knockdown and mortality were also assessed after 1, 6 and 24 h.

Data for knockdown and mortality on each sample date were combined because under field conditions insects that are knocked down do not usually have an opportunity to escape the treated environment. The combined value was used to determine significant differences between the EC and WP formulations for each strain exposed on the painted and unpainted panels after each of the three exposure intervals. Significance was determined using the *t*-Test procedure of the Statistical Analysis System (SAS Institute 1987).

Results

Unpainted panels. Control mortality was zero on all test dates. Knockdown + mortality for all red flour beetles exposed on the unpainted panels treated with either the EC or WP cyfluthrin formulation was 100% after 1 h exposure for each test date during storage. All but six of the 3,240 individuals exposed during the entire test were dead after 1 h; these six were dead at the 6 h reading. Knockdown + mortality for all confused flour beetles exposed on the unpainted panels treated with either the EC or WP formulation was also 100% after 1 hr exposure for each test date. All but two of the 3,240 individuals exposed were dead after 1 h; these two were dead at the 6 h reading.

Painted panels, Red Flour Beetle. Control mortality was zero on all test dates. Knockdown + mortality for all five strains and the SAVLAB strain after 1 h exposure on panels treated with either the EC or WP formulation was zero on all test dates except for 7 d (Table 1). Residual knockdown + mortality for the KY and UT strains at 7 d was significantly greater on panels treated with the WP than on panels treated with the EC. There were no significant differences for the remaining four strains. Mean percentage knockdown + mortality for the six strains exposed for 6 h on the panels treated with the WP and EC formulations declined sharply after 7 d (Fig. 1). The range for the SEM indicates variation in the data; the only significant difference between the WP and EC formulations occurred at 55 d for the UT strain. Mean percentage knockdown + mortality for 24 h exposure on panels treated with the WP and EC formulations also declined after 7 d, with wide variation in the data (Fig. 2). The only significant differences between the WP and EC formulations occurred at 18 d for the UT strain and 55 d for the IA strain, with the order of significance reversed for the two strains ($P \leq 0.05$). Tests were discontinued after 116 d because of low residual toxicity for both formulations.

Table 1. Mean percentage knockdown + mortality (± SEM) for five field strains and one susceptible laboratory strain of red flour beetles exposed for one 1 h on painted steel panels 7 d after the panels were treated with cyfluthrin EC and WP formulations.

Strain	WP	EC
Ky	73 ± 6.7 a	30 ± 5.7 b
UT	100 ± 0.0 a	6 ± 5.7 b
IA	97 ± 3.3 a	57 ± 1.3 a
OK1	100 ± 0.0 a	83 ± 1.7 a
OK2	90 ± 10.0 a	80 ± 6.7 a
LAB	100 ± 0.0 a	97 ± 3.3 a

Means between columns for a strain followed by the same letter are not significantly different ($P \geq 0.05$, *t*-Test procedure, SAS Institute 1987).

Painted panels, Confused Flour Beetle. Control mortality was zero on all test dates. Percentage knockdown + mortality after 1 h exposure was zero for all five field strains and the SAVLAB strain on all test dates, with the exception of 7 ± 3.3 for the CO strain and 3 ± 3.3 for the TX strain exposed on panels treated with the WP and EC formulations, respectively, at 12 d. Percentage knockdown + mortality after 6 h exposure on panels treated with the EC and the WP declined after 12 d (Fig. 3). Data for the confused flour beetle were variable, as indicated by the range in the SEM; the only significant difference between formulations occurred at 12 d for the CO strain ($P < 0.05$). Twenty-four h percentage knockdown + mortality also declined after 12 d, and significant differences between the 2 formulations occurred only at 12 d for the CO and TX strains (Fig. 4, $P \leq 0.05$). Test were discontinued after 123 d because of low residual toxicity for both formulations.

Discussion

The red flour beetle field strains appeared to be as susceptible to the cyfluthrin residues as was the pesticide-susceptible SAVLAB strain. Malathion resistance frequencies for the KY, UT, IA, OK1, and OK2 strains were 83, 99, 100, 98, and 100%, respectively, indicating that all five were extremely resistant (Zettler 1991). The confused flour beetle field strains and the pesticide-susceptible SAVLAB strains were also equally susceptible to cyfluthrin. Malathion resistance frequencies for the CO, MO, TN, TX, and NY strains were 15, 0, 78, 33, and 49%, respectively, which shows that the confused flour beetle strains were comparatively less resistant than the red flour beetle strains (Zettler 1991). The label rate for malathion EC is 204 g [AI] per 92.9 m^2, or 204 mg per 0.092 m^2. The equivalent rates for the cyfluthrin EC and WP are 3.84 and 3.80 mg [AI] per 0.092 m^2, respectively, which are considerably less than the label rate for malathion.

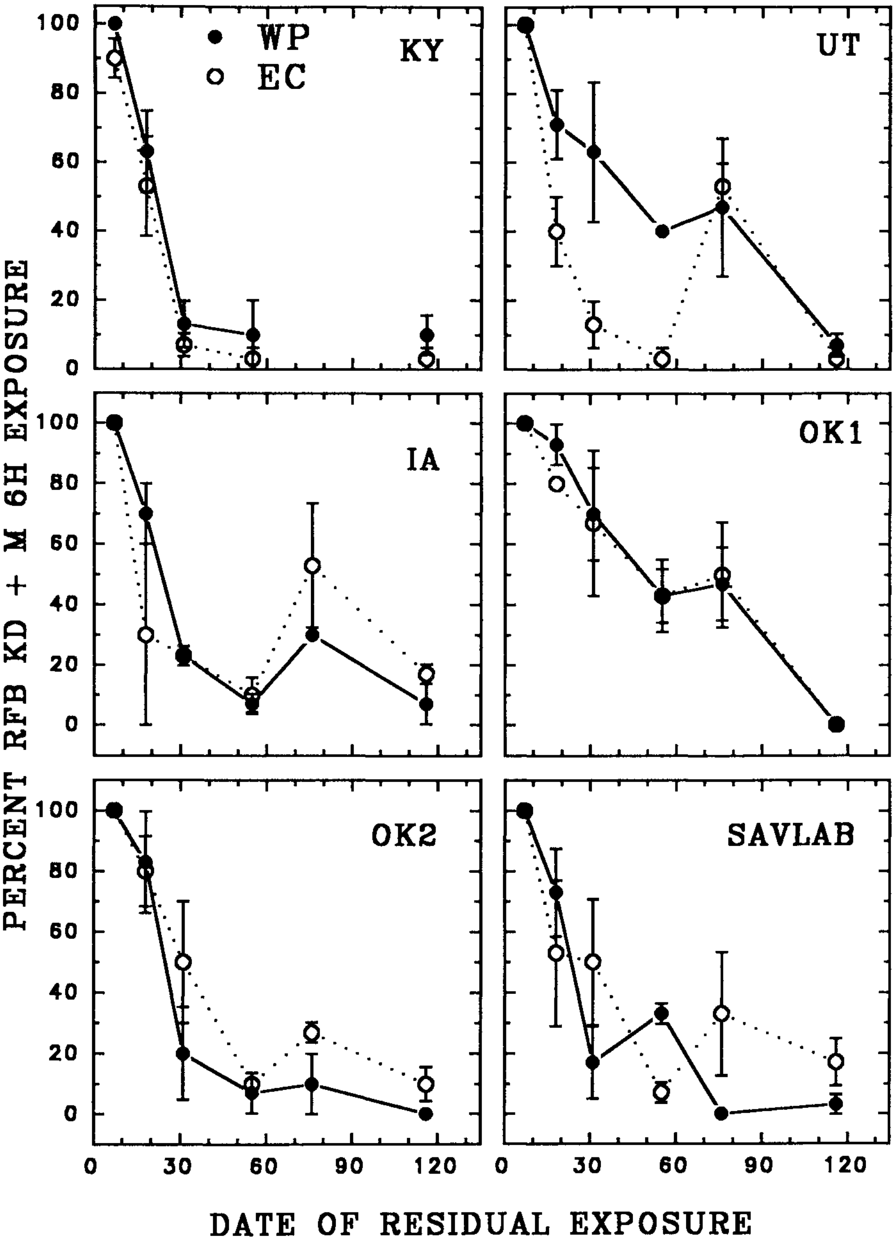

Fig. 1. Mean percentage (± SEM) knockdown + mortality (KD + M) for 5 red flour beetle (RFB) field strains and 1 pesticide-susceptible laboratory strain after 6 h exposure on painted steel panels treated with either cyfluthrin EC or cyfluthrin WP. Trials conducted at selected intervals after treatment.

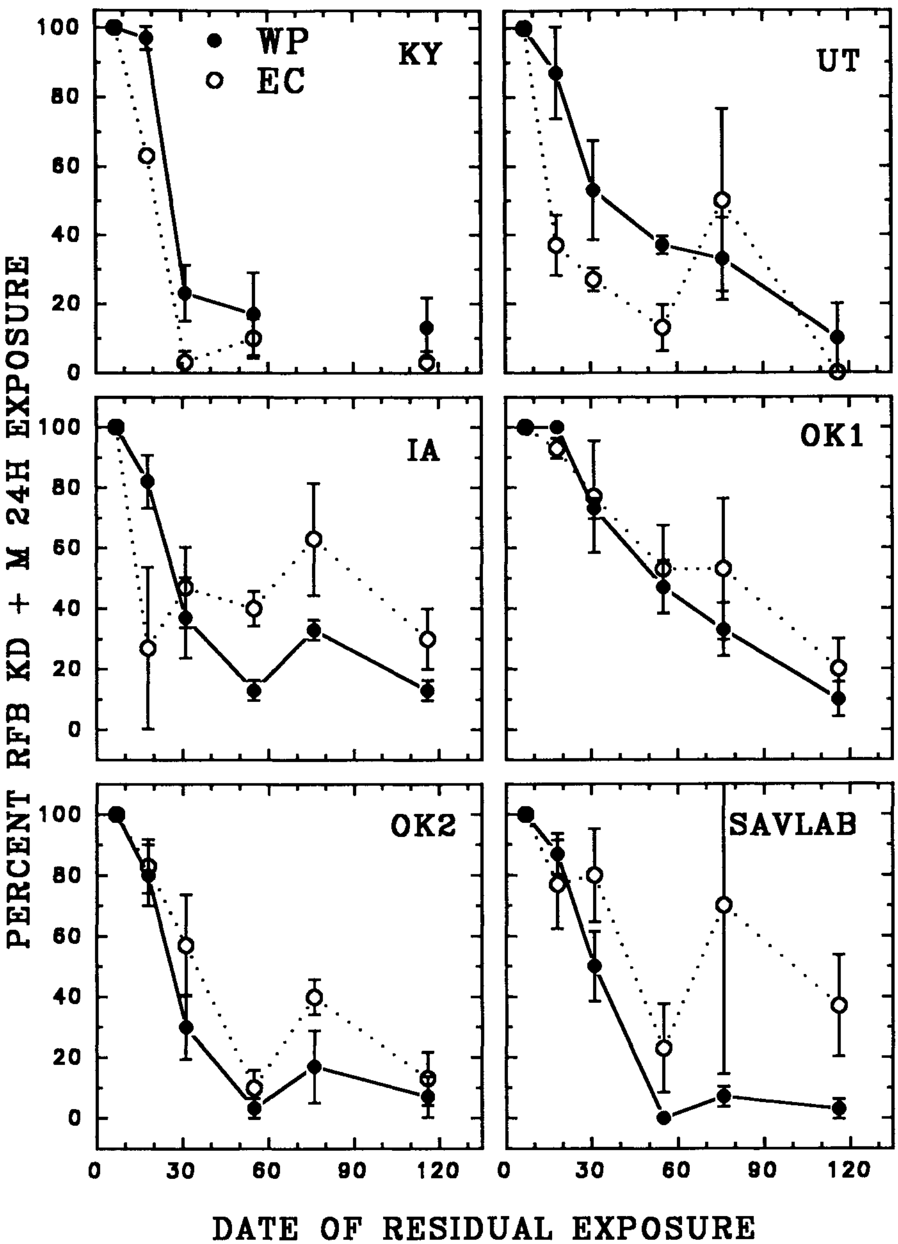

Fig. 2. Mean percentage (± SEM) knockdown + mortality (KD + M) for 5 red flour beetle (RFB) field strains and 1 pesticide-susceptible laboratory strain after 24 h exposure on painted steel panels treated with either cyfluthrin EC or cyfluthrin WP. Trials conducted at selected intervals after treatment.

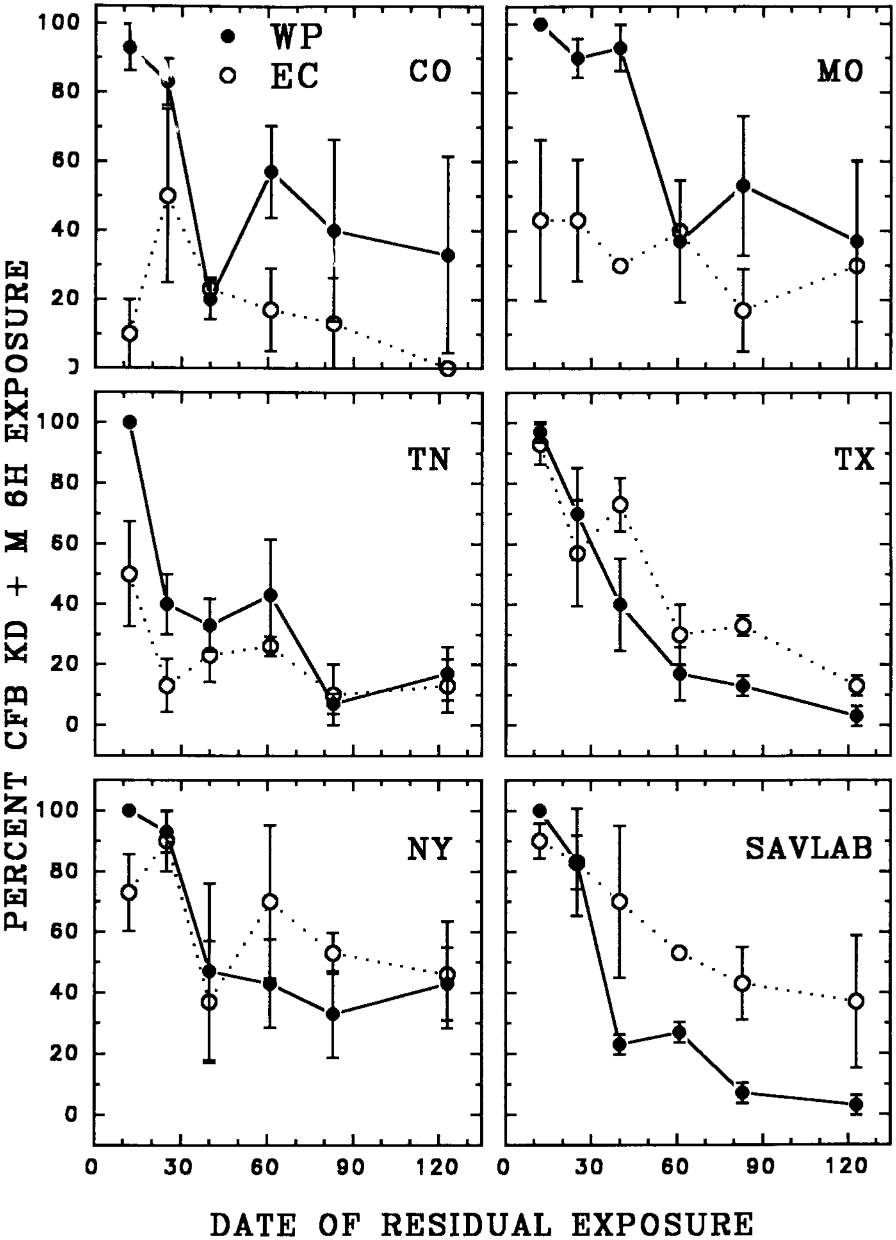

Fig. 3. Mean percentage (± SEM) knockdown + mortality (KD + M) for 5 confused flour beetle (CFB) field strains and 1 pesticide-susceptible laboratory strain after 6 h exposure on painted steel panels treated with either cyfluthrin EC or cyfluthrin WP. Trials conducted at selected intervals after treatment.

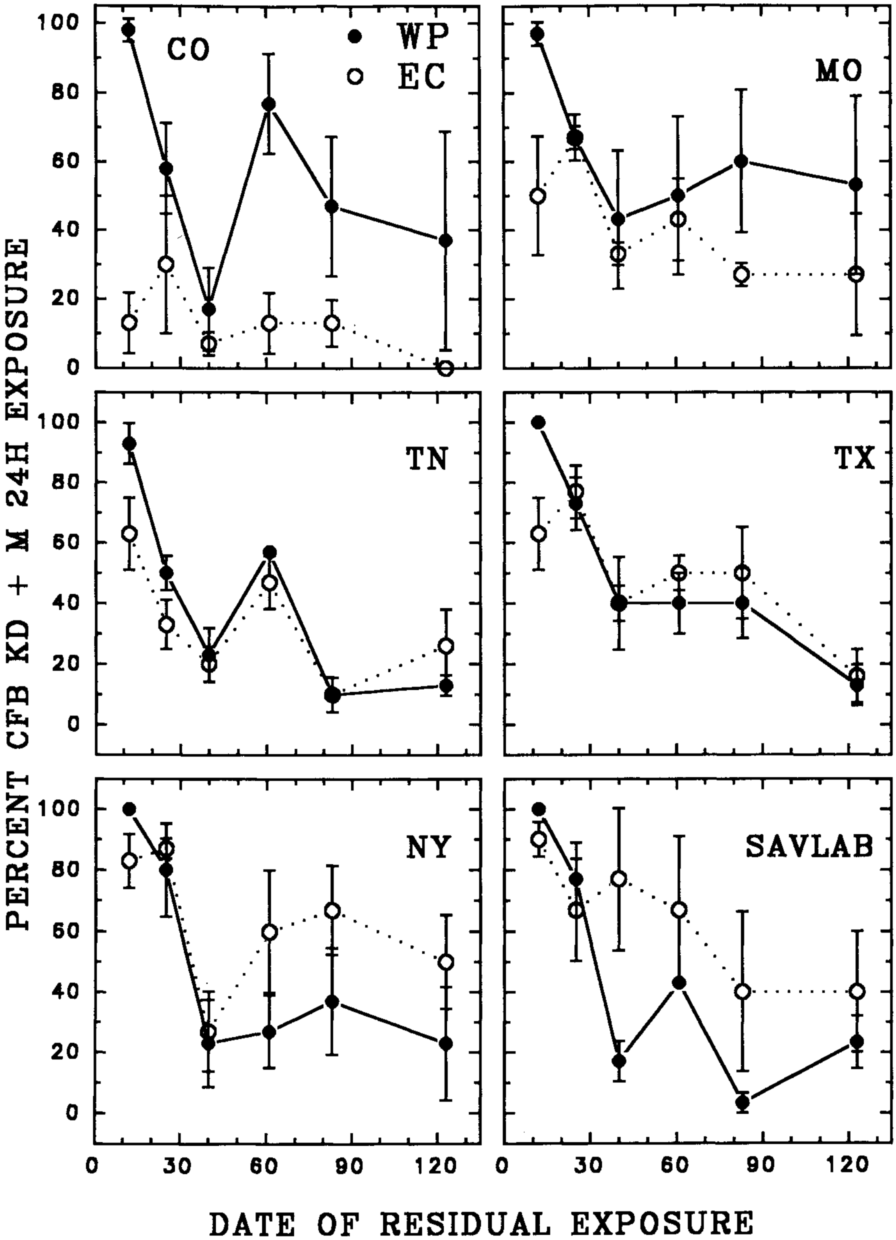

Fig. 4. Mean percentage (± SEM) knockdown + mortality (KD + M) for 5 confused flour beetle (CFB) field strains and 1 pesticide-susceptible laboratory strain after 24 h exposure on painted steel panels treated with either cyfluthrin EC or cyfluthrin WP. Trials conducted at selected intervals after treatment.

The standard grey enamel paint used on Naval ships greatly decreases the residual efficacy of cyfluthrin formulations applied to galvanized steel surfaces. Residues from both the EC and WP formulations were effective for only two weeks, even though both were applied at maximum label rates. When the formulations were applied, the bulk of the insecticide residues may have become embedded in the paint layer. In addition, the enamel paint could have affected residue degradation, because mortality quickly declined after the first few weeks of the test. Jain and Yadav (1989) found reduced residual efficacy of deltamethrin, etrimphos, and malathion on painted plywood, as compared to unpainted plywood, which could be an indication that paint has a similar effect on porous and non-porous surfaces.

In contrast, residues from either the cyfluthrin EC or WP on unpainted steel gave 100% kill eight months after insecticide application. Nearly all test insects died within 1 h exposure to the residues, indicating that cyfluthrin can offer long-term residual control in some storage situations. Either the cyfluthrin EC or WP formulation would be suitable for control programs on Navy ships, if the steel decks in food storage areas are not painted.

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