Efficacy of Cyfluthrin, Cyfluthrin + Piperonyl Butoxide, and Cyfluthrin + Piperonyl Butoxide + Chlorpyrifos-Methyl as Protectants of Stored Peanuts[1]

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ABSTRACT

Inshell peanuts were treated with 0.5, 1.0, 2.0, and 4.0 ppm cyfluthrin, each rate of cyfluthrin + 8.0 ppm piperonyl butoxide, and each rate of cyfluthrin + piperonyl butoxide + 25 ppm chlorpyrifos-methyl. After 10 months red flour beetle, *Tribolium castaneum* (Herbst), populations in peanuts treated with 0.5 and 1.0 ppm cyfluthrin averaged 89.5 and 34.2 adults per 12.7 kg peanuts; populations in peanuts treated with 1.0 and 1.5 ppm cyfluthrin + piperonyl butoxide averaged 72.0 amd 41.5 adults per 12.7 kg peanuts. Populations in the remaining 8 treatments ranged from 0.5 to 7.2 adults. Indianmeal moth, *Plodia interpunctella* (Hübner), and almond moth, *Cadra cautella* (Walker), populations remained low in all treatments. At 10 months the percentage of insect-damaged kernels from cracked pods ranged from 8.7 to 28.8% in the cyfluthrin and cyfluthrin + piperonyl butoxide treatments, while the percentage of damaged kernels was 4.4 to 6.1% in the 4 treatments with chlorpyrifos-methyl.

Key Words: *Arachis hypogaea*, cyfluthrin, Tempo, piperonyl butoxide, chlorpyrifos-methyl, insects.

For many years the organophosphate insecticide malathion was used to protect inshell peanuts from insect damage during storage. Surveys have shown malathion resistance in the primary insect pests of stored peanuts, the Indianmeal moth, *Plodia interpunctella* (Hübner); the almond moth, *Cadra cautella* (Walker); and the red flour beetle, *Tribolium castaneum* (Herbst), has risen to levels where malathion may not control local populations (10, 12). In addition, stored peanuts are among the uses that will be deleted when malathion is re-registered with the Environmental Protection Agency (1). The peanut industry has concerns regarding the use of existing stocks and the acceptance of malathion residues in processed peanuts before regulatory decisions have been finalized. There are no viable alternative protectants registered for stored peanuts. Previous research studies established the efficacy of two organophosphates, pirimiphos-methyl (8, 15, 16) and chlorpyrifos-methyl (9) as potential replacements for malathion. Both insecticides are labeled for other stored commodities but neither has been registered for peanuts. *Bacillus thuringiensus* (Dipel®) is labeled as a surface treatment but is rarely used by the peanut storage industry. Dichlorvos aerosol applications and phosphine fumigation are the usual chemical treatments, and pest populations are also developing resistance to these insecticides (10, 19).

The pyrethroid insecticide cyfluthrin (Tempo®) is labeled as a residual treatment in empty storage structures, including those used for raw agricultural commodities and oilseed crops. Low application rates provide excellent residual control of malathion-resistant red flour beetles (7). The objectives of this study were to: 1) evaluate several application rates of cyfluthrin, applied alone or in combination with piperonyl butoxide synergist, and 2) determine the efficacy of combinations of cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl.

Materials and Methods

Twelve insecticide treatments, 0.5, 1.0, 2.0, and 4.0 ppm cyfluthrin, each rate + 8.0 ppm piperonyl butoxide, and each rate + piperonyl butoxide + 25 ppm chlorpyrifos-methyl along with an untreated control were evaluated at the USDA Stored-Product Insects Research and Development Laboratory, Savannah, GA. Segregation 1 runner variety peanuts held at approximately 4C were removed from storage and allowed to warm to ambient temperature inside a warehouse for 3 days before they were treated with insecticide. Cyfluthrin EC (240 mg[AI]/mL), piperonyl butoxide synergist (960 mg[AI]/mL), and chlorpyrifos-methyl EC (480 mg[AI]/mL) provided by Gustafson, Inc. (Plano, Tex.) were used to prepare individual concentration rates of 19.0 mL formulated spray applied per 12.7 kg (28 lbs, or 1 bushel) of peanuts. An insecticide delivery system equipped with a Teejet nozzle #650033 (Spraying Systems, Wheaton, IL.) was used to spray individual replicates with the treatment spray solutions as the peanuts fell from a conveying chute into a 0.03 m^3 (1 ft^3) cardboard box. Each insecticide treatment and the untreated control (sprayed with 19 mL distilled water) was replicated 4 times. Applications were made on 21 and 22 October 1991.

After treatment, peanuts were transported to an insulated metal shed, arranged randomly, and stored under ambient conditions for 10 months. One hundred eggs each of the Indianmeal moth and almond moth, and 50 1-2 wk old adults of the red flour beetle were then introduced into each box. Individual boxes were sampled on 31 December (approximately 2 months) by placing a StoreGard WB probe II plastic pitfall trap (Trécé Co., Salinas, Cal.) and a 30.5 by 2.5 cm strip of corrugated cardboard which was rolled and taped to provide pupation sites for moths. After 1 week, live insects were counted and returned to the box from which they were removed, and each insect species was re-introduced into the boxes as described above. The sampling process was repeated on 22 Febuary (4 months), 24 April (6 months) 25 June (8 months), and 24 August (10 months), and insects were always re-introduced after sampling was completed. After the final sample, a 500 g surface sample was taken by removing the top 7.26 cm layer from each box. A 500 g sample was taken from the remainder of the box. One hundred cracked-pod kernels from each sample (surface, whole box) and all loose-shell kernels (LSK) in each of the respective samples were examined for insect damage.

Data were analyzed using the General Linear Model (GLM) Procedure of the Statistical Analysis System (18) to obtain treatment means for the individual species at each of the sample months and to obtain treatment means for damaged kernels from the surface and whole-box samples taken at 10 months. Orthogonal contrasts (also GLM) were used to determine differences in insect numbers and damaged kernels between untreated controls vs the 12 chemical treatments. The GLM Procedure was also used to estimate insect numbers and damaged kernels with increasing rates of cyfluthrin within each of the three treatment groups (cyfluthrin, cyfluthrin + PBO, and cyfluthrin + PBO + chlorpyrifos-methyl).

Results

A total of 2,368 red flour beetles were captured in the untreated controls and 12 chemical treatments, and of that total 2,321 were caught in the pitfall traps and 47 were captured in the cardboard pupation traps set out for the moths. These numbers were combined within each treatment and sample date into one value per replicate (12.7 kg peanuts) to obtain treatment averages (Table 1). At 6 months, the number of red flour beetles in each of the 12 chemical treatments averaged less than 1 per 12.7 kg of peanuts, except for the 0.5 ppm cyfluthrin treatment,

[1]Mention of a proprietary product does not constitute a recommendation or endorsement by the U.S. Department of Agriculture.

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which averaged 1.7 ± 1.1. By 8 months the number of beetles increased to 17.7 ± 2.0 and 5.2 ± 1.6 in peanuts treated with 0.5 and 1.0 ppm cyfluthrin, and to 8.0 ± 2.3 and 5.0 ± 1.5 in peanuts treated with 0.5 and 1.0 ppm cyfluthrin + piperonyl butoxide. Populations remained below 1 per 12.7 kg in the remaining 8 treatments. At the conclusion of the test (10 months), red flour beetle populations in peanuts treated with the two lowest rates of cyfluthrin applied alone or with piperonyl butoxide ranged from 34.2 ± 1.5 to 89.5 ± 9.8 per 12.7 kg. The average number of beetles per 12.7 kg was below 5 for all remaining treatments except 2.0 ppm cyfluthrin and 1.0 ppm cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl.

Because there were no beetles in the chemical treatments at months 2 and 4, and few at month 6, orthogonal contrasts were performed only on the 8 and 10-month data. Average numbers were significantly different in controls vs treatments at 8 months (F=191.2, df=1,39, p=0.0001) and 10 months (F=153.3, df=1,39, p=0.0001). There were no significant differences in beetle populations between cyfluthrin vs cyfluthrin + piperonyl butoxide at 8 months (F=0.39, df=1,39, p=0.5363) or 10 months (F=0.11, df=1,39, p=0.7372). Beetle populations in cyfluthrin + piperonyl butoxide vs cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl were not significantly different at 8 months (F=1.86, df=1,39, p=0.1804), but were significantly different at 10 months (F=12.70, df=1,39, p=0.0010).

The effect of increasing concentrations of cyfluthrin on beetle populations after 8 and 10 months of storage were analyzed by regressing concentration on average number of beetles per 12.7 kg, for cyfluthrin, cyfluthrin + piperonyl butoxide, and cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl (Fig. 1). Regressions for both sample months were significant for all three groups (p<0.05, y=0 at 8 months for cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl). Predicted values for chlorpyrifos-methyl + piperonyl butoxide + chlorpyrifos-methyl indicate the increase in efficacy resulting from the addition of chlorpyrifos-methyl when the concentration of cyfluthrin is less than 2 ppm. A total of 60 Indianmeal moths (larvae, pupae, and adults) were captured in all treatments; 57 were caught in the cardboard traps and only 3 were caught in the pitfall traps. Indianmeal moth populations did not develop in untreated controls after red flour beetles became established (Table 2). Average numbers in peanuts treated with cyfluthrin or cyfluthrin + piperonyl butoxide remained low throughout the storage period, while only 1 live moth was detected in the 4 ppm cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl treatments (Table 2).

A total of 54 almond moths were collected during the test, all in the cardboard pupation traps. No almond moths were found in untreated controls or peanuts treated with cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl (Table 2). Numbers were low in all other treatments; the maximum levels were 2.2 ± 1.3, 2.0 ± 1.1, and 2.0 ± 0.0, in 1.0 ppm cylfluthrin, 2.0 cyfluthrin, and 4.0 ppm cyfluthrin + piperonyl butoxide, respectively, at 10 months. Because there were few moths in the untreated controls or the chemical treatments, no orthogonal contrasts were performed.

The percentage of insect damaged kernels was lowest in peanuts treated with cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl, and within each cyfluthrin grouping the percentage of insect damaged kernels decreased as the concentration of cyfluthrin increased (Table 3). Contrasts between untreated controls vs treatments were significant for surface samples (F=533.17, df=1,39, P=0.0001) and whole-box samples (F=1039.77, df=1,39, P=0.0001). Contrasts between cyfluthrin vs cyfluthrin + piperonyl butoxide were not significant for surface samples (F=3.95, df=1,39, P=0.0540) but were significant for whole-box samples (F=19.38, df=1,39. P=0.0001). Contrasts between cyfluthrin + piperonyl butoxide vs cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl were significant for surface samples (F=385.77, df=1,39, P=0.0001) and whole-box

Table 1. Average number (± SEM) of red flour beetles per 12.7 kg (28 lbs, 1 bushel) of runner variety peanuts treated with 4 rates of cyfluthrin (CYF), CYF + 8.0 ppm piperonyl butoxide (PBO), or CYF + 8.0 ppm PBO + 25.0 ppm chlorpyrifos=methyl (CM).

Treatment	Months After Treatment 6	8	10
Untreated Controls[a]	8.5 ± 3.2	90.7 ± 21.6	177.0 ± 32.2
0.5 ppm CYF[b]	1.7 ± 1.1	17.7 ± 2.0	89.5 ± 9.8
1.0 ppm CYF	0.2 ± 0.2	5.2 ± 1.6	34.2 ± 1.5
2.0 ppm CYF	0.0 ± 0.0	0.7 ± 0.5	7.2 ± 2.2
4.0 ppm CYF	0.5 ± 0.3	0.0 ± 0.0	1.2 ± 0.2
0.5 ppm CYF + PBO	0.7 ± 0.2	8.0 ± 2.3	72.0 ± 21.3
1.0 ppm CYF + PBO	0.0 ± 0.0	5.0 ± 1.5	41.5 ± 16.7
2.0 ppm CYF + PBO	0.0 ± 0.0	0.0 ± 0.0	3.2 ± 1.0
4.0 ppm CYF + PBO	0.0 ± 0.0	0.0 ± 0.0	4.0 ± 0.4
0.5 ppm CYF + PBO + CM	0.0 ± 0.0	0.0 ± 0.0	5.2 ± 0.9
1.0 ppm CYF + PBO + CM	0.0 ± 0.0	0.2 ± 0.0	2.2 ± 0.9
2.0 ppm CYF + PBO + CM	0.0 ± 0.0	0.0 ± 0.0	3.0 ± 1.1
4.0 ppm CYF + PBO + CM	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.5

[a] Average for untreated controls at 2 and 4 months were 3.5 ± 2.5 and 6.7 ± 1.5, respectively.
[b] All treatment averages for months 2 and 4 were 0 except 0.2 ± 0.2 in 2.0 ppm CYF + PBO + CM and 4.0 ppm CYF + PBO + CM at 4 months.

samples (F=803.69, df=1,39, P=0.0001). Regressions for percent damaged kernels on increasing concentrations of cyfluthrin were significant and fit the data for cyfluthrin and cyfluthrin + piperonyl butoxide. Regressions gave a comparatively poorer fit to data for cyfluthrin + piperonyl butoxide + chlorpyrifos-methyl (Fig. 2).

Discussion

Although red flour beetle populations increased in untreated controls during the storage period, Indianmeal moth and almond moths did not become established in the controls. The red flour beetle can prey on moth eggs and larvae (13, 14), and probably inhibited moth population development in this test. Earlier research studies with peanuts have also documented declining moth populations as populations of the red flour beetle increased during the storage period (4, 5, 8, 9). However, in these same tests the percentages of insect-damaged kernels also increased during storage, and much of the damage was caused by moth larvae tunneling through the nuts. Most of the insect-damaged

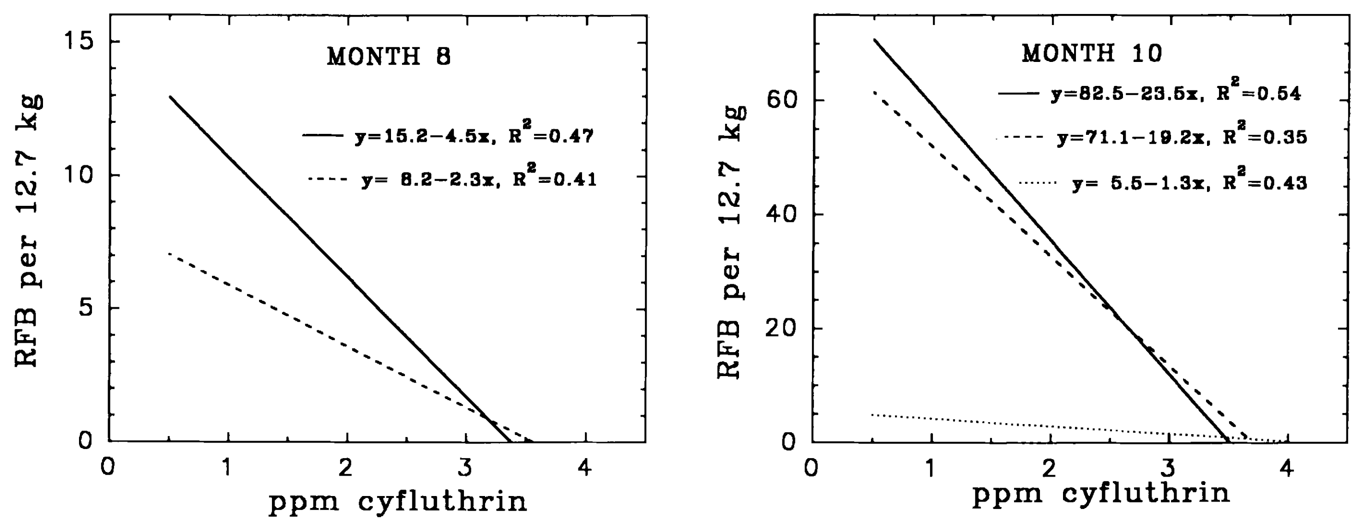

Fig. 1. Linear regression of the number of red flour beetles (RFB) per 12.7 kg peanuts at 8 and 10 months as the rate of cyfluthrin is increased from 0.5 - 4.0 ppm. — = cyfluthrin alone, --- = cyfluthrin + 8.0 ppm piperonyl butoxide, ... = cyfluthrin + piperonyl butoxide + 6.0 ppm chlorpyrifos-methyl.

Table 2. Average number (± SEM) of Indianmeal moths[a] and almond moths[b] per 12.7 kg (28 lbs, 1 bushel) of runner variety peanuts treated with 4 rates of cyfluthrin (CYF), CYF + 8.0 ppm piperonyl butoxide (PBO), or CYF + 8.0 ppm PBO + 25.0 ppm chlorpyrifos-methyl (CM).

Treatment	Months After Treatment			
	8		10	
	Indianmeal moth[c]	Almond moth[d]	Indianmeal moth	Almond moth
Untreated Controls	1.0 ± 0.06	0.0 ± 0.0	0.7 ± 0.5	0.0 ± 0.0
0.5 ppm CYF	0.7 ± 0.7	1.0 ± 0.6	3.5 ± 1.7	2.2 ± 1.3
1.0 ppm CYF	0.7 ± 0.5	1.2 ± 0.6	1.2 ± 0.5	1.5 ± 0.6
2.0 ppm CYF	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.4	2.0 ± 1.1
4.0 ppm CYF	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2
0.5 ppm CYF + PBO	0.0 ± 0.0	0.5 ± 0.5	2.2 ± 0.9	1.2 ± 0.5
1.0 ppm CYF + PBO	0.5 ± 0.5	0.0 ± 0.0	1.0 ± 0.0	0.7 ± 0.7
2.0 ppm CYF + PBO	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.5 ± 0.3
4.0 ppm CYF + PBO	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 0.0
0.5 ppm CYF + PBO + CM	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.2	0.0 ± 0.0
1.0 ppm CYF + PBO + CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
2.0 ppm CYF + PBO + CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
4.0 ppm CYF + PBO + CM	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

[a] Average number of Indianmeal moths in untreated controls at month 2 was 1.0 ± 0.0 and 0.0 for months 4 and 6.
[b] Average number of almond moths in untreated controls was 0 for months 2, 4 and 6.
[c] All values for Indianmeal moths at sample months 2, 4, and 6 were 0 except for 0.2 ± 0.2 in 2.0 ppm CYF, 2.0 ppm CYF + PBO + CM and 4.0 ppm CYF + PBO + CM at 2 months and 0.2 ± 0.2 in 4.0 ppm CYF + PBO + CM at 4 months.
[d] All values for almond moths at sample months 2, 4, and 6 were 0 except for 0.2 ± 0.2 in 2.0 ppm CYF and 4.0 ppm CYF + PBO at 2 months.

kernels in this test contained tunnels and cuts typically caused by the Indianmeal moth and almond moth.

Nearly all of the published research with pyrethroid-synergist combinations have been conducted on grain crops bioassayed with a variety of stored product insect species. In this test the addition of piperonyl butoxide synergist did not increase cyfluthrin residual efficacy on peanuts, as measured by population estimates, and gave conflicting results regarding the percentages of insect-damaged kernels. This contrasts with published research with cyfluthrin and other pyrethroids. Field trials in Australia with 2 ppm cyfluthrin + 10 ppm piperonyl butoxide were effective for 2 of 3 field strains of rice weevils, *Sitophilus oryzae* (L.) (11). Samson and Parker (17) showed deltamethrin applied at 1 ppm + 8 ppm piperonyl butoxide was much more toxic than 1 ppm deltamethrin alone on corn bioassayed with the maize weevil, *Sitophilus zeamais* (Motschulsky), and the rice weevil. Ardley (2) and Ardley and Desmarchelier (3) reported that 4 ppm bioresmethrin + 16 ppm piperonyl butoxide applied to wheat gave 100% control of rice weevils for 12 months, whereas Arthur (6) reported that applications of 2 and 5 ppm unsynergised bioresmethrin on wheat gave only 61 and 49% mortality, respectively, after 2 months in storage. The inclusion of 25 ppm chlorpyrifos-methyl with all 4 rates of cyfluthrin gave virtually complete control for 10 months, which was expected because 25 ppm chlorpyrifos-methyl alone resulted in excellent residual control on peanuts (9).

Peanuts are loaded into storage during October and November, and are rarely stored past May of the following year. All 12 chemical treatments were effective for 6 months, which is a typical storage period for most peanuts stored in the Southeastern United States. However, local conditions may affect residual control so that the 8 and 10 month counts are more indicative of what could be expected under field conditions. The 4.0 ppm rate for cyfluthrin may be necessary to protect peanuts stored in the Southeast, and there is no apparent advantage of including piperonyl butoxide as a synergist.

Table 3. Average percentage of insect-damaged kernels from all LSK and 100 cracked-pod kernels from 500 g samples taken from the top 7.26 cm of each replicate peanut box (surface) and a 500 g sample from the remainder of the box (whole box) after 10 months of storage.

Treatment	Surface sample	Whole-box sample
Untreated	49.7 ± 1.1	41.1 ± 0.9
0.5 ppm CYF	32.4 ± 1.3	25.2 ± 0.8
1.0 ppm CYF	27.5 ± 0.3	27.5 ± 0.4
2.0 ppm CYF	22.8 ± 2.3	18.3 ± 1.0
4.0 ppm CYF	18.1 ± 0.7	12.6 ± 0.5
0.5 ppm CYF + PBO	35.2 ± 2.0	28.8 ± 0.8
1.0 ppm CYF + PBO	25.4 ± 1.6	21.7 ± 1.7
2.0 ppm CYF + PBO	20.0 ± 0.9	14.8 ± 0.3
4.0 ppm CYF + PBO	13.0 ± 1.5	8.7 ± 0.5
0.5 ppm CYF + PBO + CM	8.2 ± 1.1	6.1 ± 0.7
1.0 ppm CYF + PBO + CM	7.7 ± 0.7	5.9 ± 0.5
2.0 ppm CYF + PBO + CM	6.9 ± 0.9	4.6 ± 0.5
4.0 ppm CYF + PBO + CM	6.2 ± 0.8	4.4 ± 0.4

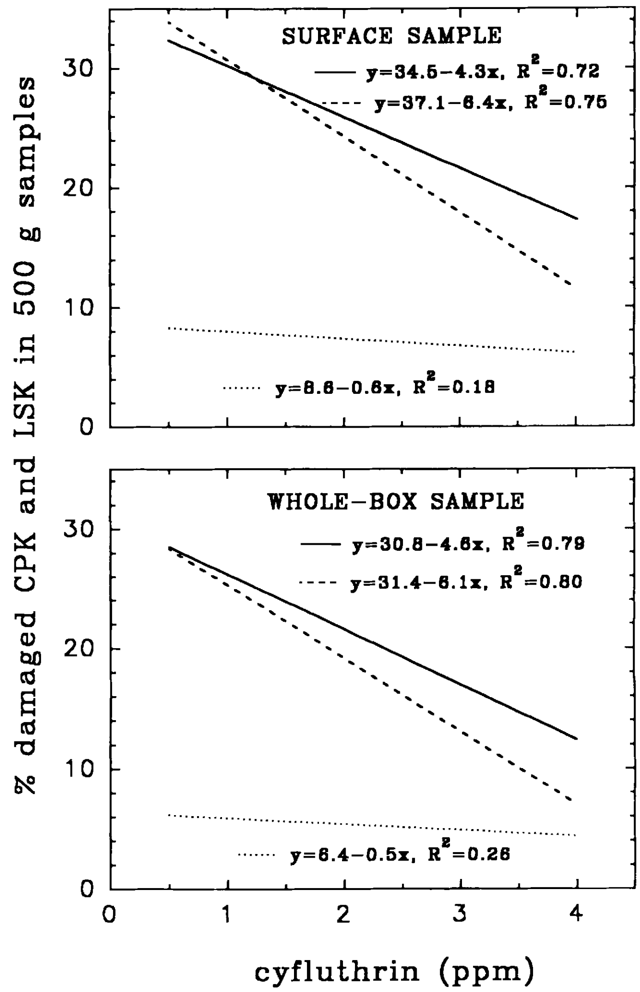

Fig. 2. Linear regression of the percentage of insect-damaged cracked pod kernels (CPK) and loose-shell kernels in 500 g samples taken after 10 months, as the rate of cyfluthrin increased from 0.5 - 4.0 ppm. — = cyfluthrin alone, --- = cyfluthrin + 8.0 ppm piperonyl butoxide, ... = cyfluthrin + piperonyl butoxide + 6.0 ppm chlorpyrifos-methyl.

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