Effectiveness of pyrethroids as protectants of raw agricultural commodities stored in southeast Georgia, USA

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Abstract

This paper summarises recent research studies at the USDA Stored-Product Insects Research and Development Laboratory, Savannah, Georgia, USA, in which the pyrethroids tralomethrin, resmethrin, bioresmethrin, deltamethrin, and cyfluthrin were evaluated as protectants of raw agricultural commodities. All insecticides and application rates were effective against the lesser grain borer, *Rhyzopertha dominica*, but in most instances these same rates did not control the rice weevil, *Sitophilus oryzae*. When these pyrethroids were applied on maize, residues from the highest application rates were effective against the maize weevil, *Sitophilus zeamais*. All insecticides and application rates on maize controlled the red flour beetle *Tribolium castaneum*. Cyfluthrin was shown to be an effective protectant for stored peanuts.

Introduction

The organophosphate insecticide malathion was registered in 1958 as a protectant of stored grains and oilseed crops, and for many years was used extensively to control insect pests. It was applied as a routine treatment when grains were loaded into storages. Many insect pest species, including the stored-product insects, eventually developed resistance to malathion. Currently malathion resistance is a worldwide problem, and this insecticide has been replaced by other insecticides. Malathion will not be reregistered as a protectant for grains stored in the United States (Abramson 1991).

The most important stored commodities in the southeastern United States are wheat, corn, and peanuts. Currently the organophosphates chlorpyrifos-methyl and pirimiphos-methyl are the only conventional insecticides labelled as protectants for stored grains. Chlorpyrifos-methyl is labelled for barley, oats, rice, sorghum, and wheat; pirimiphos-methyl is labelled for corn and sorghum only. Once malathion is removed from the market there will be no protectant registered for stored peanuts. Insect pests in peanut warehouses are controlled primarily by application of dichlorvos aerosol and fumigation with phosphine.

Pyrethroid insecticides in many stored-product systems outside the United States have complemented or replaced older organophosphorous insecticides. Unlike organophosphate degradation, pyrethroid degradation is not affected by temperature and commodity moisture. Therefore, effective application rates are usually lower than rates required for control with organophosphates. Also, pyrethroids are more expensive than organophosphates, and low application rates are often required for economic reasons. Pyrethroids are often combined with piperonyl butoxide synergist to increase insecticidal efficacy. However, reregistration procedures initiated by the Environmental Protection Agency may eventually limit the use of piperonyl butoxide synergist in the United States.

Although no pyrethroids are currently labelled in the United States as grain protectants, developmental research in this area has been conducted at the USDA Stored-Product Insects Research and Development Laboratory in Savannah, Georgia. This paper summarises these studies and discusses potential uses for pyrethroids as protectants for stored raw commodities in the warm humid Gulf Coast and lower Atlantic regions of the southeastern United States.

Protectant Trials with Wheat

Most wheat grown in the southeastern United States is soft red winter wheat which is usually harvested from mid-May to late June. There are several large commercial storages in Georgia, but extended on-farm storage through the summer and fall is rare. Chlorpyrifos-methyl breaks down rapidly at storage temperatures of 30 and 35°C (Arthur et al. 1991, 1992), and the summer temperature in the southeast is conducive to the rapid growth of insect pest populations. In addition, one of the major pests of stored wheat, the lesser grain borer, *Rhyzopertha dominica* (F.), has developed resistance to chlorpyrifos-methyl (Zettler and Cuperus 1990). This species is no longer listed on the chlorpyrifos-methyl label.

Tralomethrin was one of the first pyrethroids tested at the Savannah Laboratory. Wheat treated with 0.75 ppm tralomethrin + 3.75 ppm piperonyl butoxide and 2.00 ppm unsynergised tralomethrin was artificially infested with red flour beetle, *Tribolium castaneum* (Herbst), lesser grain borer, sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), Indianmeal moth, *Plodia interpunctella* (Hübner), and almond moth, *Cadra cautella* (Walker), at selected post-treatment intervals (Halliday et al. 1992) Few insects were detected in the treated wheat until 11 months post-treatment. Small bins containing the wheat were held inside an enclosed warehouse, which moderated adverse environmental effects. The rice weevil, *Sitophilus oryzae* (L.), a major pest of stored wheat in the United States, was not included in this particular study. Resmethrin and bioresmethrin synergised with piperonyl butoxide have been tested in Australia as protectants of wheat (Ardley 1976; Ardley and Desmarchelier 1978). Arthur (1992) conducted bioassays with wheat treated with 2 and 5 ppm unsynergized resmethrin and 2 and 5 ppm unsynergized bioresmethrin. Residues from both application rates of both pyrethroids killed all introduced lesser grain borers for 10 months. However, neither pyrethroid controlled the rice weevil, as indicated by the survival and subsequent F_1 progeny values given in Table 1. The apparent tolerance of the rice weevil to bioresmethrin and resmethrin limits their potential as protectants for wheat stored in the U.S.

Arthur (1992) also evaluated application rates of 0.5, 0.75, and 1.0 ppm deltamethrin as wheat protectants. Treated wheat was stored at ambient conditions for 10 months and bio-

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Table 1. Percentage survival (x ± SEM) 5 days after 100 adult rice weevils were introduced into each of four 0.95-litre jars containing 500 g untreated wheat or wheat treated with 2 or 5 ppm resmethrin and 2 or 5 ppm bioresmethrin; number of F_1 adults + original introduction (x ± SEM) 49 days after introduction

Treatment	Months post-treatment					
	0	2	4	6	8	10
			Survival			
Untreated	99 ± 0.2	97 ± 1.1	97 ± 1.2	95 ± 1.2	93 ± 0.6	89 ± 1.3
2 ppm resmethrin	0 ± 0.0	36 ± 8.2	43 ± 17.4	96 ± 0.8	93 ± 2.1	98 ± 1.0
5 ppm resmethrin	0 ± 0.0	34 ± 10.8	70 ± 6.0	95 ± 1.7	87 ± 1.4	88 ± 8.3
2 ppm bioresmethrin	34 ± 4.6	90 ± 2.3	92 ± 2.0	93 ± 2.2	94 ± 1.3	98 ± 0.6
5 ppm bioresmethrin	1 ± 0.5	50 ± 4.4	81 ± 4.6	77 ± 5.3	95 ± 1.9	98 ± 0.5
			F_1 Progeny (+ original introduction)			
Untreated	3291 ± 209.1	4171 ± 363.8	3997 ± 152.0	2580 ± 300.0	3996 ± 162.7	2728 ± 167.9
2 ppm bioresmethrin	1 ± 1.3	549 ± 201.6	923 ± 323.1	1155 ± 503.4	3354 ± 181.6	2263 ± 228.5
5 ppm resmethrin	0 ± 0.0	587 ± 173.3	994 ± 57.9	1200 ± 293.9	2380 ± 284.4	1891 ± 355.7
2 ppm bioresmethrin	505 ± 87.7	2635 ± 130.2	2662 ± 195.5	2940 ± 77.4	3231 ± 391.6	3038 ± 274.9
5 ppm bioresmethrin	80 ± 80.0	887 ± 89.1	1598 ± 149.2	1920 ± 129.6	2484 ± 134.1	2883 ± 372.3

assayed every two months with lesser grain borer and rice weevil. Lesser grain borer survival after initial exposure was variable throughout the test (Table 2). However, no progeny were produced and the wheat was not damaged, indicating that introduced lesser grain borers eventually died from exposure to the deltamethrin residues. Rice weevil survival and subsequent progeny production decreased with the increasing application rates of deltamethrin (Table 3).

The pyrethroid cyfluthrin is labelled as a pre-bin spray, and evaluations have been conducted using cyfluthrin as a protectant (Arthur, unpublished data). Wheat treated with 0.5, 1.0, 1.5, and 2.0 ppm was stored for 10 months and bioassayed every two months. Results were similar to those obtained for deltamethrin. Lesser grain borers did survive 5-day exposure (Table 4), but no progeny were produced and the wheat was undamaged. Rice weevil survival on wheat treated with 0.5 ppm exceeded 50% at 2 months and gradually increased to 94.5% survival at 10 months (Table 5). Survival decreased as the application rates increased. The survivors at the low concentrations produced a considerable number of F_1 progeny (Table 5).

Protectant Trials with Corn

Corn is usually harvested in late August-early September in the Georgia Coastal Plain, and is often stored on farm for human and animal consumption. Daytime temperatures during September can range from 25–35°C, and binned corn is vulnerable to infestation before the onset of cooler weather. Once malathion is removed from the market, the organophosphate pirimiphos-methyl will be the only protectant labelled for corn. New pyrethroids would certainly benefit insect pest management programs in stored corn.

Several pyrethroids evaluated as wheat protectants have also been tested on corn, using the maize weevil, *Sitophilus zeamais* (Motschulsky), and the red flour beetle as the primary test insect species. Corn treated with 0.75 ppm tralomethrin + 3.75 ppm piperonyl butoxide and 2.00 ppm unsynergised tralomethrin was artificially infested with maize weevil, red flour beetle, sawtoothed grain beetle, lesser grain borer, Indianmeal moth, and almond moth at regular intervals for 15 months (Halliday et al. 1992). Few individuals of any species were collected from test bins containing treated corn. Bioassays of treated corn gave 100% control of maize weevils and 92–100% control of red flour beetles for approximately 12 months.

Arthur (1994a) showed unsynergised deltamethrin applied at 0.5, 0.75, and 1.0 ppm on corn gave excellent residual control of maize weevils and red flour beetles for 10 months (Table 6). Maize weevil survival decreased with the increasing rate of deltamethrin, and F_1 progeny did not exceed 1.5 adults in the deltamethrin treatments. Samson and Parker (1989) reported that unsynergised deltamethrin was less effective against *Sitophilus* species than the lesser grain borer; however, in my tests deltamethrin was effective against the lesser grain borer and the maize weevil. Red flour beetle survival was variable but no larval or adult F_1s were detected in the deltamethrin treatments (Table 6).

Cyfluthrin was also evaluated on corn at application rates of 0.5, 1.0, 1.5, and 2.0 ppm (Arthur 1994b). Maize weevil survival and subsequent progeny production was extensive on corn treated with 0.5 ppm, but decreased markedly at the two highest rates (Table 7). Red flour beetle survival was variable at all rates, but there was no progeny production or apparent feeding damage (Table 8).

Protectant Trials with Peanuts

Peanuts are an important crop in Georgia, Alabama, and north Florida. The normal harvest occurs in late September to mid-October, and peanuts can be held in storage until May of the following spring. Peanuts are stored in the shell, and the primary insect pests are the Indianmeal moth, the almond moth, and the red flour beetle. Malathion resistance in these three species has been extensively documented, and many warehouse managers have eliminated malathion in pest management programs. Malathion will not be re-registered as a peanut protectant, and there is a limited market for new insecticides because of the low potential insecticide sales for stored peanuts in the United States.

Cyfluthrin appears to have potential as a protectant of stored peanuts. In a recent test, peanuts were treated with 0.5, 1.0, 2.0, and 4.0 ppm cyfluthrin, stored for 10 months, and infested with Indianmeal moth eggs, almond moth eggs, and adult red flour beetles. Individual treatments were subsequently sampled and reinfested at bimonthly intervals. Beetle populations remained low until the 8- and 10-month samples, while few Indianmeal moths and almond moths were ever detected in untreated peanuts or peanuts treated with cyfluthrin (Table 9). Predation

Table 2. Percentage survival (x ± SEM) 5 days after 100 adult lesser grain borers were introduced into each of four 0.95-litre jars containing 320 g untreated wheat or wheat treated with 0.5, 0.75, and 1.0 deltamethrin; no F_1 adults 49 days after introduction

Treatment	Months post-treatment					
	0	2	4	6	8	10
Untreated	92 ± 2.4	88 ± 1.7	92 ± 1.2	92 ± 3.3	86 ± 2.0	94 ± 2.1
0.5 ppm deltamethrin	30 ± 5.2	31 ± 2.2	17 ± 2.7	28 ± 2.8	28 ± 2.8	48 ± 6.7
0.75 ppm deltamethrin	16 ± 0.4	17 ± 1.9	15 ± 1.8	21 ± 2.1	23 ± 2.2	34 ± 3.6
1.0 ppm deltamethrin	9 ± 0.7	10 ± 0.9	14 ± 1.4	11 ± 1.1	13 ± 1.1	8 ± 0.6

Table 3. Percentage survival (x ± SEM) 5 days after 100 adult rice weevils were introduced into each of four 0.95-litre jars containing 320 g untreated wheat or wheat treated with 0.5, 0.75, or 1.0 ppm deltamethrin; F_1 adults counted 49 days after introduction

Treatment	Months post-treatment					
	0	2	4	6	8	10
			Survival			
Untreated	95 ± 1.6	93 ± 0.7	96 ± 1.3	97 ± 0.8	95 ± 2.4	92 ± 0.9
0.5 ppm deltamethrin	22 ± 9.3	55 ± 6.2	57 ± 4.7	59 ± 9.1	77 ± 6.2	85 ± 3.2
0.75 ppm deltamethrin	5 ± 4.4	16 ± 9.4	21 ± 6.7	17 ± 3.4	19 ± 5.6	26 ± 4.5
1.0 ppm deltamethrin	1 ± 0.7	3 ± 1.3	2 ± 1.2	1 ± 0.5	2 ± 1.2	3 ± 1.5
			F_1 Adults			
Untreated	1543 ± 72.6	1240 ± 144.2	1635 ± 132.5	1662 ± 99.5	1198 ± 147.7	1498 ± 185.2
0.5 ppm deltamethrin	222 ± 93.8	515 ± 54.7	666 ± 131.4	630 ± 164.8	882 ± 111.9	1145 ± 38.9
0.75 ppm deltamethrin	5 ± 4.4	16 ± 9.4	21 ± 6.7	50 ± 17.3	44 ± 17.7	155 ± 28.2
1.0 ppm deltamethrin	1 ± 0.7	3 ± 1.3	2 ± 1.2	3 ± 3.2	2 ± 0.9	7 ± 4.8

Table 4. Percentage survival (x ± SEM) 5 days after 50 adult lesser grain borers were introduced into each of four 0.95-litre jars containing 320 g untreated wheat or wheat treated with 0.5, 1.0, 1.5, and 2.0 ppm cyfluthrin; no F_1 adults 49 days after introduction

Treatment	Months post-treatment					
	0	2	4	6	8	10
Untreated	88 ± 3.2	90 ± 1.8	90 ± 0.4	92 ± 3.6	89 ± 3.1	93 ± 2.7
0.5 ppm cyfluthrin	0 ± 0.0	23 ± 5.4	27 ± 2.6	37 ± 5.0	11 ± 2.6	34 ± 5.4
1.0 ppm cyfluthrin	0 ± 0.0	12 ± 1.4	16 ± 1.2	9 ± 2.4	8 ± 1.4	20 ± 1.8
1.5 ppm cyfluthrin	0 ± 0.0	7 ± 0.6	13 ± 1.2	7 ± 1.2	10 ± 1.8	23 ± 3.4
2.0 ppm cyfluthrin	0 ± 0.0	2 ± 0.4	12 ± 2.6	2 ± 0.8	4 ± 0.8	7 ± 2.0

Table 5. Percentage survival (x ± SEM) 5 days after 50 adult rice weevils were introduced into each of four 0.95-litre jars containing 320 g untreated wheat or wheat treated with 0.5, 1.0, 1.5, and 2.0 ppm cyfluthrin; F_1 adults counted 49 days after introduction

Treatment	Months post-treatment					
	0	2	4	6	8	10
			Survival			
Untreated	92 ± 0.8	98 ± 1.3	93 ± 2.7	98 ± 1.6	98 ± 0.8	98 ± 0.9
0.5 ppm cyfluthrin	13 ± 12.3	60 ± 11.4	66 ± 9.2	78 ± 10.8	80 ± 8.8	95 ± 1.7
1.0 ppm cyfluthrin	1 ± 1.0	3 ± 1.7	4 ± 3.2	11 ± 4.4	35 ± 11.9	44 ± 11.9
1.5 ppm cyfluthrin	0 ± 0.0	3 ± 1.5	3 ± 0.5	8 ± 2.8	38 ± 14.9	20 ± 2.2
2.0 ppm cyfluthrin	0 ± 0.0	3 ± 2.7	2 ± 1.5	1 ± 0.5	13 ± 11.7	8 ± 7.3
			F_1 Adults			
Untreated	1413 ± 162.4	833 ± 53.9	958 ± 189.3	1401 ± 96.8	851 ± 77.8	825 ± 161.8
0.5 ppm cyfluthrin	120 ± 118.1	383 ± 71.8	357 ± 60.1	701 ± 115.4	760 ± 191.1	896 ± 71.8
1.0 ppm cyfluthrin	5 ± 2.9	49 ± 44.5	18 ± 16.1	40 ± 27.2	233 ± 125.8	398 ± 147.2
1.5 ppm cyfluthrin	0 ± 0.0	15 ± 2.6	4 ± 10.2	54 ± 19.6	203 ± 110.4	81 ± 36.4
2.0 ppm cyfluthrin	0 ± 0.0	15 ± 14.5	10 ± 0.3	2 ± 2.0	18 ± 17.3	15 ± 12.0

Table 6. Percentage survival (x ± SEM) 5 days after 50 adult maize weevils and 100 red flour beetles were introduced into each of four separate 0.95-litre jars containing untreated corn and corn treated with 0.5, 0.75, or 1.0 ppm deltamethrin; F_1 adult maize weevils 49 days after introduction did not exceed 1.5, no red flour beetle F_1 adults or larvae.

Treatment	Months post-treatment					
	0	2	4	6	8	10
			Maize weevils			
Untreated	94 ± 1.2	93 ± 1.3	96 ± 0.5	95 ± 1.3	95 ± 1.5	92 ±1.1
0.5 ppm deltamethrin	3 ± 1.0	6 ± 1.2	24 ± 2.8	11 ± 3.0	13 ± 3.7	17 ± 3.6
0.75 ppm deltamethrin	2 ± 0.5	1 ± 1.0	17 ± 3.7	6 ± 1.1	8 ± 2.8	9 ± 1.9
1.0 ppm deltamethrin	1 ± 0.6	1 ± 0.5	4 ± 0.8	1 ± 0.6	0 ± 0.0	1 ± 0.6
			Red flour beetles			
Untreated	99 ± 0.4	99 ± 0.2	99 ± 0.4	99 ± 0.3	99 ± 0.5	99 ± 0.3
0.5 ppm deltamethrin	9 ± 2.8	12 ± 3.2	15 ± 2.6	14 ± 5.6	6 ± 1.3	19 ± 4.1
0.75 ppm deltamethrin	5 ± 0.2	12 ± 1.4	16 ± 1.0	13 ± 2.3	3 ± 0.9	4 ± 0.5
1.0 ppm deltamethrin	8 ± 1.4	7 ± 1.4	9 ± 0.5	6 ± 0.8	2 ± 0.4	1 ± 0.6

Table 7. Percentage survival (x ± SEM) 5 days after 50 adult maize weevils were introduced into each of four 0.47-litre jars containing untreated corn or corn treated with 0.5, 1.0, 1.5, and 2.0 ppm cyfluthrin; F_1 adults counted 49 days after introduction.

Treatment	Months post-treatment					
	0	2	4	6	8	10
			Survival			
Untreated	88 ± 1.3	88 ± 1.5	92 ± 1.8	94 ± 1.6	97 ± 2.4	99 ± 0.5
0.5 ppm cyfluthrin	40 ± 7.6	59 ± 5.6	76 ± 4.3	89 ± 3.2	76 ± 6.4	72 ± 7.8
1.0 ppm cyfluthrin	16 ± 4.7	22 ± 3.6	29 ± 3.4	21 ± 2.6	4 ± 0.8	26 ± 5.0
1.5 ppm cyfluthrin	2 ± 0.9	4 ± 1.8	12 ± 1.7	7 ± 2.8	1 ± 0.6	2 ± 0.9
2.0 ppm cyfluthrin	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
			F_1 adults			
Untreated	260 ± 18.3	251 ± 12.5	84 ± 9.6	120 ± 12.5	172 ± 28.6	217 ± 8.3
0.5 ppm cyfluthrin	25 ± 3.9	92 ± 43.2	26 ± 11.2	55 ± 16.6	75 ± 24.3	58 ± 16.5
1.0 ppm cyfluthrin	1 ± 0.6	8 ± 6.7	2 ± 1.2	2 ± 1.6	3 ± 1.5	19 ± 4.2
1.5 ppm cyfluthrin	1 ± 0.9	0 ± 0.0	0 ± 0.0	0 ± 0.0	1 ± 0.6	2 ± 1.7
2.0 ppm cyfluthrin	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.6	0 ± 0.0

Table 8. Percentage survival (x ± SEM) 5 days after 50 adult red flour beetles were introduced into each of four 0.47-litre jars containing 320 g corn or corn treated with 0.5, 1.0, 1.5, and 2.0 ppm cyfluthrin; no F1 adults or larvae 49 days after introduction.

Treatment	Months post-treatment					
	0	2	4	6	8	10
Untreated	95 ± 0.9	99 ± 0.6	100 ± 0.5	99 ± 0.8	100 ± 0.0	99 ± 0.8
0.5 ppm cyfluthrin	24 ± 6.6	48 ± 9.6	43 ± 1.4	28 ± 1.7	31 ± 11.4	29 ± 5.2
1.0 ppm cyfluthrin	14 ± 0.9	21 ± 1.7	29 ± 1.2	8 ± 1.8	12 ± 2.8	11 ± 1.7
1.5 ppm cyfluthrin	9 ± 0.5	13 ± 2.0	21 ± 2.5	1 ± 0.6	9 ± 2.0	9 ± 2.9
2.0 ppm cyfluthrin	5 ± 0.9	7 ± 1.4	10 ± 1.4	0 ± 0.0	5 ± 1.2	3 ± 0.5

of moth eggs and early instars by red flour beetles in untreated controls could have accounted for the low moth populations. Additional research is necessary to determine the efficacy of cyfluthrin on the Indianmeal moth and the almond moth, particularly on the large wandering-phase 5th instars.

Summary

Results of these studies indicate the potential of certain pyrethroids, particularly deltamethrin and cyfluthrin, as replacements for organophosphates in pest management programs for stored commodities. However, the apparent tolerance of the rice weevil to pyrethroids may dictate application rates that will not be economical on stored wheat. One answer to this problem is a combination treatment of pyrethroids + an organophosphate, since most pyrethroids appear to be effective against the lesser grain borer. In several of the studies previously mentioned, combinations of pyrethroids + chlorpyrifos-methyl protected treated wheat from insect damage for at least 10 months.

Table 9. Average number (x ± SEM) of red flour beetles, Indianmeal moths, and almond moths per 12.7 kg of untreated peanuts and peanuts treated with 0.5, 1.0, 2.0, and 4.0 ppm cyfluthrin

Treatment	Months post-treatment		
	6	8	10
		Red flour beetles	
Untreated	9 ± 3.2	91 ± 21.6	177 ± 32.2
0.5 ppm cyfluthrin	2 ± 1.1	18 ± 2.0	90 ± 9.8
1.0 ppm cyfluthrin	0 ± 0.0	5 ± 1.6	34 ± 1.5
2.0 ppm cyfluthrin	0 ± 0.0	1 ± 0.5	7 ± 2.2
4.0 ppm cyfluthrin	1 ± 0.3	0 ± 0.0	1 ± 0.2
		Indianmeal moths	
Untreated	0 ± 0.0	1 ± 0.1	1 ± 0.5
0.5 ppm cyfluthrin	0 ± 0.0	1 ± 0.7	4 ± 1.7
1.0 ppm cyfluthrin	0 ± 0.0	1 ± 0.5	1 ± 0.5
2.0 ppm cyfluthrin	0 ± 0.0	1 ± 0.0	1 ± 0.4
4.0 ppm cyfluthrin	0 ± 0.0	0 ± 0.0	0 ± 0.0
		Almond moths	
Untreated	0 ± 0.0	0 ± 0.0	0 ± 0.0
0.5 ppm cyfluthrin	0 ± 0.0	1 ± 0.5	1 ± 0.5
1.0 ppm cyfluthrin	0 ± 0.0	0 ± 0.0	1 ± 0.7
2.0 ppm cyfluthrin	0 ± 0.0	0 ± 0.0	1 ± 0.3
4.0 ppm cyfluthrin	0 ± 0.0	0 ± 0.0	2 ± 0.0

The registration process for new insecticides requires a considerable investment in time and money. Unlike insecticides that can be sprayed repeatedly in field crops because they leave no residue, protectant insecticides are usually applied only at binning and are not recommended to control existing infestations. Potential sales of protectant insecticides in the United States may not justify registration. Also, the increasing demand of consumers in the United States for pesticide-free food products will affect future registrations for protectant chemicals.

This paper reviews the results of research only. Mention of a chemical does not constitute a recommendation or endorsement by the U.S. Department of Agriculture.

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