CONTROL OF *TRIBOLIUM CASTANEUM* AND *CRYPTOLESTES FERRUGINEUS* WITH THE INSECT GROWTH REGULATOR FENOXYCARB ON WHEAT OR STRUCTURAL SURFACES

D.G. White

Agriculture Canada Research Station, Winnipeg, Manitoba, Canada

Abstract

Five adult males and five adult females of Tribolium castaneum or Cryptolestes ferrugineus were placed in stored wheat with 0, 5, 25, 100% of the kernels treated with 8 ppm fenoxycarb and held at 30°C, 70% RH for up to 32 weeks when the grain was cleaned and 20 adults reintroduced into the grain. Fenoxycarb applied to 5% of wheat kernels reduced but did not completely prevent development of T. castaneum and C. ferrugineus. Treatment of 25% of the kernels, however, controlled these insects indicating that a treatment somewhere between 5 and 25% of the seeds at 8 ppm would be adequate; residual effectiveness was not decreased after 32 weeks of storage at 30°C. Last instar larvae of both insects were exposed for 24h to plywood, galvanized steel or concrete surfaces sprayed with 0.25 or 0.50 g/m^2 fenoxycarb. Residues of 0.25 g/m^2 were usually as effective as 0.50 g/m^2 for both species except on concrete. Residues on steel were the most effective, preventing adult development up to 32 weeks after treatment; sprayed wood did not completely prevent adult emergence whereas sprayed concrete was least effective over time indicating a breakdown of the fenoxycarb. Larval production by adult T. castaneum and C. ferrugineus in 2-cm deep layers of wheat at 25°C, 65% RH for 5 weeks above wood, steel, or concrete sprayed with 0.25 or 0.50 g/m^2 fenoxycarb was negligible for both species at both concentration on steel. T. castaneum larval numbers above wood and concrete were reduced at both concentrations while C. ferrugineus numbers were not greatly affected. Treatment of empty galvanized steel granaries at 0.25 g/m^2 is adequate for long-term control of these insects.

Introduction

Insect Growth Regulators (IGR's) are a group of insect control agents which adversely interfere with the development and growth of insects, usually by either inhibiting chitin synthesis with molt disruption or by mimicking juvenile hormones and interfering with metamorphosis (Retnakaran et al., 1985). IGR compounds show considerable promise in controlling insects because only target organisms are usually affected, mammalian toxicity is low, and these compounds are effective against malathion-resistant insects (Amos et al., 1977, Kramer et al., 1981); unfortunately, older compounds have been expensive and had insufficient persistence in the field (Staal, 1975, 1982) and insect resistance to them can develop (Dyte, 1972).

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Fenoxycarb (RO 13-5223) is a relatively new juvenile hormone analog which belongs to the phenoxy-ethyl-carbamate chemical group rather than to the previous terpenoid compounds. Fenoxycarb is persistent, has low dermal toxicity and an oral LD_{50} of 16,800 mg/kg in rats (Dorn et al., 1981). In stored products, it controls most beetles at dosages <0.1 ppm (Dorn et al., 1981) although dosages as high as 10 ppm may be required for some species (Kramer et al., 1981). Fenoxycarb also can act as a synergist for pyrethroid insecticides because of its molecular structure (Ishaaya et al., 1984) offering useful combination of chemicals for insect control.

Much research as been done on previous IGR's in stored products (Amos et al., 1974, 1982, Loschiavo, 1976, Williams and Amos, 1974, Mian and Mulla, 1982a, b, 1983) especially on hydroprene and methoprene, but these compounds are relatively ineffective on internal seed feeders such as Sitophilus oryzae (L.) and S. granarius (L.) while fenoxycarb gives good control (Edwards and Abraham, 1985, Edwards and Short, 1984, Kramer et al., 1985). Wheat seed treated with fenoxycarb at 10 ppm has residues of 25 ppm in the bran and 1 ppm in the endosperm. Such levels of residue are sufficient for control of endosperm-feeding immature insects (Kramer et al., 1985).

Minett and Williams (1971, 1976) have indicated that treatment of a small percentage of wheat kernels with relatively high concentrations of malathion gives superior long-term control of stored-product insects than an even application of the insecticide to produce a similar mean concentration throughout bulk-stored grain. The use of fenoxycarb at relatively low concentrations on only a fraction of seeds in a bulk could possibly suppress progeny production in stored-product insects with lower total residues than if all of the grain was treated.

Also, the residual effectiveness of fenoxycarb in controlling insects in sprayed, empty granaries could be useful in preventing infestations of newly harvested grain.

The aim of this study was to determine the extent of immature mortality and progeny reduction in the red flour beetle, Tribolium castaneum (Herbst) and the rusty grain beetle, Cryptolestes ferrugineus (Stephens), 1) in quantities of wheat with various proportions of kernels treated with 8 ppm fenoxycarb, 2) following exposure of larvae to treated structural surfaces, and 3) in populations developing in small quantities of wheat above treated structural surfaces.

Materials and Methods

Various Percentages of Treated Seed

Fenoxycarb (ethyl [2-(p-phenoxyphenoxy) ethyl] carbamate) as a 125 g active ingredient/liter emulsifiable concentrate (Maag Agrochemicals) was diluted to 1.25 g/liter with distilled water and 41.6 ml of solution were applied with a pipette to 6.5 kg whole wheat held in three glass jars to yield a concentration of 8 ppm. The wheat (Triticum aestivum L., cv. Neepawa) was then thoroughly mixed and allowed to stand in the sealed jars for 48 h at 2.5°C.

Two hundred, 397-ml glass jars were each partially filled with 100 g of whole wheat and 5 g of ground wheat with particles smaller than 0.84 cm. Wheat treated with fenoxycarb was mixed with untreated grain to yield four treatments where 0, 5, 25, or 100% of seeds in a jar contained 8 ppm of the chemical. All ground wheat was untreated.

Pupae of T. castaneum and C. ferrugineus were collected from laboratory cultures maintained at 30±1°C, 70±5% RH. The sex of the pupae (T. castaneum) or individually separated adults (C. ferrugineus) was determined.

Males and females were kept separate. Two days after emergence of adults five males and five females of T. castaneum were added to the grain in each of 100 jars and five males and five females of C. ferrugineus were added to the grain in another 100 jars.

There were three chemical treatments and untreated controls and on each of five sampling dates the adult and immature insects present in five replicate jars per species were counted after sieving and further removal of mobile life stages by Berlese funnel. The initial sample consisted of adult insects exposed to the treated grain for 24 h followed by removal to untreated wheat plus ground wheat for 4 weeks. Subsequent samples were of insects that had been continously exposed to the treatments for 4, 8, 16, and 32 weeks at 30±1°C, 70±5% RH. After 32 weeks, insects were removed from the final sample-set of grain that was then frozen at -15°C for 48 h. Afterwards, the grain was remoisturized to 13.2% moisture content. Initial dust and ground wheat was removed and new gound wheat added. Twenty young adults, less than 3 days old, of T. castaneum and C. ferrugineus of undetermined sex were added to the jars that had held these corresponding species for the previous 32 weeks. The jars were held at 30±1°C, 70±5% for a further 5 weeks to measure the residual effectiveness of the fenoxycarb on new adults.

The initial moisture content of the wheat was 13.4% and the final moisture content was 13.2%.

Treated Surfaces

Fenoxycarb diluted to 1.25 g active ingredient/liter in acetone was applied to fir plywood panels, galvanized steel panels, and concrete blocks using a Paasche air brush. The wood and steel panels were 35 x 35 cm and the concrete blocks were 45 x 25 x 4 cm. The wood or steel panels were treated with 3.1 or 6.2 ml of the fenoxycarb solution to give deposits of 0.25 and 0.50 g/m^2, respectively. Corresponding volumes for the concrete blocks were 2.8 and 5.6 ml. Controls were treated only with acetone.

Six wood panels, six steel panels, and six concrete blocks were treated: two of each were controls, two had 0.25 g/m^2, and two had 0.50 g/m^2 fenoxycarb. Each panel or block held 15 copper rings, 5 cm diam x 2.1 cm high, sealed at the bottom perimeter to the surface with paraffin wax.

Fourth instar larvae of T. castaneum and C. ferrugineus reared in laboratory cultures were used to assay the surfaces with a 24-h exposure

at 22±2°C at one day, 4, 8, 24, and 32 weeks after treatment. Three replicates of 20 larvae/species were placed on each panel or block; the same rings were not used twice. Following exposure, larvae were placed in plastic vials, 2.7 diam x 5.0 cm high, containing 15 g ground wheat, with particles less than 0.84 cm, plus 0.6 g wheat germ. The insects were held at 30±1°C and 70±5% RH for 4 weeks when numbers were determined by sifting the grain. The moisture content of the grain was 16.5%. On each of the five sampling dates, 540 larvae of each species were exposed to the surfaces (3 rings x 3 surfaces x 2 concentrations + controls x 20 larvae).

Adults in Wheat Above Treated Surfaces

A fenoxycarb solution in acetone was applied to 12 fir plywood and 12 galvanized steel panels (35 x 35 cm) and 12 concrete blocks (45 x 25 x 4 cm) using a Paasche air brush. Six panels or blocks of each surface material were treated with 0.25 g active ingredient/m^2 and six of each surface material received 0.50 g/m^2; a further six panels or blocks were treated with acetone only (controls). Six copper rings, 5 cm diam x 2.1 cm high, were placed on each panel or block (108 rings) and sealed at the bottom perimeter to the surface with paraffin wax. Each ring held 30 g of untreated wheat plus 0.7 g ground wheat and 0.7 g wheat germ. Twenty young adults of *T. castaneum* were placed in each of 54 rings and 20 young adults of *C. ferrugineus* were placed in the remaining 54 rings (1 species/panel, 6 rings/panel, 3 dosages, 3 surfaces). Once insects were added to the wheat the rings were covered with filter papers and sealed at the top perimter with paraffin wax. The surfaces and insects were held at 25 ± 3°C, 60±5% RH for 5 weeks when the grain was sifted and numbers of adult and immature insects counted. The moisture content of the wheat was initially 16.5%.

Data were analyzed where appropriate by analysis of variance and Duncan's new multiple range test of means.

Results and Discussion

Various percentages of Treated Seed

The exposure of five males and five females of *T. castaneum* or *C. ferrugineus* to quantities of wheat with 0, 5, 25, or 100% of the kernels treated with 8 ppm fenoxycarb resulted in fewer adult progeny as mean chemical concentrations rose (Table I). Many juvenile hormone anologs are known to block embryonic development in adult female insects and are ovicidal (Retnakaran, 1980), but the short exposure period of 24 h for the adults at the concentrations of fenoxycarb used in this study did not affect egg production or subsequent larval development in *T. castaneum* or *C. ferrugineus*.

Table I. Mean numbers (±S.E.)[1] of live *Tribolium castaneum* and *Cryptolestes ferrugineus* present in jars of wheat containing 0, 5, 25, or 100% of kernels treated with 8 ppm fenoxycarb after an initial five male and five female adults of one or the other species were added to the grain which was stored at 30±1°C, 70±5% RH. After 32 weeks 20 adults of each species were re-introduced into the stored grain

Exposure period	% seeds treated	*T. castaneum*			*C. ferrugineus*		
		A[2]	P[2]	L[2]	A	P	L
24 h (4 wk on untreated wheat)	0	35± 7	29± 4	31± 7	13± 1	0	34± 7
	5	30± 4	22± 9	26± 2	13± 1	0	56± 6
	25	37± 6	15± 4	21± 5	11± 1	0	81±12
	100	25± 4	16± 3	31± 3	14± 1	0	79± 5
4 wk	0	40± 6	107±10	126±13	13± 0	8±1	150± 8
	5	17± 7	17±16	79±14	7± 1	0	5± 2
	25	10± 1	0	24± 6	8± 1	0	0
	100	10± 0	0	0	8± 1	0	0
8 wk	0	276± 9	21± 1	141± 9	289± 8	0	166± 9
	5	14± 2	2± 1	62±15	15± 4	0	13± 4
	25	8± 1	0	21± 6	5± 0	0	1± 1
	100	9± 0	0	0	4± 1	0	0
16 wk	0	419± 6	20± 2	256±14	89±20*	0	4± 1
	5	12± 3	1± 1	39± 9	50±17	0	27±10
	25	6± 0	0	0	0	0	0
	100	5± 1	0	0	0	0	0
32 wk	0	323±35	2± 1	550±85	1± 1*	0	0
	5	12± 4	3± 2	38±16	26± 6	0	1± 1
	25	1± 1	0	0	0	0	0
	100	1± 1	0	0	0	0	0
4 wk (after 32 wk storage)	0	66± 5	127± 7	183±18	19± 1	0	226±15
	5	20± 0	0	147±20	20± 0	0	55± 8
	25	20± 0	0	4± 1	16± 1	0	3± 1
	100	20± 0	0	0	18± 0	0	0

[1] n=5 replicates
[2] A=adult, P=pupa, L=larva
*300-500 dead adults

After 4 weeks of exposure there were significantly fewer ($P<0.05$) adults and larvae of both species in the 5% treatment than in the controls; a few larvae did develop into adults. In the 25% treatment, the original *T. castaneum* adults and a reduced number of larvae were present while only the original *C. ferrugineus* adults were present. In the 100% treatment there were no offspring from the original adults of either species.

From weeks 8 to 32 a few insects of both species developed into adults in the 5% treatment but no second generation adults emerged from pupae in the 25 or 100% treatments. Exposure of new adults of both species to all treatments for 4 weeks after 32 weeks of storage resulted in no F_1 adult emergence from pupae in the 5, 25, and 100% treatments. Increasing levels of fenoxycarb also resulted in decreasing numbers of larvae, probably reflecting a decrease in egg production caused by this chemical.

A treatment of 5% of the wheat kernels at 8 ppm fenoxycarb, which was equivalent to a mean concentration of 0.4 ppm, did not completly control either species although populations were sharply reduced. Treatments of 25% of the kernels, equivalent to a mean concentration of 2 ppm fenoxycarb, completely controlled the insects. The efficacy of the treatments was not affected by 32 weeks of storage at 30°C.

Treated Surfaces

Exposure of last instar larvae of *T. castaneum* and *C. ferrugineus* to surfaces treated with fenoxycarb often indicated a significant difference ($P<0.05$) among the types of surfaces (Table II). On the wood surfaces there were usually a few insects of each species which successfully developed into adults. Typically, fewer adults of *T. castaneum* occurred at 0.5 g/m^2 than 0.25 g/m^2 but both concentrations were equally effective for *C. ferrugineus*.

Steel surfaces treated with fenoxycarb virtually prevented adult development for both species although a few *C. ferrugineus* adults were observed at 0.25 g/m^2 on weeks 4 and 24. Concrete surfaces treated with fenoxycarb were the least effective; adults were usually present, except after larval exposure at 1 day after treatment. The numbers of adults from 0.25 and 0.50 g/m^2 treatments were usually similar and were significantly lower ($P<0.05$) than the controls. Larval production from adults which had been exposed to fenoxycarb shortly before their pupation appeared to be lower at 0.5 g/m^2 than at 0.25 g/m^2 fenoxycarb.

Generally, wood treated with 0.25 g/m^2 fenoxycarb was equally effective to 0.50 g/m^2 and did not completely prevent adult survival in both species but longer exposure periods would have increased the chemical's effectiveness; residual activity was unchanged over 32 weeks. Sprayed steel was the most effective treatment virtually eliminating adults of both species at 0.25 g/m^2 for 32 weeks. Sprayed concrete was a relatively ineffective treatment; it was most effective 1 day after spraying the surfaces and control decreased as the deposits aged, and the higher concentration was more effective than the lower concentration. The high alkalinity of the concrete (Watters, 1976) probably caused appreciable chemical breakdown of the fenoxycarb by hydrolysis.

Table II. Mean numbers (±S.E.)[1] of live Tribolium castaneum and Cryptolestes ferrugineus present on ground wheat at 30±1°C, 70±5% RH, 4 weeks after a 24-h exposure of fourth instar larvae to surfaces treated with fenoxycarb.

Period since surface treatment	Fenoxycarb concentration (g/m²)	Life stage[2]	T. castaneum			C. ferrugineus		
			Wood	Steel	Concrete	Wood	Steel	Concrete
1 day	0	A	20± 0	20± 0	20± 0	9± 1	10± 4	9±4
		L	136±15	164± 5	166±34	77±22	79±19	63±29
	0.25	A	7± 1	0	4± 2	1± 1	0	1± 1
		L	4± 3*	7± 2*	7± 2*	0	1± 1	0
	0.50	A	2± 1	0	3± 2	3± 2	0	0
		L	2± 1*	5± 1*	3± 1*	2± 1	0	0
4 wk	0	A	20± 0	19± 1	20± 0	14± 2	12± 1	9± 4
		L	166±20	135±16	191± 9	73± 5	92±10	64±39
	0.25	A	2± 1	0	12± 0	2± 1	1± 1	3± 3
		L	7± 5	11± 2*	96±12	2± 2	1± 1	22±22
	0.50	A	5± 2	0	12± 2	3± 1	0	5± 1
		L	2± 2*	10± 2*	82±27	2± 1	0	24± 6
8 wk	0	A	20± 0	19± 1	19± 1	6± 2	7± 3	7± 1
		L	153±17	163±14	179±46	40± 4	36±35	42± 4
	0.25	A	1± 1	0	7± 1	0	0	7± 5
		L	8± 1*	11± 1*	45±20	0	0	25±17
	0.50	A	1± 1	0	6± 1	2± 1	0	6± 1
		L	12± 3*	12± 1*	20±10	1± 1	2± 1*	13± 6
24 wk	0	A	19± 1	12± 5	17± 3	12± 5	11± 2	13± 2
		L	87±10	130±23	120±13	112±34	91±25	152±11
	0.25	A	0	0	4± 2	5± 2	1± 0	15± 1
		L	6± 1*	10± 1*	90±32	1± 1	5± 1*	131±15
	0.50	A	0	0	2± 1	3± 2	0	7± 3
		L	9± 2*	6± 3*	15±15	5± 3*	6± 1*	44± 5
32 wk	0	A	20± 0	18± 2	19± 1	10± 3	13± 1	11± 3
		L	152±19	123± 3	151±19	76±41	63±28	96±27
	0.25	A	5± 3	0	15± 0	5± 3	0	9± 3
		L	7± 7	14± 1*	134±19	2± 2*	8± 1*	54±33
	0.50	A	2± 2	0	13± 2	1± 1	0	8± 2
		L	5± 0*	9± 2*	36±14	6± 2*	12± 2*	26±10

[1]n = 3 replicates of 20 larvae
[2]A = adult, L = larva
*original, exposed larvae which did not pupate; dead pupae not reported

Adults in Wheat Above Treated Grain

All three surfaces treated with fenoxycarb had a significant effect on populations of T. castaneum in wheat 2-cm deep above the surfaces, whereas only populations of C. ferrugineus in wheat above steel were affected (Table III). Fenoxycarb deposits of 0.25 g/m^2 were as effective as deposits of 0.50 g/m^2 in reducing larval numbers for both species. Galvanized steel surfaces treated with 0.25 g/m^2 fenoxycarb produced good control of T. castaneum and C. ferrugineus.

Effectiveness of Fenoxycarb

Treatment of varying percentages of wheat seeds with fenoxycarb can be a practical method of application when relatively active, external seed feeders such a T. castaneum or insects which develop inside the germ of seeds such as C. ferrugineus are the main pests in stored cereals. Treatment of one seed in twenty at 8 ppm is ineffective but treatment of one in four is effective. Although fenoxycarb breaks down slowly in dry grain its residual effectiveness may be lengthened by this method of application. Fenoxycarb sprayed on galvanized steel at 0.25 g/m^2 remains highly effective in preventing successful pupation for over 32 weeks and can control populations of insects in grain residues up to 2 cm deep. Modern granaries in Canada are made of galvanized steel with concrete floors and there is a growing trend towards perforated steel floors as aeration systems become more common. Concrete has an adverse effect on fenoxycarb deposits indicating a need to use alternate formulations such as an impregnated dust.

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Table III. Mean numbers (±S.E.)[1] of live Tribolium castaneum and Cryptolestes ferrugineus present in 2-cm deep columns of whole wheat above surfaces treated with fenoxycarb after 20 adults of one or the other species were added to the grain and held at 25±3°C, 60±5% RH for 5 weeks.

Fenoxycarb concentration (g/m^2)	Life stage[2]	T. castaneum			C. ferrugineus		
		Wood	Steel	Concrete	Wood	Steel	Concrete
0	A	15± 3	19± 1	17± 2	18± 1	18± 0	18± 1
	L	54±12	83±10	100±18	40± 4	69± 6	24± 5
0.25	A	20± 0	20± 0	20± 0	17± 0	17± 1	18± 1
	L	11± 2	2± 1	19± 4	36± 6	2± 2	25± 2
0.50	A	20± 0	19± 1	19± 1	17± 1	17± 1	17± 1
	L	9± 2	1± 1	15± 3	22± 7	1± 1	50± 10

[1] n = 6 replicates of 20 adults
[2] A = adults, L = larvae

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