DEVELOPMENT OF GRAIN PROTECTANTS FOR USE IN AUSTRALIA

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ABSTRACT

Since the early 1960's Austalia's high standard of pest control in stored grain has depended chiefly on the application of grain protectants. Malathion was used until 1976–79, malathion-resistant strains then became predominant so alternative insecticides, chiefly fenitrothion but also pirimiphos-methyl and chlorpyrifos-methyl, were substituted progressively in the various States. Addition of synergised bioresmethrin was required in areas, initally the Eastern States, where prevalent strains of *Rhyzopertha dominica* were cross-resistant to the newer materials.

Development of appropriate protectant treatments commences with surveys of insecticide-resistant strains in storages and establishment of laboratory cultures of significant strains. Initial screening of candidate compounds is done in the laboratory using impregnated-paper assays and treated-grain assays. Field testing is then carried out in commercial storages with periodic grain samples tested in laboratory bioassays and chemical assays.

Compounds under development which have potential to control all species include methacrifos, deltamethrin, cyfluthrin and cypermethrin. Fenvalerate, permethrin and phenothrin have potential to control *Rhyzopertha dominica*. Data generated include residue levels both on grain and in major grain products e.g. bran, germ, flour and bread. Data are also generated on the rate of breakdown of these compounds at a range of grain temperatures and grain moistures. All residue levels must conform to maximum residue limits recommended by the Codex Alimentarius Commission.

INTRODUCTION

Grain protectants have been widely used in Australia for the control of pests of stored grain since the introduction of malathion for the purpose in the early 1960's. The standard of pest control required is high. Over 60% of production is exported and is subject to an export inspection, the standard of which is nil tolerance for live insects.

Most of the grain is stored in bulk in central premises and the grain protectants are sprayed into the grain stream during intake into storage. In unaerated storages the grain is typically hot and dry, and grain temperature averages around 30°C during the storage interval. Approximately 25% of storages have aeration, and in these the grain temperature is reduced to 15°C after 5 months storage. The Co-operatives and state run Instrumentalities receiving grain are empowered to prevent the growers from delivering commodities with high moisture contents to central premises. Currently, the maximum permissible moisture content for wheat is 12% and for sorghum 13.5%.

By the 1970's malathion-resistant strains of grain storage insects had developed both in Australia and in many overseas countries (Champ and Dyte, 1976). Research in Australia established that chlorpyrifos-methyl, fenitrothion and pirimiphos-methyl were effective against most of the malathion-resistant strains. Synergised bioresmethrin, carbaryl and synergised natural pyrethrins were shown effective against *Rhyzopertha dominica* (F.) including strains not effectively controlled by the organophosphorus compounds listed. All of these compounds have been cleared for use as grain protectants within Australia and use of malathion progressively declined form 1976 to 1979. The major usage has been of fenitrothion and this is combined with synergised bioresmethrin in the Eastern States and South Australia where resistant *R. dominica* predominate.

Further development of resistance must be anticipated and recent testing of additional alternative insecticides for use as grain protectants will be described.

TEST PROCEDURES

Resistant Strains

Test insects to be used in evaluation of newer grain protectants need to be representative of insecticide-resistant strains of the major pest species. Extensive surveys were carried out using the techniques developed by Champ (1968) to determine the insecticide-resistant status of insects collected from storages throughout Australia. Cultures of significant strains are now maintained in the laboratory under continuous selection with insecticides. Surveys continue and new strains are added to the battery of test insects as appropriate.

Laboratory Assays

Acute toxicity of candidate compounds is estimated initially using impregnated-paper assays adapted from the FAO method for measurement of resistance (Anon., 1974). Promising compounds are further evaluated using treated-grain assays. Test criteria include mortality of test adults at 3 and 26 days and reduction in progeny in F_1 and F_2 generations. These assays are carried out on samples of treated grain taken at intervals over the period of a year. Chemical residues are determined simultaneously.

Field Testing

Promising compounds are field tested at application rates suggested by laboratory studies. Field testing provides the ultimate assessment of the performance of a protectant under industry conditions. Important aspects include stability and ease of mixing of formulations, residues in grain dust and in grain products and acceptability of the compound to industry.

Laboratory bioassays and chemical assays are carried out on samples of treated grain and these are the most important criteria. The presence of natural field infestation is evidence of failure of a treatment but absence of field infestation is not strong evidence of success unless testing involves numerous (more than 20) storages.

This field testing has involved extensive industry co-operation throughout Australia. The Australian Wheat Board's Working Party on Grain Protectants undertakes field testing in each of the mainland States and other boards and authorities co-operate in work with other grains. These groups receive excellent co-operation from the chemical industry.

COMBINATIONS OF GRAIN PROTECTANTS

By the early 1970's common strains of *Tribolium castaneum* (Herbst), *Sitophilus oryzae* (L.) and *R. dominica* in eastern Australia were malathion-resistant. Significantly, the malathion-resistant strains of *T. castaneum* and *S. oryzae* could be controlled at acceptable application rates by available organophosphorus materials:chlorpyrifos-methyl, fenitrothion and pirimiphos-methyl. Unfortunately the common strains of *R. dominica* were cross-resistant to all of these compounds and for convenience these strains here will be termed multi-resistant. The multi-resistant strains were nevertheless susceptible to bioresmethrin, the most active of the available synthetic pyrethroids.

The response of some important strains to bioresmethrin and fenitrothion is shown in Table 1. The responses to chlorpyrifos-methyl and pirimiphos-methyl were essentially parallel to those for fenitrothion.

TABLE 1 - KC 99.9 ($mg\ kg^{-1}$) in newly treated grain based on significant response of test insects after 3 days in treated grain at 25°C and 70% RH.

Species	Strain	Resistance status	Malathion resistance factor	Bioresmethrin	Fenitrothion
Sitophilus oryzae	QSOLS2	Susceptible	-	15.8	0.2
	QSO56	Resistant	x 3.5	10.4	0.4
	CSO231	Highly resistant	x 8.9	352.0	2.0
Rhyzopertha dominica	QRD14	Susceptible	-	0.6	7.7
	QRD2	Resistant	x 5.7	0.8	12.4
	QRD63	Multi-resistant	x 78.0	0.6	10.9
Tribolium castaneum	QTC39	Susceptible	-	7.5	0.5
	QTC34	Highly resistant	x 39.4	26.2	0.5

In the absence of a single insecticide capable of controlling all pest species, combinations of insecticides provided the obvious pragmatic solution (Bengston *et al.*, 1975). Bioresmethrin has been widely used in combination with one of the organophosphorus materials and results have been excellent (Desmarchelier *et al.*, 1981).

PROTECTANTS TO CONTROL MAJOR PESTS (EXCLUDING MULT-RESISTANT *R. DOMINICA*)

Extensive testing established that all significant grain storage pests in Australia, excluding multi-resistant *R. dominica*, were controlled by chlorpyrifos-methyl, fenitrothion or pirimiphos-methyl. Current work indicates that etrimfos will be equally effective. Species tested include *S. oryzae*, *S. granarius* (L.), *R. dominica*, *T. castaneum*, *T. confusum* Jacquelin du Val, *Oryzaephilus surinamensis* (L.), *Ephestia cautella* (Walker) and *Plodia interpunctella* (Hubner).

PROTECTANTS TO CONTROL MULTI-RESISTANT *R. DOMINICA*

Insecticides of both the carbamate and synthetic pyrethroid groups are generally potent against multi-resistant *R. dominica*. Carbaryl (a carbamate) and bioresmethrin, cyfluthrin, cypermethrin, deltamethrin, fenvalerate, permethrin and phenothrin (synthetic pyrethroids) have all been shown effective in field testing (Bengston *et al.*, 1980 a,b, 1983 a,b).

PROTECTANTS TO CONTROL ALL MAJOR PESTS

Methacrifos and synergised cyfluthrin, cypermethrin and deltamethrin, have been shown effective against all the currently prevalent strains of major pest species. However, the synergised synthetic pyrethroid materials when formulated as emulsifiable concentrates all produced a nasal irritation to workmen with inhalation exposure. The problem was resolved by substitution of an unsynergised suspension concentrate formulation of deltamethrin. Alternative unsynergised formulations of cyfluthrin and cypermethrin are currently being tested.

SYNERGISM OF SYNTHETIC PYRETHROIDS

Available synthetic pyrethroid insecticides have been relatively expensive and synergism with piperonyl butoxide has been an important means of reducing application rates and hence costs.

Data on synergism of important compounds are given in Table 2.

TABLE 2 - Synergism of synthetic pyrethroid insecticides with piperonyl butoxide 10 mg kg^{-1}, based on mortalities of test insects after 3 days in treated grain at 25°C and 70% RH.

Insecticide	Species	Strain	Synergism Factor	(95% Limits)
Bioresmethrin	*Rhyzopertha dominica*	QRD63	2.24	(1.76 - 2.91)
Cypermethrin	*Sitophilus oryzae*	QS056	4.74	(4.35 - 5.16)
Deltamethrin	*Sitophilus oryzae*	QS056	2.33	(2.10 - 2.60)
	Rhyzopertha dominica	QRD63	6.60	(5.00 - 9.42)
Fenvalerate	*Rhyzopertha dominica*	QRD63	1.93	(1.78 - 2.08)
Permethrin	*Rhyzopertha dominica*	QRD63	2.07	(1.87 - 2.29)
Phenothrin	*Rhyzopertha dominica*	QRD63	2.38	(2.02 - 2.81)

COMPARISON BETWEEN GRAINS

Most of the detailed research of the efficacy of grain protectants in Australia has been carried out in relation to wheat which is the major cereal species produced. Recent studies have shown differences of surprising magnitude in the responses to insecticides of test insects in wheat and sorghum (Bengston *et al.*, 1983 a,b). The relative potencies of three insecticides are presented in Table 3.

TABLE 3 - Relative potencies of insecticides on sorghum compared to wheat, based on mortalities of test insects after 3 days in treated grain at 25°C and 70% RH.

Insecticide	Species	Strain	Relative Potency	(95% limits)
Bioresmethrin	*Rhyzopertha dominica*	QRD63	0.27	(0.25 - 0.30)
Carbaryl	*Rhyzopertha dominica*	QRD63	0.54	(0.42 - 0.69)
Fenitrothion	*Sitophilus oryzae*	QS056	0.45	(0.39 - 0.50)

Data suggest that to control an established infestation in sorghum an insecticide application rate 2 to 3 times that of wheat would be required. At the same time experience in the grain industry in Australia is that the frequency of pest problems during storage of sorghum is less than that for wheat. Factors such as lower mean grain temperature for stored sorghum in comparison to wheat (25°C compared to 30°C) are probabbly important. Currently the same application rates are used on the major cereal species.

SUMMARY OF APPLICATION RATES

In Australia, application rates are calculated so as to give effective protection from infestation during storage of from 3 to 9 months duration. In general these rates are halved for storage from 0 to 3 months and retreatment is considered appropriate for longer term storage. Application rates which have been shown to be effective for 9 months storage are shown in Table 4.

TABLE 4 - Grain protectants for control of malathion-resistant insects in Australia during 9 months storage.

MAJOR SPECIES EXCLUDING MULTI-RESISTANT *RHYZOPERTHA DOMINICA*

Chlorpyrifos-methyl	10 mg kg^{-1}
Fenitrothion	12 mg kg^{-1}
Pirimiphos-methyl	4 mg kg^{-1}

RHYZOPERTHA DOMINICA ONLY

Bioresmethrin 1 mg kg^{-1} plus piperonyl butoxide 10 mg kg^{-1}
Carbaryl 8 mg kg^{-1}
Deltamethrin 0.1 mg kg^{-1} plus piperonyl butoxide 10 mg kg^{-1}
Fenvalerate 1 mg kg^{-1} plus piperonyl butoxide 10 mg kg^{-1}
Permethrin 1 mg kg^{-1} plus piperonyl butoxide 10 mg kg^{-1}
(1)-phenothrin 2 mg kg^{-1} plus piperonyl butoxide 10 mg kg^{-1}

ALL MAJOR SPECIES

Cyfluthrin 2 mg kg^{-1} plus piperonyl butoxide 10 mg kg^{-1}
Cypermethrin 4 mg kg^{-1} plus piperonyl butoxide 10 mg kg^{-1}
Deltamethrin 1 mg kg^{-1}
Methacrifos 20 mg kg^{-1}

RESIDUES

Extensive studies have enabled the residue levels likely to arise from use of these compounds to be predicted with an adequate level of accuracy. Desmarchelier (1978) provided an explanation of the rate of decay of organophosphorus materials on various grains at different grain temperatures and moisture levels. Noble and Hamilton (1981) and Hargreaves *et al.* (1982) have provided recent data on the residual behaviour of pyrethroids. Information has also been obtained on residue levels in major grain products e.g. bran, germ, flour and bread.

Australia has actively supported consideration of residues of these compounds on grains by the Codex Alimentarius Commission of the United Nations and maximum residue limits in Australia are based upon Codex recommendations. We envisage that support by Australia for the work of the Codex Alimentarius Commission will continue.

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