Recent developments in grain protectants for use in Australia

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Abstract

Widespread use of grain protectants commenced in Australia in the mid 1960s with the introduction of malathion, and later involved major use of fenitrothion, synergised bioresmethrin and chlorpyrifos-methyl. The development of resistance to these compounds prompted the assessment of further compounds.

Laboratory bioassays and field experiments established that methoprene 1 mg/kg provided effective protection against *Rhyzopertha dominica* (Fabricius), *Tribolium castaneum* (Herbst) and *Oryzaephilus surinamensis* (Linnaeus) in wheat during 9 months storage. Similar protection was provided by methacrifos 10 mg/kg against *Sitophilus oryzae* (Linnaeus), *Sitophilus granarius* (Linnaeus), *Tribolium castaneum* (Herbst), *Oryzaephilus surinamensis* (Linnaeus) and *Ephestia cautella* (Walker). The combination of methacrifos plus methoprene provided complete protection against all currently prevalent strains of storage insects infesting cereals in Australia.

Introduction

Grain protectants are used to prevent insect infestation in around 30% of cereal grain in storage in Australia. The storage system is very suited to use of grain protectants since most grain is handled in bulk in central storage and can be treated during inloading. The proportion of grain treated has been reduced in recent years in response to market preference for residue-free grain but grain protectants remain a relatively cheap and effective method of safeguarding grain right up till the time of consumption.

The major pest species in Australia are cosmopolitan species and the pest complex present reflects the treatments applied and the storage conditions. Grain is generally dry (<12% grain moisture for wheat) and warm (typically 25–35°C in unaerated storage). In central storage probably the most destructive pest species is *Rhyzopertha dominica* (Fabricius), the most prevalent beetle is *Tribolium castaneum* (Herbst) and the most prevalent moth is *Ephestia cautella* (Walker). *Oryzaephilus surinamensis* (Linnaeus) is common in central storage where resistance has developed, whilst on farms *Sitophilus oryzae* (Linnaeus) is the most common species. In cooler regions *S. granarius* (Linnaeus) displaces *S. oryzae*.

Markets in Australia and overseas demand grain free from insects, and all grain exported from Australia is inspected under the export grains regulations and must meet a nil tolerance for live insects. Industry practice suggests that a failure rate which involves development of insect infestation in less than 1–2% of storages is desirable. Infestations which develop in grain treated with protectants are controlled by fumigation.

The aim of work in regard to grain protectants in Australia has been to develop treatments which virtually prevent insect infestation throughout the storage interval of up to one year.

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Historical Aspects

Major use of grain protectants in Australia commenced in the mid-1960s with the introduction of malathion, and it produced a dramatic reduction in the frequency of infestation. However, malathion-resistant strains of *T. castaneum* and *R. dominica* became prevalent (Champ and Campbell-Brown 1970) and led in the early 1970s to the introduction of the treatment combination fenitrothion plus synergised bioresmethrin. By the mid-1980s resistance in *O. surinamensis* to fenitrothion was prevalent (Heather and Wilson 1983; Collins and Wilson 1987) and chlorpyrifos-methyl was substituted for fenitrothion. In 1990 resistance to bioresmethrin in *R. dominica* occurred in central Queensland (Collins et al. 1993) and to chlorpyrifos-methyl in *O. surinamensis* in Victoria and southern New South Wales.

This summary necessarily oversimplifies the actual situation. The precise timing of the introduction of treatments has been an operational decision based upon the results of surveys for resistance and experience in control failures, and has varied in different parts of Australia. In addition there have been several minor or special uses. Dichlorvos is used to control moth species and to disinfest grain. Pirimiphos-methyl is used as an alternative to chlorpyrifos-methyl, and phenothrin as an alternative to bioresmethrin, chiefly on farms. Carbaryl is used in place of bioresmethrin on grain for animal feed.

Working Party on Grain Protection

Since the early 1970s the introduction of grain protectants for use in Australia has largely been implemented by a National Working Party on Grain Protection. This working party comprises representatives from the Australian Wheat Board, the CSIRO Division of Entomology, Grain Handling Authorities from each mainland State, and State and Federal Departments of Agriculture/Primary Industries. The field experiments outlined in this paper were carried out by members of the working party and will be published in detail later.

Development of Methoprene

The control of *R. dominica* in Australia in the 1980s depended almost entirely on use of bioresmethrin on grain for human consumption and on carbaryl for animal feed. Given the probability of resistance, alternative compounds were required. Insect growth regulators were clearly of interest and many authors have subsequently undertaken studies (Snelson 1987).

As reported earlier (Bengston 1987; Bengston et al. 1992) laboratory studies confirmed reports of others that insect growth regulators were highly potent against *R. dominica* and are generally of low potency against *Sitophilus* spp. A decision was therefore taken to develop use of methoprene in mixtures with other compounds effective against *Sitophilus* spp. Field testing of S-methoprene has been reported earlier (Bengston et al. 1992) but commercial considerations later suggested that the racemic mixture of methoprene would be commercially available. The current work was carried out various times from 1984 to 1991 and involved additional species and resistant strains.

Bioassays were carried out on fresh deposits in which adults were added to grain one day after treatment. Methoprene diluted from an emulsifiable concentrate formulation was applied to wheat of 11% grain moisture by pipetting 10 mL/kg onto the walls of the bottle immediately above the grain mass. The bottle containing the grain was then tumbled for five minutes to ensure adequate mixing. Because of the water added with the methoprene the moisture content of the treated grain was 12%.

In most bioassays, 50 adults were added to 83 g of treated grain (167 for *T. castaneum*) in each of 3 replicates of 6 doses, plus an untreated control. Bioassays were at 25°C (30°C during progeny development of *R. dominica* and *T. castaneum*). Adult response was estimated at 3 and 26 days after commencement and at that time all parent insects were removed. F_1 progeny were counted after 10 weeks and F_2 progeny after 16 weeks.

Data on the potency of methoprene are given in Table 1. Methoprene was highly effective against *R. dominica*, *T. castaneum* and *O. surinamensis*.

Field experiments on treatments which included methoprene were carried out in silos of the grain handling authorities in conditions approximating commercial storage (Table 2). Separate commercially available emulsifiable concentrate formulations were used for each compound. Individual formulations were first diluted with approximately their own volume of water. They were then added to the spray vat initially containing approximately 10% of the final volume of water and the remainder of the required water was then added. The diluted insecticides were sprayed into the grain stream at the rate of 1 L/t during turning of the grain from one bin to another using small electrically powered spray pumps. Spray nozzles were positioned over a moving grain stream in the under cell area.

Treated grain was sampled from the silos at designated time intervals during storage. A vacuum sampling probe was used to draw samples from a depth of 2 m below the grain surface at six points on each of two transects at right angles to each other across the grain surface. Grain was mixed and subsampled into tins for dispatch to co-operating laboratories for bioassay and residue analysis. Grain temperatures were measured at 2 m depth at five points in each bin using electronic thermome-

Table 1. Potency of methoprene in preventing production of F_1 progeny in laboratory bioassays on wheat at 25°C and 55% r.h. (12% grain moisture).

Species	Strain	Resistance	LD_{50} mg/kg	$LD_{99.9}$ mg/kg
Sitophilus oryzae	QSO56	Organophosphorous	>25[a]	–
	CSO231	High organophosphorous	>>25[a]	–
Rhyzopertha dominica	QRD14	Susceptible	0.022	-0.18
	QRD2	Organophosphorous	0.027	0.20
	QRD63	High organophosphorous	0.010	0.083
	QRD318	Pyrethroid	0.01	0.17
Tribolium castaneum	QTC4	Susceptible	0.019	0.127
	QTC279	Pyrethroid	0.019	0.299
	QTC285	Organophosphorous	0.017	0.236
Oryzaephilus surinamensis	QOS42	Organophosphorous	0.004	0.010

[a]After Bengston (1987)

Table 2. Wheat used in field experiments on the efficacy of methoprene in combination with other insecticides.

Treatment	Number of silos	Total quantity of wheat (t)	Grain moisture range (%)	Grain temperature range (°C)
		9 months storage		
Methoprene 1 mg/kg plus chlorpyrifos-methyl 10 mg/kg	4	2 216	9.6–12.5	14–34
Methoprene 1 mg/kg plus fenitrothion 12 mg/kg	8	4 669	9.0–12.1	19–33
Methoprene 1 mg/kg plus malathion 12 mg/kg	4	2 035	9.3–11.3	15–32
Methoprene 1 mg/kg plus methacrifos 10 mg/kg	5	2 747	9.0–11.3	19–32
		3 months storage		
Methoprene 0.5 mg/kg plus fenitrothion 6.0 mg/kg	5	2 592	9.6–11.5	15–31

ters. Grain moistures were measured on subsamples of grain from the main samples using capacitance or conductivity type moisture meters.

Treated grain from the field experiments was bioassayed using the standard bioassay technique. Residues of methoprene were estimated using an ultraviolet detector following high performance liquid chromatography of a methanol extract partitioned into hexane.

At each field sampling occasion and during outturn of the grain from the silo at the completion of the experiment, 20 kg of grain was sieved to determine natural infestation. In addition staff from the grain handling authorities carried out routine monitoring to determine the presence of infestation.

Data on the response of *R. dominica* to grain treated with methacrifos plus methoprene are given in Table 3. Mortality of parents was incomplete at the initial sampling and declined during the storage interval. It is known from earlier reports and studies that methoprene has no effect on parent mortality, which was due here to the action of methacrifos. Reduction in progeny production was virtually complete throughout. The occasional records of progeny were not inconsistent with experimental error since it is difficult to ensure that all parent insects were removed.

Parallel results were obtained for all bioassays for *R. dominica* and *O. surinamensis* of both organophosphorous-susceptible and resistant strains in grain sampled from each of the 26 silos. No field infestation was recorded at any site.

It is therefore concluded that methoprene is effective at the doses used, for the prevention of infestation by both *R. dominica* and *O. surinamensis*.

Development of Methacrifos

Significant work on the development of methacrifos as a grain protectant in Australia commenced in the early 1970s (K.W. McDougall, unpublished data). The compound gave excellent results in large-scale field testing (Bengston and Desmarchelier 1979; Bengston et al. 1983). Commencement of widespread use has been delayed by the regulatory process.

Until 1990 the work aimed to develop methacrifos as a single grain protectant against all species of the pest complex. To achieve this an application rate of 20 mg/kg was required for 9 months protection. The maximum residue limit for raw cereals recommended by the Codex Alimentarius Commission is 10 mg/kg so the current work aimed to develop methacrifos in combination with other compounds for the control of *R. dominica*. If successful this would allow the application rates of methacrifos to be restricted to 10 mg/kg.

A summary regarding the wheat used in the field experiments carried out in 1990–91 is given in Table 4. Data on grain treated with methacrifos plus methoprene were given in Table 2.

Laboratory bioassays established that for *S. oryzae* and *S. granarius* mortality of parents was complete at 3 and 26 days and no progeny were produced.

No field infestation was recorded at any site.

The combination of methacrifos plus methoprene has potential to control all currently prevalent strains of grain storage insects infesting cereals present in Australia. Methoprene has been used successfully as a grain protectant in Australia since 1990 and a decision regarding methacrifos is pending.

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Table 3. Response of *Rhyzopertha dominica* (strain QRD63) in wheat treated with methoprene 1 mg/kg plus methacrifos 10 mg/kg and stored in concrete silos prior to assay at Malu, Queensland 1990–91.

Time after treatment (months)	Mortality at 3 days (%)	Mortality at 26 days (%)	Reduction in F_1 progeny[a] (%)	Reduction in F_2 progeny[b] (%)
0	49	57	100	100
1.5	13	2	99.82[c]	100
3	0	13	100	100
4.5	0	7	100	99.9[c]
6	0	5	99.83	100
9	–	–	99.9	100

[a] Mean number of F_1 progeny (N=3) in untreated controls 621
[b] Estimated number of F_2 progeny in untreated controls 7 713
[c] Dead at the time of assessment

Table 4. Wheat used in field experiments on the efficacy of methacrifos in combination with other insecticides.

Treatment	Number of silos	Total quantity of wheat (t)	Grain moisture range (%)	Grain temperature range (°C)
methacrifos 10 mg/kg plus bioresmethrin 1 mg/kg plus piperonyl butoxide 8 mg/kg	4	2365	9.8–12.3	14–29
methacrifos 10 mg/kg plus permethrin 1 mg/kg plus piperonyl butoxide 8 mg/kg	4	2452	9.0–11.9	14–30

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