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The use of inert dusts and insect growth regulators in Malawi to protect stored maize and red kidney beans from insect attack

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Abstract

Trials were conducted at Chitedze, Malawi, to determine the efficacy of three inert dusts admixed with commodity and three insect growth regulators (IGRs) applied as aqueous sprays, as storage protectants of shelled and unshelled maize (Zea mays) and shelled red kidney beans (*Phaseolus vulgaris*). All treatments were better than the untreated controls, with little difference between the performance of the inert dusts and IGR sprays. The evidence suggested that shelled maize is best protected from attack by *Sitophilus zeamais* by the use of inert dusts whilst unshelled maize is better protected by IGR sprays. *Tribolium castaneum*, on both shelled and unshelled maize, is probably best controlled by the use of IGR sprays or the inert dust Gasil 23D. For protection of shelled maize against *Sitotroga cerealella*, the IGR sprays appear more effective than the inert dusts; however, none of the treatments offered good protection of unshelled maize against this species. Beans were protected by all of the treatments, and no differences in efficacy were found among treatments.

Introduction

Insect growth regulators (IGRs) and inert dusts have proved effective in both laboratory and large-scale trials against a range of storage pests (Dales et al., 1994; Golob, 1997). They are generally safe to use (Banks and Fields, 1995), having negligible acute oral mammalian toxicity (Subramanyam et al., 1994), and as such, are potentially important contenders as major control components of any integrated commodity management system.

The biological activity of IGRs covers a wide spectrum that ranges from ovicidal and larvicidal to lethal effects on pupae as well as adults of the F_1 generation (Ramesh Babu et al., 1991). There are currently relatively few IGRs registered for food storage use but this is likely to change as pressures to reduce reliance on conventional insecticides, particularly organophosphates, mounts.

World-wide, locally available inert materials have been used by farmers for many generations to protect their stored commodities: traditional materials include wood ash, lime and fine sand. Their main drawback, however, is the large quantities that are required to provide effective protection (Golob et al., 1982). Their mode of action is likely to be a combination of their abrasive properties and the inhibition of normal insect behaviour, affecting movement and reproduction by blocking the air spaces between the grains (Golob, 1997).

Inert dusts have been shown to be more effective than these traditional inert materials at controlling pests of stored products, and many of the newer silica dust formulations are effective at rates in the region of 1 – 2 kg/tonne. The effects of inert dusts are exerted by the lipophilic nature of the material that adsorbs the lipid components of the insect cuticle exposing the pests to desiccation stress (Ebeling, 1971).

Trials were undertaken to investigate the efficacy of three chitin-synthesis inhibiting IGRs (Flufenoxuron, Hexaflumuron and Triflumuron) and three inert dusts (Dryacide, Gasil 23D, and Protect-it) as protectants of maize and beans stored for up to 10 months against the storage pests *Sitophilus zeamais* Motchulsky (Coleoptera: Curculionidae), *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae), *Tribolium castaneum* (Herbst) (Col.: Tenebrionidae) and *Acanthoscelides obtectus* (Say) (Col.: Bruchidae).

Materials and Methods

Experimental location

The trials were undertaken under ambient conditions at Chitedze Research Station in Central Malawi between July 1995 – April 1996 and September 1996 – May 1997.

Chemicals

The IGRs tested were: Hexaflumuron (Dow Elanco Ltd),

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Flufenoxuron (Cyanamid International), and Triflumuron (Bayer AG). The inert dusts used were: Dryacide (Dryacide Ltd), Gasil 23D (Crossfield) and Protect-it (Hedley Technologies Plc). The organophosphate dust Actellic (Zeneca) was tested as a known control method.

Commodities

Shelled maize (Zea mays)

Freshly harvested and shelled MH18 variety maize, was obtained in Lilongwe and used for this study. The maize was randomly mixed and, after having a batch sample removed from the bulk to check the initial level of infestation, treated with IGR sprays or inert dusts in 10 kg increments. The treated maize was bagged into 10 kg-capacity hessian sacks (minibags) and stacked on pallets in a drying house, with separate blocks comprising all replicates of a single treatment. Sufficient commodity was prepared to measure the level of infestation and damage at 2, 4, 6, 8 and 10 months after treatment for the first year's trial and at approximately 5, 6 and 8.5 months after treatment for the second year's trial.

The IGRs were applied as aqueous sprays from a pneumatic sprayer (Hozelock Premiere 3L). They were applied at 2 and 5 ppm and sprayed onto a single layer of maize spread out on plastic sheeting. The maize was left to dry in partial shade. Control treatments for these spray treatments included both untreated commodity (dry control) and commodity sprayed with water only (wet control) during the first year's trial, but water-sprayed commodity only for the second year's trial. The inert dusts used in the first year's trial (Dryacide and Gasil) were applied to the 10 kg units of maize at 0.1, 0.2 and 0.3% (w/w). In addition to these, a third dust, Protect-it, was used at application rates of 0.01 and 0.05% (w/w) during the second year's trials. Further batches of untreated commodity acted as control for the dusts. All treatments were replicated four times.

Maize cobs

The maize variety MH18 was used. A batch sample was removed to check the initial infestation level. Four hundred and fifty dehusked cobs were treated for each treatment and placed in a traditional bamboo storage basket (*nkhokwe*), measuring 0.8m diameter at the base and 1.05 – 1.2m high, the maize cobs half filled the *nkhokwe*. Each treatment was stored in a separate *nkhokwe* that was placed on a storage platform constructed of blue gum poles raised 1 m from the ground and protected by a sloping roof composed of plastic sheeting and local grasses. At each sampling period, 15 cobs were selected from the top, middle and bottom of each *nkhokwe*, giving a total of 45 cobs per treatment for each sampling. Sufficient commodity was prepared to measure the level of infestation and damage at 2, 4, 6, 8 and 10 months after treatment during the first year's trial and at approximately 4, 5.5 and 7 months after treatment during the second year's trial.

The IGRs were applied as aqueous sprays from a pneumatic sprayer (Hozelock Premiere 3L). They were applied at 0.5 mg active ingredient/m^2. In order to ensure an even spray coverage, the cobs were spread out on plastic sheeting and sprayed with half the volume of spray solution before being dried and turned and sprayed with the other half of spray solution. The inert dusts (Dryacide and Gasil) were sprinkled onto the cobs as they were stacked in the *nkhokwe* layer-by-layer at application rates of 6 g/m^2. Actellic dilute insecticidal dust was applied to the cobs at a rate of 80 g of 2% dust on the volume of cobs which fill a 100 kg sack (equivalent to 36 ppm of active ingredient on the total weight or 46 ppm on the grain weight). Further batches of unsprayed cobs acted as control treatments. All treatments were replicated four times.

Red kidney beans (Phaseolus vulgaris)

The beans purchased at Chimbiya market in Dedza district, were of varying appearance (red, pale pink and pink striped) and were well-mixed before a batch sample was removed from the bulk to check the level of infestation. After infestation was assessed, the remaining bulk was divided into 4kg units, treated as necessary, bagged into 4 kg-capacity hessian sacks and stacked on pallets with each block comprising all replicates of a single treatment. Sufficient commodity was prepared to measure the level of infestation and damage at 2, 4, 6, 8 and 10 months after treatment during the first year's trial and at approximately 2.5, 5.5 and 6.5 months after treatment during the second year's trial.

The only IGR applied to beans was Hexaflumuron, as an aqueous spray from a pneumatic sprayer (Hozelock Premiere 3L). It was applied at 10 ppm and sprayed onto a single layer of beans spread out on plastic sheeting. The beans were left to dry in partial shade. Control treatments for these spray treatments included both untreated commodity and commodity sprayed with water only. The inert dusts (Dryacide and Gasil) were applied to the 4 kg units of beans at 0.1 and 0.2 % (w/w). Actellic dilute dust was also applied to the beans at a rate of 8.8 ppm active ingredient (1.76g/4kg). Further batches of untreated commodity acted as control for the dusts. All treatments were replicated four times.

Analysis of samples

At each sampling period the four replicates of each treatment of shelled maize and beans were removed, coned and quartered repeatedly until samples in the region of 300 g were obtained. Cob samples were shelled before division. Each sample was sieved and the number and identification of insects present assessed, as well as the number and weight of damaged, holed and undamaged grains. A further sample was incubated, after being weighed, and numbers of emergent adult insects scored after 6 – 8 weeks.

The numbers of insects and the percentage of holed grains/beans, were analysed using Genstat and Minitab. Appropriate transformations were used when needed, both transformed and untransformed data are shown in the tables. An analysis of variance was carried out on the data. However, if log-transformed data remianed heterogeneous, a Kruskal Wallis test was performed. Differences of approximately twice the standard error of the differences in transformed means (s. e. d) could be considered significant at the 5% level.

Results

Initial damage level

Initial damage levels assessed from batch samples, indicated that damage was less than 1% in all commodities, with no live insects being observed.

Shelled maize

In both year trials significant differences (at the 1% level) in the mean total number of *S. zeamais* among the treatments and controls were evident at the 4 – 5 month sampling period. The inert dusts protected the shelled maize in minibags better than the IGR spray treatments, and this difference became more apparent as the storage period increased (Table 1). In the second year's trial, Protect-it reduced infestation at the higher concentration of 0.05% and was shown to be better than other inert dusts or IGR sprays.

Table 1. Mean total[a] number of *S. zeamais* in shelled maize sub-samples taken at the two later sampling periods of the first year's trial and last sampling period of the second year's trial.

Treatment	8 months Year 1	10 months Year 1	8.5 months Year 2
Insect growth regulators			
Flufenoxuron 2ppm	1338(7.2)	894	649
Flufenoxuron 5ppm	1042(7.0)	759	534
Triflumuron 2ppm	1175(7.1)	849	1417
Triflumuron 5ppm	487(6.2)	759	1497
Hexaflumuron 2ppm	555(6.3)	545	766
Hexaflumuron 5ppm	1754(7.5)	931	485
Wet Control (for sprays)	12964(9.5)	11226	6949
Inert dusts			
Gasil 0.1%	212(5.4)	634	740
Gasil 0.2%	85(4.5)	526	841
Gasil 0.3%	139(4.9)	296	902
Dryacide 0.1%	1021(6.9)	683	573
Dryacide 0.2%	150(5.0)	891	448
Dryacide 0.3%	67(4.2)	489	561
Protect-it 0.01%	–	–	546
Protect-it 0.05%	–	–	528
Dust Control	10937(9.3)	10415	3860
s.e.d.[b]	0.483	315.5	various

[a] Transformed means in parenthesis alongside back transformed means

[b] Standard error of the difference between two transformed means

Table 2. Mean total[a] number of *T. castaneum* and *S. cerealella* in shelled maize sub-samples taken at the three sampling periods of the second year's trial.

Treatment	*Tribolium castaneum* 5 months	*Tribolium castaneum* 6 months	*Tribolium castaneum* 8.5 months	*Sitotroga cerealella* 5 months	*Sitotroga cerealella* 6 months	*Sitotroga cerealella* 8.5 months
Insect growth regulators						
Flufenoxuron 2ppm	87(4.5)	44(3.8)	53	218	191	171
Flufenoxuron 5ppm	79(4.4)	47(3.9)	26	201	226	145
Triflumuron 2ppm	72(4.3)	45(3.8)	73	136	123	149
Triflumuron 5ppm	76(4.3)	45(3.8)	73	146	187	183
Hexaflumuron 2ppm	77(4.4)	68(4.2)	68	148	227	153
Hexaflumuron 5ppm	62(4.1)	68(4.2)	39	170	227	246
Wet Control (for sprays)	17(2.9)	77(4.4)	84	207	169	192
Inert dusts						
Gasil 0.1%	60(4.1)	41(3.7)	68	421	506	446
Gasil 0.2%	63(4.2)	19(3.0)	60	637	287	313
Gasil 0.3%	27(3.3)	22(3.1)	124	572	490	200
Dryacide 0.1%	63(3.3)	127(4.9)	181	466	214	172
Dryacide 0.2%	58(4.0)	110(4.7)	120	230	285	132
Dryacide 0.3%	59(4.1)	77(4.4)	162	441	192	132
Protect-it 0.01%	150(5.0)	108(4.7)	145	159	145	50
Protect-it 0.05%	128(4.9)	75(4.3)	165	197	152	28
Dust Control	29(3.4)	41(3.7)	242	365	52	13
s.e.d.[b]	0.195	0.195	10.8	various	42.6	various

[a] Transformed means in parenthesis alongside backtransformed means

[b] Standard error of the difference between two transformed means

Mean total numbers of other insects found during the second year trial was variable (Table 2). The very low counts obtained for both the wet and dust controls at some sampling times suggests that interpretation of the data must be taken very cautiously. Gasil showed lower total mean counts of *T. castaneum* than Dryacide and the IGR spray treatments during the first six months of storage. There is some evidence that spray treatments performed better than the dusts at protecting shelled maize from attack by *S. cerealella*; however, Protect-It showed good control against *S. cerealella* after 8.5 months (Table 2). Analysis of the numbers of *S. cerealella* was difficult due to the heterogeneous nature of the data.

Mean percentage of grains with holes echoed the findings of the mean total number of S. zeamais (Table 3). In the first year's trial, treatment of grain with Flufenoxuron at the higher application rate of 5ppm, resulted in a significantly lower mean number of holes (at the 5% level) than the 2ppm application rate. The Gasil and Dryacide dusts reduced infestation at application rates of 0.2 and 0.3%, in the first year's trial (Table 3).

Table 3. Mean percentage of holed grains in shelled maize samples taken at the 6 month sampling period of the first year's trial and last sampling period of the second year's trial.

Treatment	6 months Year 1	8.5 months Year 2
Insect growth regulators		
Flufenoxuron 2ppm	30.9	57.4
Flufenoxuron 5ppm	10.2	47.1
Triflumuron 2ppm	17.4	54.1
Triflumuron 5ppm	20.7	49.9
Hexaflumuron 2ppm	18.1	40.2
Hexaflumuron 5ppm	26.6	53.7
Wet Control (for sprays)	97.4	91.5
Inert dusts		
Gasil 0.1%	18.0	43.3
Gasil 0.2%	7.9	41.6
Gasil 0.3%	7.0	36.2
Dryacide 0.1%	30.4	39.8
Dryacide 0.2%	10.5	35.5
Dryacide 0.3%	5.4	35.2
Protect-it 0.01%	-	29.5
Protect-it 0.05%	-	32.9
Dust Control	97.0	81.1
s.e.d.[a]	5.65	4.89

[a] Standard error of the difference between two means

Maize cobs

During the first year's trial, differences in the number of *S. zeamais* adults present on tested samples were only apparent from the sixth month of storage onwards (ANOVA, $p < 0.001$). From 8 months, the IGR sprays Triflumuron and Hexaflumuron gave the best protection of maize cobs from attack by *S. zeamais* (Table 4). There was no clear evidence of a difference among treatments during the second year's trial.

Table 4. Mean total number of *S. zeamais* from samples of 45 maize cobs taken at the two later sampling periods of the first year's trial and last sampling period of the second year's trial.

Treatment	8 months Year 1	10 months Year 1	7 months Year 2
Insect growth regulators			
Flufenoxuron 0.5mg/m^2 a.i.	155	365	413
Triflumuron 0.5mg/m^2 a.i.	47	152	245
Hexaflumuron 0.5mg/m^2 a.i.	86	147	274
Inert dusts			
Gasil 6g/m^2	205	683	527
Dryacide 6g/m^2	246	422	471
Control	276	561	352
s.e.d.[a]	68.3	112.6	103.1

[a] Standard error of the difference between two means

Data on the other insects infesting maize cobs was only available from the second year's trial (Table 5). As for protection of shelled maize against *T. castaneum*, the IGR sprays gave better protection than the dusts with Flufenoxuron appearing to give the best protection against attack. However, the very low control counts suggest that caution should be exercised when interpreting the results. None of the treatments offered any protection against attack by *S. cerealella*.

Although the second year's trials showed no significant differences between treatments and controls in the number of maize grains with holes, the first year's trial showed differences among treatments after 4 months (ANOVA, $p < 0.01$). Overall, the IGR sprays performed best, with Gasil performing reasonably well. After eight months there was no difference in the level of performance of the three IGR (Table 6).

Table 5. Mean total number of *T. castaneum* and *S. cerealella* from samples of 45 maize cobs taken at the three sampling periods during the second year's trial.

Treatment	Tribolium castaneum			Sitotroga cerealella		
	4 months	5.5 months	7 months	4 months	5.5 months	7 months
Insect growth regulators						
Flufenoxuron 0.5mg/m^2 a.i.	9.5	13.8	19.8	20.5	11.8	29.8
Triflumuron 0.5mg/m^2 a.i.	21.0	13.8	28.3	36.0	21.5	29.3
Hexaflumuron 0.5mg/m^2 a.i.	23.8	27.5	27.5	27.2	12.3	32.0
Inert dusts						
Gasil 6g/m^2	30.3	32.5	55.3	28.8	15.3	24.0
Dryacide 6g/m^2	46.5	42.5	56.0	20.6	12.3	24.0
Control	18.3	12.3	20.5	28.2	18.0	24.0
s.e.d.[a]	8.7	7.2	11.3	0.34	0.44	0.79

[a] Standard error of the difference between two means

Table 6. Mean percentage of holed grains in samples of 45 maize cobs taken at the two later sampling periods of the first year's trial and last sampling period of the second year's trial.

Treatment	8 months Year 1	10 months Year 1	7 months Year 2
Insect growth regulators			
Flufenoxuron	35.5	45.2	55.3
Triflumuron	38.1	37.7	44.3
Hexaflumuron	28.3	35.3	48.9
Inert dusts			
Gasil	39.0	57.5	54.0
Dryacide	56.8	61.2	59.3
Control	52.3	63.3	55.0
s.e.d.[a]	7.71	6.83	5.79

[a] Standard error of the difference between two means

Beans

For the first year's trial, evidence of differences in the number of adult *A. obtectus* between all treatments and controls was only apparent at the 10 month sampling period (Table 7). Although there was no evidence of differences among the non-control treatments, Hexaflumuron had a significantly lower mean (at the 5% level) than the wet control, and all the dust treatments (including Actellic) had significantly lower means (at the 5% level) than the dust control. These results were reflected in the second year's findings.

The mean percentage of holed bean, is consistent with the total number of bruchids observed for the first year trial (Table 8). The data obtained from the second year's trial was inconclusive, there were no significant differences among the non-controls (Kruskal-Wallis, $p = 0.227$).

Table 7. Mean total[a] number of *A. obtectus* in bean sub-samples taken at the two later sampling periods of the first year's trial and last sampling period of the second year's trial.

Treatment	8 months Year 1	10 months Year 1	6.5 months Year 2
Insect growth regulators			
Hexaflumuron	36.0(3.6)	27.5(3.4)	41.3
Wet control (for sprays)	27.5(3.4)	283.3(5.7)	1024
Dry control (for sprays)	63.1(4.1)	–	94.0
Inert dusts			
Gasil 0.1%	39.4(3.7)	45.1(3.8)	60.5
Gasil 0.2%	50.4(3.9)	41.1(3.7)	55.8
Dryacide 0.1%	61.8(4.1)	43.3(3.8)	82.3
Dryacide 0.2%	36.7(3.6)	21.2(3.1)	30.3
Actellic dust 8.8ppm a.i.	36.0(3.6)	30.5(3.5)	40.0
Dust control	213.9(5.4)	1151.9(7.1)	1622
s.e.d.[b]	1.01	0.63	various

[a] Transformed means in parenthesis back transformed means alongside
[b] Standard error of the difference between two transformed means

Table 8. Mean percentage[a] of holed beans in samples taken at the two later sampling periods of the first year's trial and last sampling period of the second year's trial.

Treatment	8 months Year 1	10 months Year 1	6.5 months Year 2
Insect growth regulators			
Hexaflumuron	1(6.2)	1(6.8)	2.0
Wet control (for sprays)	1(6.5)	14(21.9)	24.7
Dry control (for sprays)	7(15.5)	–	11.5
Inert dusts			
Gasil 0.1%	2(7.2)	2(7.5)	2.4
Gasil 0.2%	2(7.1)	1(4.0)	1.3
Dryacide 0.1%	2(8.3)	1(6.7)	2.2
Dryacide 0.2%	1(4.6)	1(4.3)	1.5
Actellic dust 8.8ppm a.i.	1(6.2)	3(9.1)	2.6
Dust control	5(13.1)	26(30.4)	22.1
s.e.d.[b]	4.18	4.39	various

[a] Transformed means in parenthesis back transformed means alongside
[b] Standard error of the difference between two transformed means

Incubated commodity samples

In a large number of cases, counts of insects were repetitions of zeros and so interpretation and evaluation of statistical significance, even from the non-parametric Kruskal-Wallis tests, should be taken cautiously.

Significant differences in the numbers of *S. zeamais* emerging from incubated shelled maize were found among treatments (Kruskal-Wallis, $p < 0.05$), and highest counts were consistently found for the control treatments. During the first year's trial the lower numbers of *S. cerealella* emerged from inert dust protected shelled maize (ANOVA,

$p<0.05$). This was less evident during the second year's trial.

The lowest numbers of *S. zeamais* emerged from maize cobs treated with Triflumuron during both years (Kruskal-Wallis, $p<0.05$).

Discussion

Shelled maize was well protected from insect attack by both the IGR sprays and inert dusts. There was evidence to suggest that dusts provided better protection against the more common pest *S. zeamais*, while the sprays offered better protection against attack by *T. castaneum* and *S. cerealella*. Dales et al. (1994) found that Flufenoxuron and Hexaflumuron at 5ppm, and Triflumuron at 10ppm, gave more than 90% control of *S. zeamais* and *Rhyzopertha* dominica (Fabricius) on maize over a 12-month period. Mian and Mulla (1982) reported good control against *S. zeamais* and *R. dominica* over 12 months using Triflumuron at 1 – 10ppm on wheat, barley and maize. Eisa and Ammar (1992) showed that *S. oryzae* was completely controlled by 10ppm Triflumuron on wheat for 15 months.

The IGR sprays, particularly Triflumuron and Hexaflumuron, gave the best protection to maize cobs against attack by *S. zeamais*. However, Flufenoxuron appeared to give better protection against *T. castaneum*. There was no evidence of successful control against attack by *S. cerealella*.

Beans were protected by the use of any of the treatments tested, and there was little evidence of a difference in control level among treatments. Hexaflumuron was the only IGR tested on beans in the trial. Ramesh Babu et al. (1991) found that Triflumuron successfully prevented adult emergence of *Callosobruchus chinensis* from mungbean treated with 0.02 g a.i./kg for up to 10 months. Elek and Longstaff (1994) found exposure for two weeks to wheat treated with either Triflumuron or Flufenoxuron at a rate of 0.5mg/kg inhibited almost all F_1 production and all F_2 production of *T. castaneum* and *Sitophilus oryzae*. The current trial results support those of Giga and Chinwada (1994) who found that Dryacide, at an application rate of either 1 or 2 g/kg gave control of *A. obtectus* and *Zabrotes subfasciatus* bruchids even when aged for up to 24 weeks. Laboratory trials at the Natural Resources Institute (NRI), in the UK (K. Adesalu, unpubl. data), showed that Dryacide at 0.125% and Gasil 23D at 0.05% applied to cowpeas and red kidney beans completely prevented progeny production when adults were exposed to the commodities nine months after treatment.

Inert dusts bring about death by dessication (Ebeling, 1971), and as a consequence, their performance is affected by the ambient relative humidity. Fam et al. (1974) reported that the mortality of *S. oryzae* decreased as the moisture content (mc) of Drie-Die or katelsous-treated wheat increased. The effect of relative humidity, is directly related to that of grain moisture content and McLaughlin (1995) has recommended safe storage limits for use of Dryacide as a long-term (12 months or more) protectant of wheat at 12% mc, maize 13% mc and paddy 14% mc. In humid conditions where the relative humidity is likely to rise to a level where moisture content exceeds the safe storage limits it may be best to use IGR sprays which are less likely to be affected by the ambient conditions.

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