FIELD ASSESSMENT OF THE EFFICACY AND PERSISTENCE OF DIATOMACEOUS EARTH DUST ADMIXED WITH SORGHUM, MAIZE AND COWPEAS TO PROTECT THE GRAIN AGAINST STORAGE INSECT PESTS IN THREE AGRO-ECOLOGICAL ZONES OF ZIMBABWE DURING THE 1998/99 AND 1999/2000 STORAGE SEASONS.

by

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Introduction

In 1996 during a post-harvest needs assessment exercise in Zimbabwe, farmers ranked the need for improved methods of storage pest control as a priority issue (Donaldson *et al*., 1996; Boyd *et al*., 1997; Donaldson *et al*., 1997; Marange *et al*., 1997; Douglass *et al*., 1997). Insect pests during storage seriously damage maize and grain legumes. Without pest control, household food security is threatened. In addition, producers in sub-Saharan Africa are often forced to sell surpluses before premium prices are available at market (Golob *et al*., 1996; Brice *et al*., 1996; Marlsand & Golob, 1997). Insect pest control in developing countries is generally achieved using imported synthetic chemicals, but these are often unavailable, expensive or misused. Inert dusts, such as diatomaceous earths, offer a much safer alternative, but information on their efficacy under tropical, small-scale farming conditions is lacking (Golob, 1997).

Laboratory trials had confirmed that the diatomaceous earths Protect-it™ and Dryacide® could successfully reduce populations of the major storage insect pests in Zimbabwe, under constant climatic conditions (Carlson & Ball, 1962; Desmarchelier and Dines, 1987; Giga & Chinwanda, 1994). The objectives of the field trials were therefore:

1. to determine whether these diatomaceous earths could control naturally developing insect populations and the damage they cause in maize, sorghum and cowpeas under the climatic conditions found in Zimbabwe throughout an eight month storage period, and
2. to determine the most appropriate application concentrations.

Materials and methods

Trial sites and timing

Field trials were set up in three districts in Zimbabwe: Binga, Harare and Buhera. The areas were selected in collaboration with the AGRITEX (now AREX) field staff, and covered Natural regions IV and V. In Binga and Buhera districts, the trials were conducted on-farm and managed by researchers. In Harare the trials were conducted on-station at Hatcliffe Farm, Institute of Agricultural Engineering (IAE). As the quantity of grain to be treated during the trials was too large to be accommodated in the farmer's own granary in addition to the households grain, additional granaries were constructed. Additional granaries were constructed on-station at IAE in Harare. Four granaries were built in each of the three districts, and were used as replicates.

The storage facilities

In Binga a granary model developed to improve the design of indigenous granaries in response to declining hardwood resources was used. This was a traditional mud and wood round-shaped structure with base on top of 1metre high PVC pipe legs filled with cement, and no compartments inside the structure which is plastered both internally and externally (Plate 1). The small entrance squared-shaped hole was sealed with a wooden doorway. A traditional overhanging thatched grass roof was placed on the top of the structure, to insulate the granary and to protect the top and sides from rain damage.

Plate 1. Trial granary - Binga district

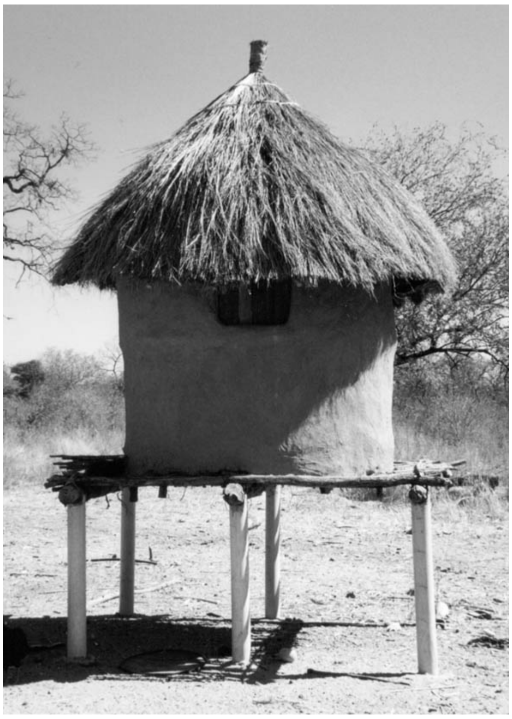
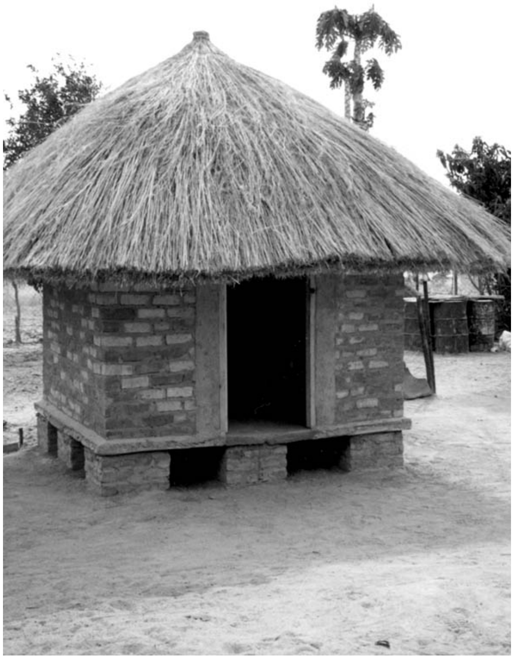


Plate 2 Trial granary - Buhera district and Hatcliffe Farm, Harare



The Buhera improved granary design was a brick structure based on the traditional pole and mud structure (Plate 2). The structure is raised ~40 cm off the ground, on small columns of brick legs, the floors and ceilings are made of cement slabs, the exterior and interior walls are built of bricks. The interior of the six compartments and the main corridor is then plastered with a anthill-sand based mud mixture. The cement ceiling slabs were omitted in the trial granaries to facilitate spear sampling. A small close fitting wooden door was fitted to each compartment. The roof was made of traditional poles and thatched with grass.

The treatments

Trials were carried out for a 40 week storage period over two seasons (1998/99 and 1999/00). The treatments included the two diatomaceous earths Dryacide® and Protect-it™ admixed at different concentrations, Actellic Super Dust and an untreated control. Different concentrations of the DEs were used in the two seasons (Table 1).

Table 1. Grain protectant treatments applied during the field trials.

1st storage season (1998/1999)	**2nd storage season (1999/2000)**
Dryacide 0.1% w/w (1g/kg)	Dryacide 0.05% w/w (0.5g/kg)
Dryacide 0.2% w/w (2g/kg)	Dryacide 0.1% w/w (1g/kg)
Protect-it 0.1% w/w (1g/kg)	Protect-it 0.05% w/w (0.5g/kg)
Protect-it 0.2% w/w (2g/kg)	Protect-it 0.1% w/w (1g/kg)
Actellic Super Dust[3]	Actellic Super Dust
Untreated control	Untreated control

[3] Actellic Super dust is a trade name for a "cocktail" of pirimiphos-methyl 1.6% and permethrin 0.3%, applied at a rate of 50g/100kg of grain or 0.05% (w/w).

In Binga the commodity used was sorghum (50kg/rep) which following treatment was loaded into a sack, labelled and randomly placed inside the single compartment granary. In Buhera, both maize (180kg/rep) and cowpeas (10kg/rep) were used in 1998/99, in 1999/2000 only maize was used due to difficulties in obtaining sufficient quantities of cowpea. Maize (180kg/rep) was also used at IAE. Following treatment, the maize was loaded as bulk into the compartments of the granary, while the cowpeas were placed in small woven sacks, which were stored in the central corridor of three of the granaries in Buhera.

Grain sampling and sample analysis
Sampling was at 8-week intervals for 40 weeks. Samples of 1.5kg of maize were collected using a multi-compartmented probe, while 1.5kg and 500g samples of sorghum and cowpeas, respectively, were collected using bag samplers. The sample was then sieved and randomly divided into three subsamples, using a Riffle divider, for the analysis of damaged grain. The sample weight, number of damaged grains, total live and dead adult insect population, and moisture content were recorded.

Statistical analysis
Data were analysed using the GENSTAT package. Initially a split-plot analysis of variance was used to assess the differences between treatments and to take account of the fact that repeated measures were taken over time. Orthogonal contrasts were used to compare: Untreated control vs Treatments; Actellic Super dust vs Inert dusts; Dryacide vs Protect-it; 0.1% w/w vs 0.2% w/w (in 1998/99 storage season) and 0.05% w/w vs 0.1% w/w (in 1999/2000 storage season). Antedependence modelling of the data, coupled with further analysis of data for each time period using an analysis of variance adjusted for covariate effect of previous time point was undertaken. This enabled the data to be tested for statistically significant differences between treatments taking the correlations between successive measurements into account.

Results

First storage season 1998/99

Maize - Buhera -1998/99
Throughout the 40 week storage period, no significant differences were found between the synthetic chemical grain protectant Actellic Super and the inert dusts (Dryacide and Protect -it), or between either of the two inert dusts or the two concentrations (0.1% and 0.2% w/w) used (Fig 1.3.2a). From 16 weeks storage onwards the damage levels between the untreated control and all the protectant treatments were highly significant (F pr. <0.001).

The main insects present in all treatments for the initial 8 weeks were *Sitophilus zeamais* and *Sitotroga cerealella* (Fig 1.3.3a). In the Actellic Super dust and Protect-it 0.2% w/w treatments very little increase in insect numbers occurred during the 40 weeks storage trial. In the Dryacide 0.1% and 0.2%w/w, and Protect-it 0.1% treatments populations of *Tribolium castaneum* began appearing after 32 weeks storage. In the untreated control treatments, *S. zeamais* populations increased dramatically from 16 weeks onwards, reaching peak populations of 600 adult insects per kg by week 32 prior to decreasing to ~400 insects pre kg. Populations of *T. castaneum* appeared and *S. cerealella* disappeared at 24 weeks storage.

Maize - IAE -1998/99
As with Buhera throughout the 40 week storage period, no significant differences were found between the two inert dusts (Dryacide and Protect-it), or between the two concentrations (0.1% and 0.2% w/w) used (Fig 1.3.2b). From 8 weeks storage onwards damage in untreated control was significantly higher than in all the protectant treatments (F pr. 0.001). Damage incidence was lower in the Actellic Super dust treatments than in the inert dusts, this difference was significant from 8 weeks storage onwards (F pr. <0.043).

Insect population trends were similar to those in the Buhera trials, although the populations remained lower in all the grain treatments (Fig 1.3.3b). In the untreated control *S. zeamais* was the most abundant pest increasing to >1100 adults insects/ kg by 40 weeks storage.

Sorghum - Binga - 1998/99
Sorghum damage levels were much lower throughout the storage period than those in the maize and cowpea studies. However, differences between damage in the untreated controls and the protectant treatments were observed from 16 weeks storage onwards (Fig 1.3.2c). By week 32 damage in the lower Dryacide concentration (0.1%w/w) treatments had increased suddenly. This sudden damage increase at week 32 in the Dryacide 0.1% w/w may be a reflection of the difficulty in controlling *Rhyzopertha dominica* (FigX.). Further analysis using different orthogonal contrasts revealed that, from 32 weeks storage onwards damage levels in all the treatments except Dryacide 0.1% w/w were significantly lower than the untreated control, and that the Actellic Super dust treatment was not more effective than the Protect-it 0.1% w/w and 0.2% w/w and Dryacide 0.2% w/w.

At the start of the storage season *S. oryzae* was the most abundant pest in all treatments, however its populations did not increase as rapidly as in the maize trials, numbers remained below 100 adult insects per kg throughout the trial period (Fig 1.3.3c). In both the untreated control and the Dryacide 0.1% w/w treatments with the highest damage levels, large populations of *R. dominica* began to develop from 24 weeks onwards. The *R. dominica* populations in the Dryacide 0.1%w/w treatments exceeded those in the control from 32 weeks onwards, reaching a population of 900 insects/kg by week 40.

Cowpeas - Buhera -1998/99
Throughout the 40 week storage period, damage levels between the two inert dusts (Dryacide and Protect-it) and between the different concentrations of inert dusts (0.1% and 0.2% w/w) were not significant (Fig 1.3.2d). Insect damage in the untreated control began to rise steeply from 16 weeks storage onwards, and were significantly different than all the treatments from week 8 onwards (p <0.035). At week 32 damage in the synthetic chemical protectant treatment Actellic Super dust became significantly lower than the inert dust treatments (p = 0.033).

The main storage pest was *Callosobruchus rhodesianus* which reached populations of >3500 adult insects per kg in the untreated control by week 24, before decreasing (Fig 1.3.3d). Populations in all the grain protectant treatments remained below 180 adult insects per kg throughout the 40 week trial period.

Figure 1.3.2a. Insect damage to maize grain treated with diatomaceous earths or synthetic chemical protectants during the 1998/99 storage season in Buhera district, Zimbabwe (n=4).

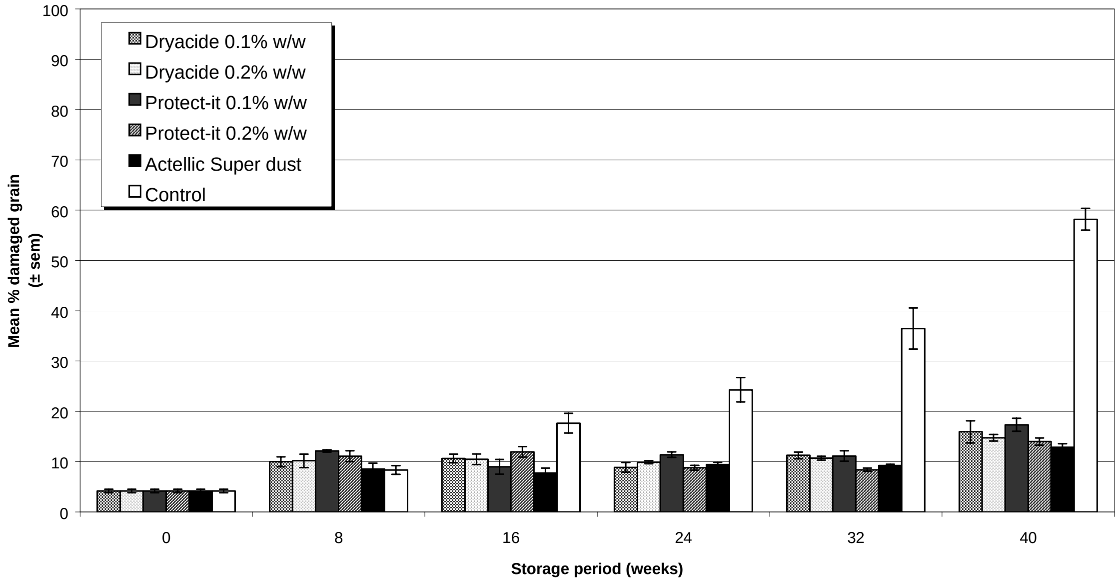


Figure 1.3.2b. Insect damage to maize grain treated with diatomaceous earths or synthetic chemical protectants during the 1998/99 storage season at IAE, Harare, Zimbabwe (n=4).

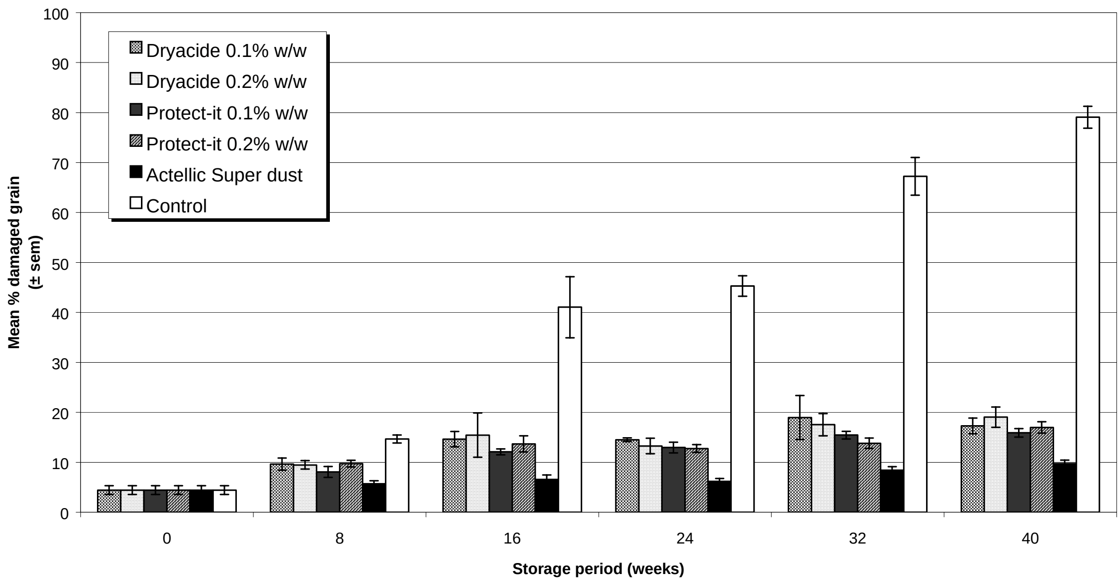


Figure 1.3.2c. Insect damage to sorghum grain treated with diatomaceous eaths or synthetic chemical protectants during the 1998/99 storage season in Binga district, Zimbabwe (n=4).

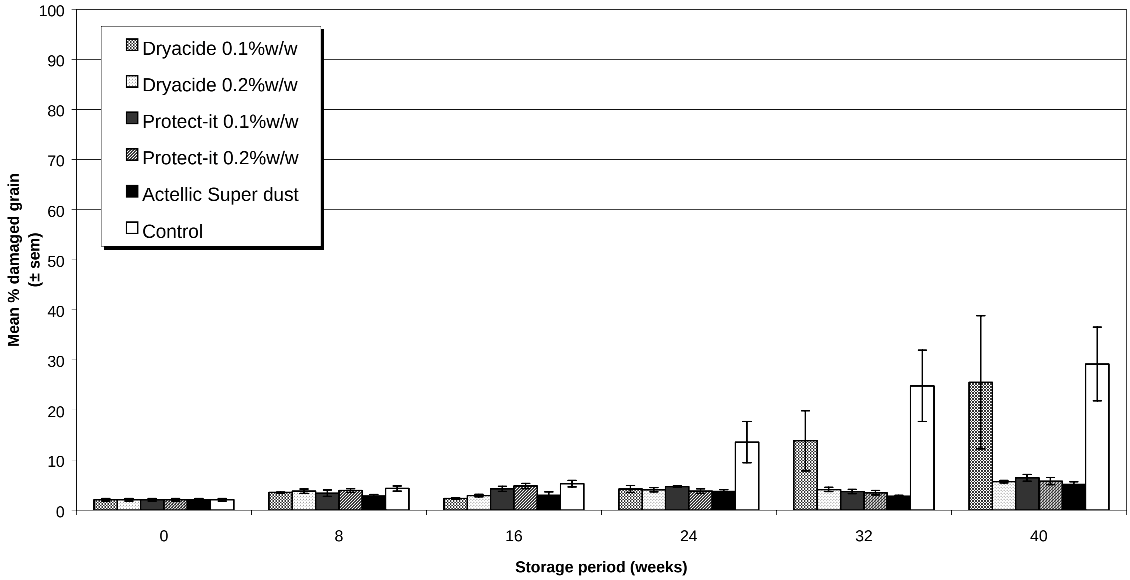


Figure 1.3.2d. Insect damage to cowpeas treated with diatomaceous earths or synthetic chemical protectants during the 1998/99 storage season in Buhera district, Zimbabwe (n=3).

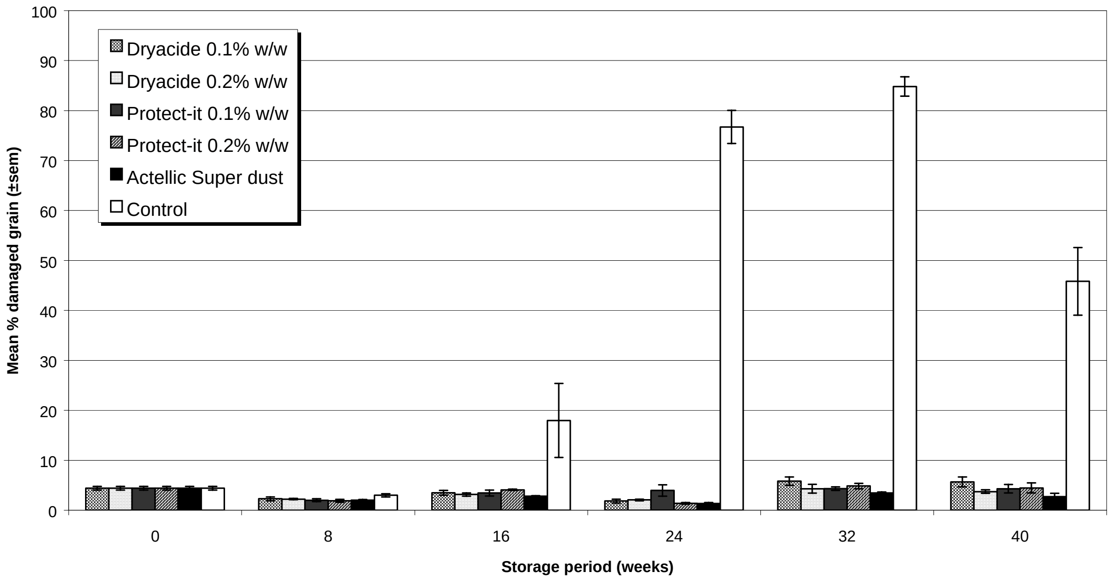


Figure 1.3.3a. Comparison of mean total number of insects per kg of maize in treated and untreated 1.5kg samples during the 1998/99 storage season in Buhera district, Zimbabwe (n=4).

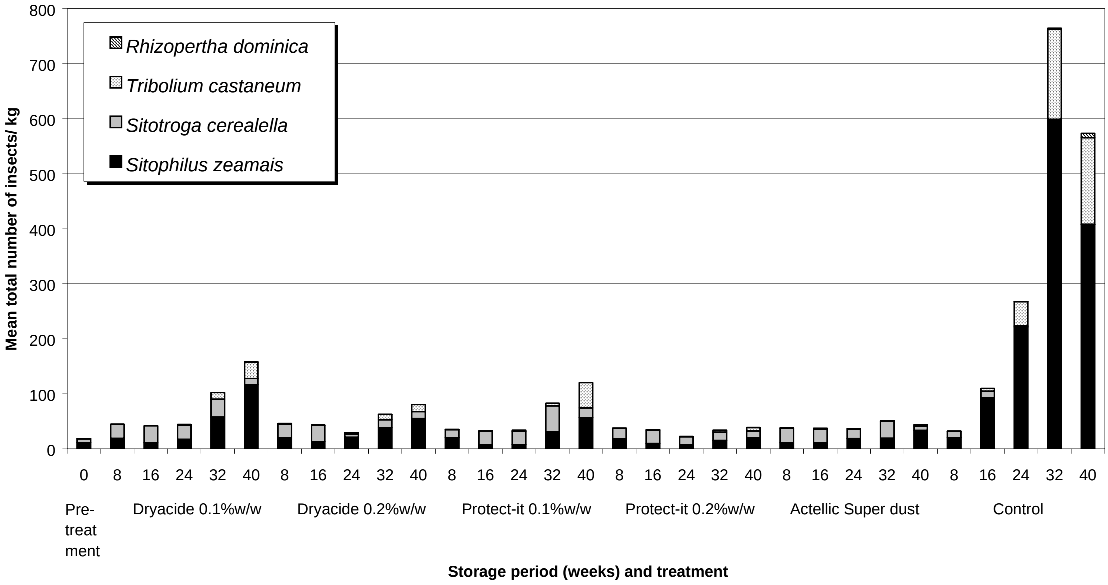


Figure 1.3.3b. Comparison of mean total number of insects per kg of maize in treated and untreated 1.5kg samples during the 1998/99 storage season, at IAE, Harare, Zimbabwe (n=4).

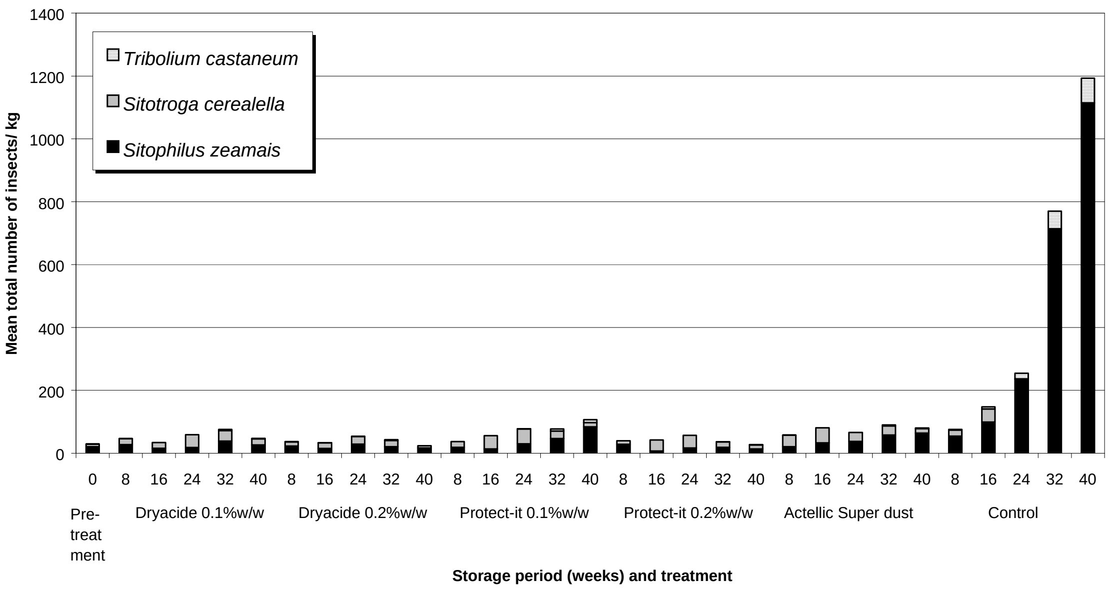


Figure 1.3.3c. Comparison of mean total number of insects per kg of sorghum in treated and untreated 1.5 kg samples during the 1998/99 storage season in Binga district, Zimbabwe (n=4).

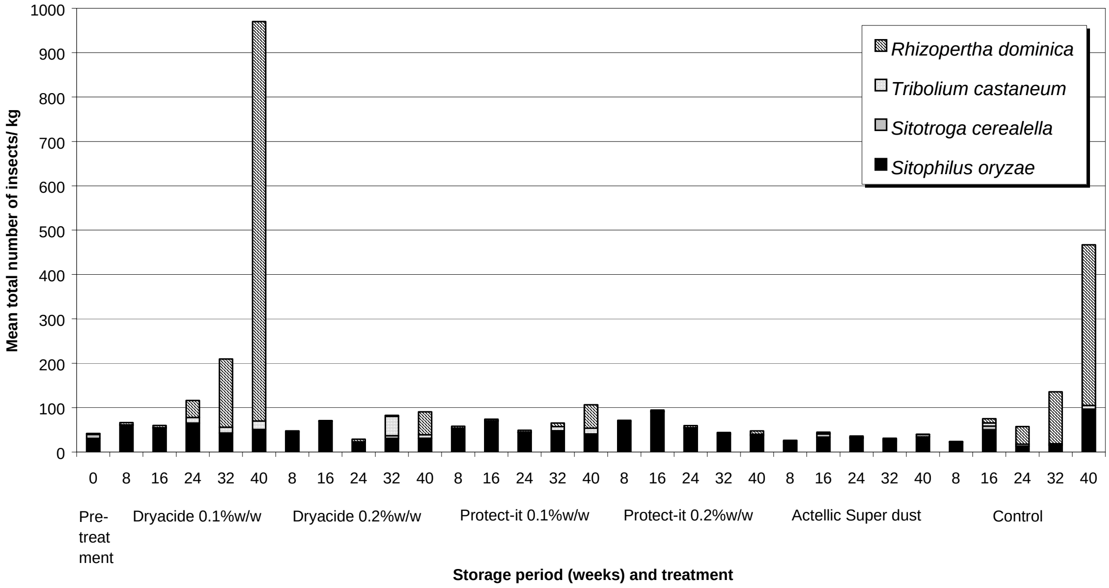
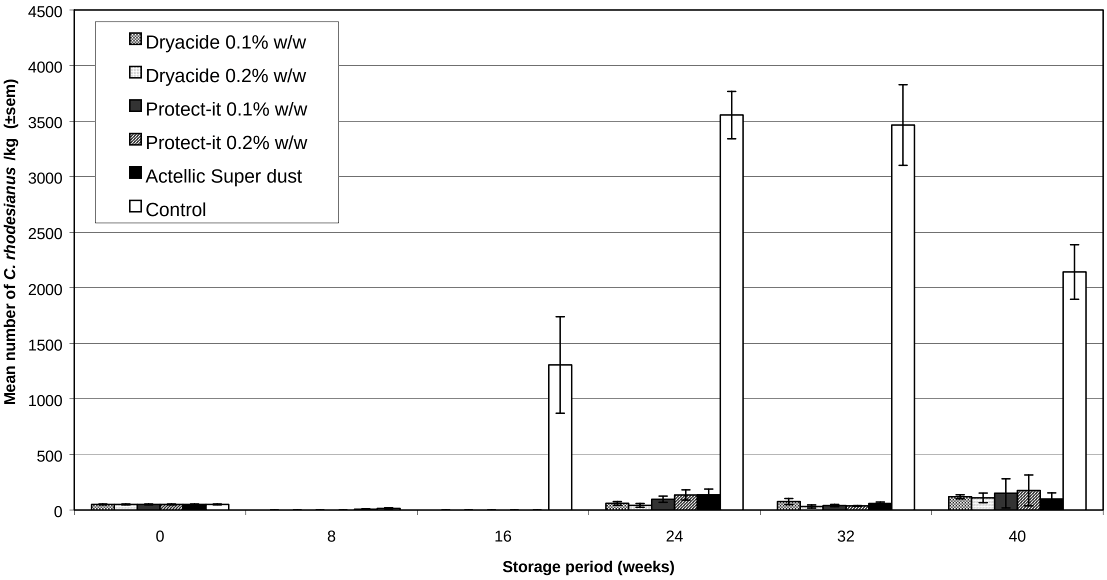


Figure 1.3.3d. Mean total number of *Callosobruchus rhodesianus* per kg of cowpeas in treated and untreated 0.5kg samples during the 1998/99 storage season in Buhera district, Zimbabwe (n=4).



Second storage season 1999/2000.

Maize - Buhera -1999/2000
As during the first storage season, insect damage in the untreated control began to increase rapidly from 16 weeks storage onwards, becoming significantly higher than the treatments (Fig 1.3.4a). By week 32 a difference also appeared between the two inert dusts, with damage levels in the Dryacide treatments becoming higher than those in the Protect-it treatments ($p = 0.008$), this difference had increased further by week 40 ($p = 0.006$).

Insect populations were initially low and composed mainly of S. cerealella and S. zeamais. By week 16, insect populations in the untreated control, Dryacide 0.05% w/w and Protect-it 0.05% w/w began to increase (Fig 1.3.5a). The population increase was most rapid in the untreated control, mainly due to *S. zeamais*, with a smaller population of *T. castaneum* appearing by week 40.

Maize - IAE -1999/2000
As during the first storage season, insect damage in the untreated control began to increase rapidly from 16 weeks storage onwards, becoming significantly higher than the treatments ($p <0.001$) (Fig 1.3.4b). From 24 weeks storage higher damage occurred in the lower (0.05% w/w) inert dust concentrations than in the 0.1% w/w. This difference between the concentrations increased during the remainder of the storage period. By 40 weeks storage differences between damage in the Dryacide and Protect-it treatments were significant ($p = 0.01$), as were differences in the damage in the Actellic Super dust and the inert dusts ($p = 0.005$). Comparison of the 1998/99 and 1999/2000 data sets shows that damage levels for the equivalent treatments and the untreated controls were higher overall during the second storage seasons (Figs. 1.3.2b&1.3.4b).

S. zeamais populations began to increase rapidly in the untreated control from 16 week onwards, by week 24 a sudden increase in insect numbers also occurred in the Dryacide 0.05%w/w treatments (Fig 1.3.5b). From 32 weeks onwards populations of *T. castaneum* were evident in all treatments. Insect numbers were lowest throughout the storage period in the Actellic Super dust and Protect-it 0.1% treatments. By week 40, *S. zeamais* and *T. castaneum* populations in the Dryacide 0.05%w/w exceeded those of the untreated control.

Sorghum - Binga -1999/2000
From 16 weeks storage onwards, insect damage began to increase in the untreated control treatments (Fig 1.3.4c). However, insect damage in the lower concentrations (0.05%) of both inert dusts also increased rapidly and exceeded that of the untreated control from 24 weeks onwards. During the first storage seasons (1998/99) a similar observation was made for the 0.1% w/w Dryacide treatment. This effect of the Dryacide 0.1% w/w has been repeated during the second season, and the reduction of the application rate has magnified the effect. These results suggest that the low concentrations of the inert dusts (Dryacide 0.1% w/w and 0.05% w/w and Protect -it 0.05% w/w) are not only failing to control the major insect pests of sorghum in this area, but may actually be negatively affecting the natural enemy population, hence the presence of much greater damage than in the untreated control. In the Protect-it 0.1% w/w and the Actellic Super dust treatments insect damage remained lower than the control throughout the 40 weeks storage, although the difference was only significant at weeks 16 and 24. Damage in the Actellic Super dust

treatment was significantly lower than the inert dust treatments from 16 weeks storage onwards.

Total insect numbers correlate well with damage levels for all treatments. Damage levels increased most rapidly in treatments with large *R. dominica* populations. Of the DE treatments lowest insect numbers were found in the Protect-it 0.1%w/w treatments (Fig 1.3.5c). However, these were still higher than those in the Actellic Super dust and untreated control treatments.

Small numbers of the hemipteran predator *Xylocoris* spp. were also found in samples after 16 weeks storage, mainly in the untreated control treatments (<21 specimens per kg), and in smaller numbers in both concentrations of the Dryacide treatments. Very small numbers of hymenopteran wasps were also observed in many of the samples.

Fig 1.3.4a. Insect damage to maize grain treated with diatomaceous earths or synthetic chemical protectants during the 1999/2000 storage season in Buhera district, Zimbabwe (n=4).

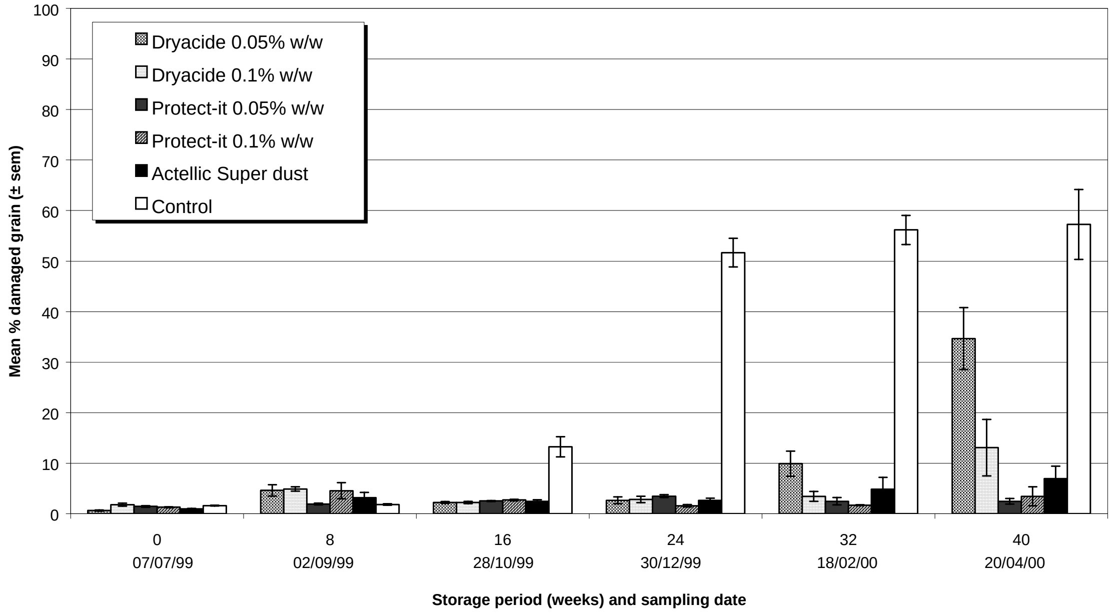


Fig. 1.3.4b Insect damage to maize grain treated with diatomaceous earths or synthetic chemical protectants during the 1999/2000 storage season at IAE, Harare, Zimbabwe (n=3).

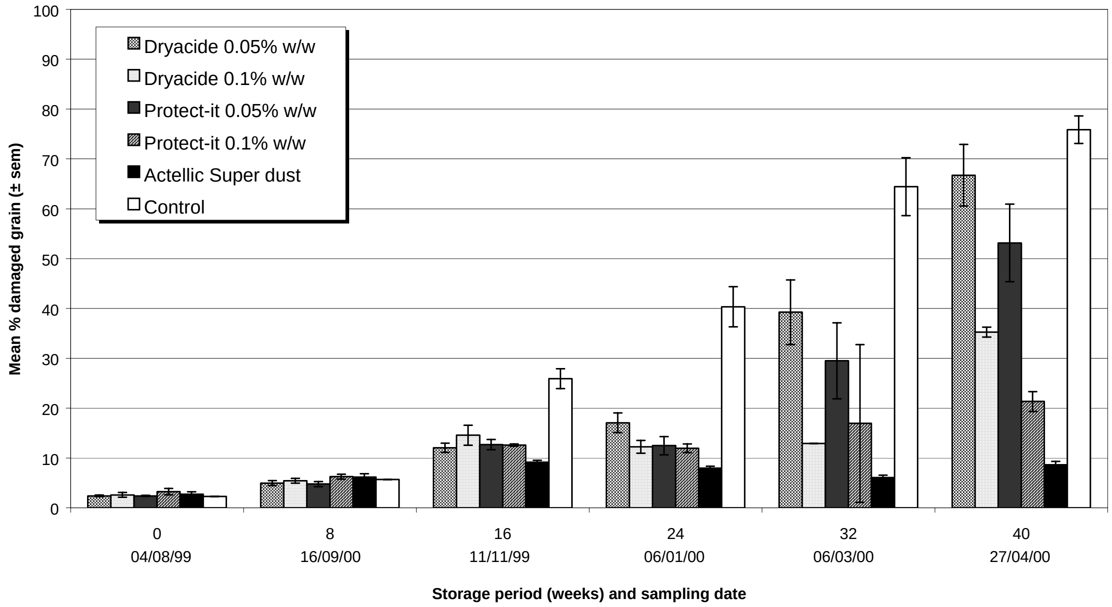


Figure 1.3.4c. Insect damage to sorghum grain treated with diatomaceous earths or synthetic chemical protectants during the 1999/2000 storage season in Binga district, Zimbabwe (n=4).

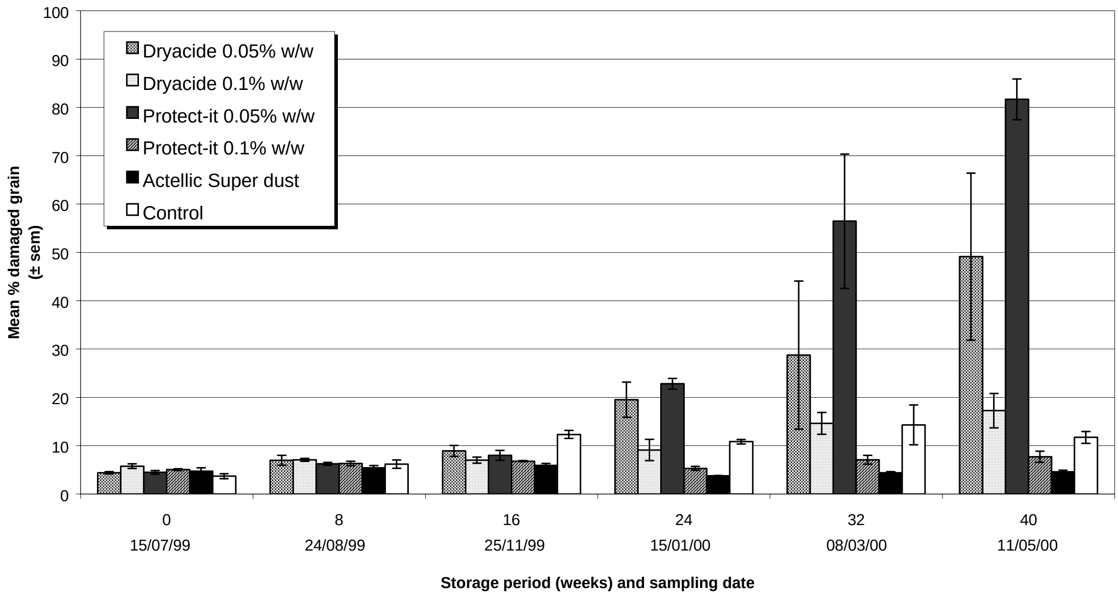


Figure 1.3.5a. Comparison of mean total number of insects per kg of maize in treated and untreated 1.5 kg samples during the 1999/2000 storage season in Buhera district, Zimbabwe (n=4).

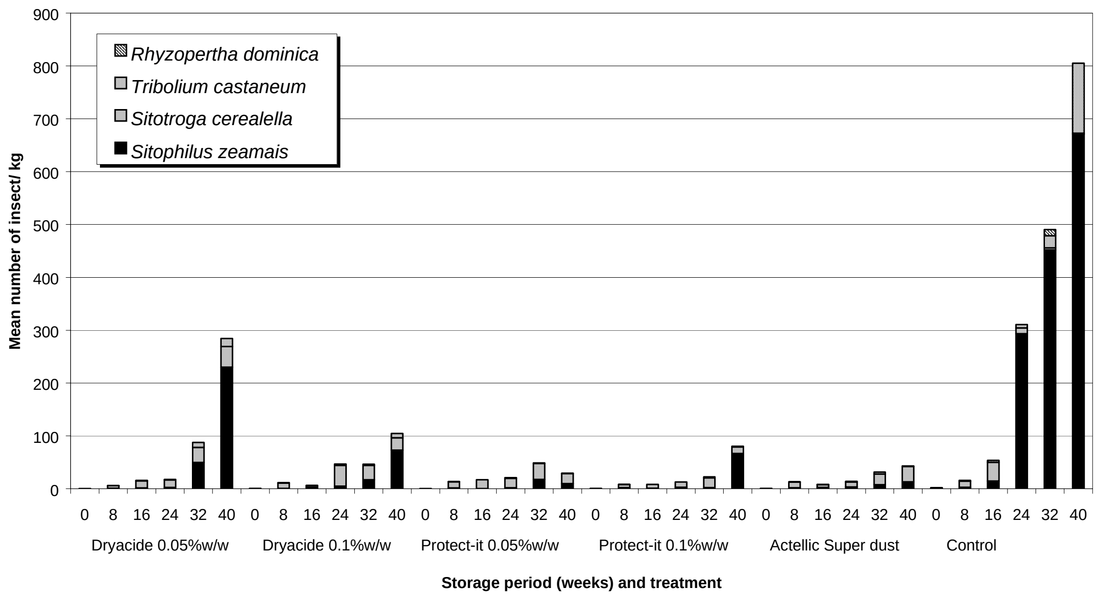


Figure 1.3.5b. Comparison of mean total number of insects per kg of maize in treated and untreated 1.5kg samples during the 1999/2000 storage season at IAE, Harare, Zimbabwe (n=3).

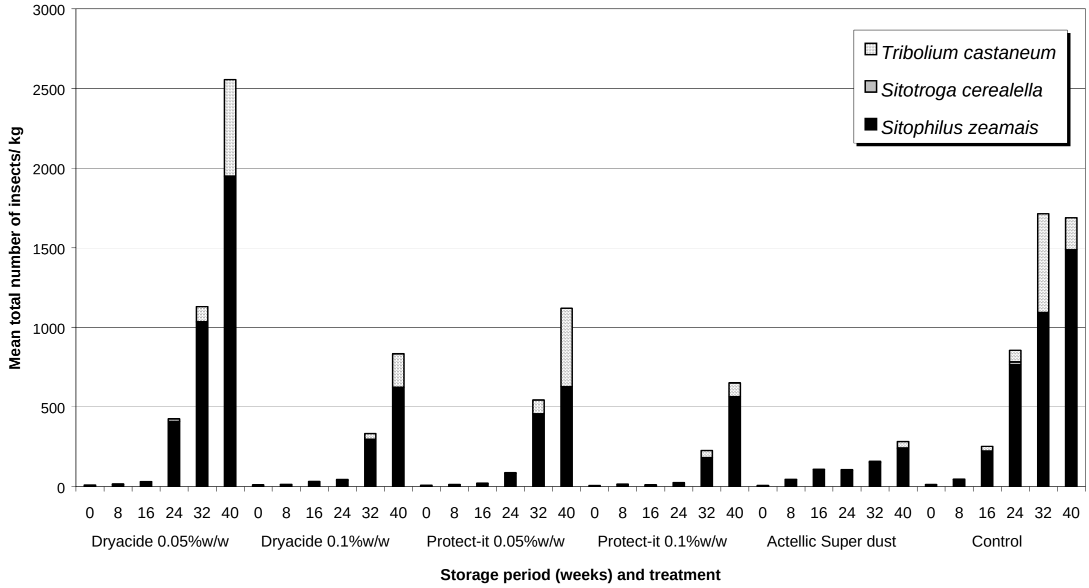
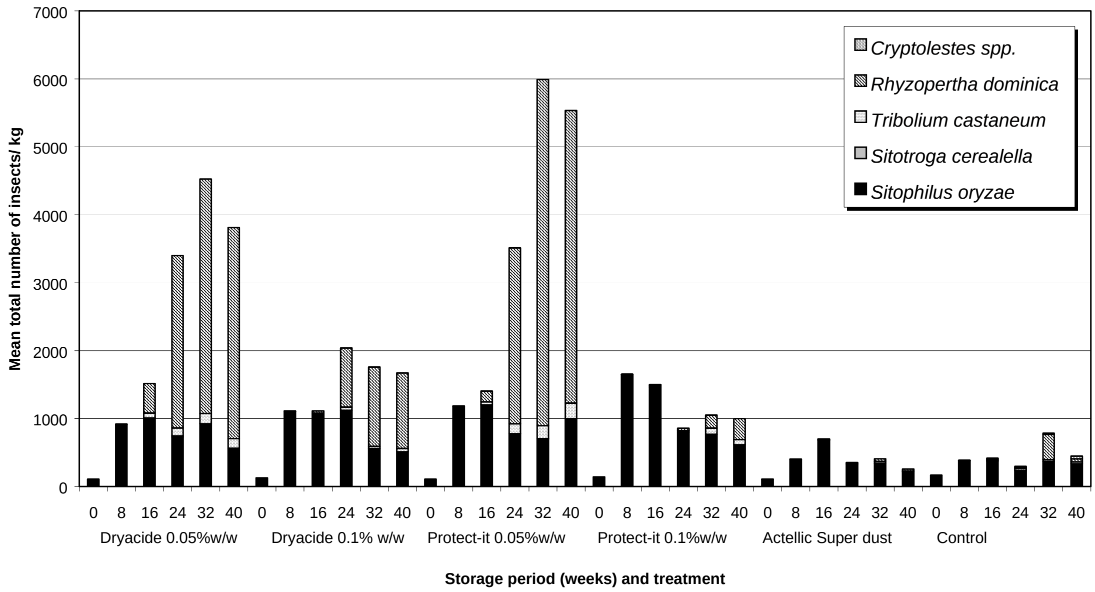


Figure 1.3.5c. Comparison of mean total number of insects per kg of sorghum in treated and untreated 1.5kg samples during the 1999/2000 storage season in Binga district, Zimbabwe (n=4).



Discussion

The results demonstrate that Protect-it™ and Dryacide® can be extremely effective and persistent grain protectants against the major insect storage pests attacking sorghum, maize and cowpeas for storage periods of 40 weeks in the climatic conditions found in Zimbabwe. However, the efficacy of these diatomaceous earths is closely linked to the application concentration, and can be seen to differ between commodities.

During the first season, both concentrations (0.1% w/w and 0.2% w/w) of Protect-it and Dryacide effectively controlled insect damage in maize and cowpeas. However, Dryacide 0.1% w/w did not protect threshed sorghum grain against insect damage and high numbers of *R. dominica* developed. Due to the efficacy of both Protect-it and Dryacide in protecting maize and cowpeas during the first season, a reduced concentration (0.05% w/w) of these two inert dusts was included during the second seasons trials. The reduced concentration (0.05% w/w) of both Protect-it and Dryacide was not found to be effective in preventing insect damage in either maize or sorghum. Although there was a large difference in the results of the Protect-it 0.05%w/w treatment on maize grain between the Buhera and Harare sites, efficacy appears to be highly location specific.

It is concerning that the application rate of 0.05%w/w Dryacide and Protect-it and 0.1% Dryacide on sorghum resulted in damage levels higher than those observed in the untreated control. This may be due to the low efficacy of the DEs against the bostrichid beetle *R. dominica* coupled with their negative effect on the natural enemy population. The hymenopteran insect, *A. calandrae* has been found to be highly susceptible to DEs mainly because of its thin cuticle (Perez-Mendoza *et al*., 1999). In the absence of their natural enemies, insect pests can multiply fast causing more damage in the treated grain than untreated where the natural enemies can thrive. Further studies would be needed in order to understand this relationship. These results suggest that treatment of sorghum with low application rates of inert dusts will actually increase a farmer's storage losses. It is important that this fact is openly discussed to prevent farmers' unnecessarily reducing their food security.

In both seasons trials very low damage levels were encountered in all the protectant treatments and the untreated control during the first 16 weeks, indicating that grain treatment in these areas of Zimbabwe would be unnecessary for any grain which is to be stored for only 4 months or less.

Conclusion and recommendations

These results suggest that an application rate of 0.1% w/w of either Protect-it or Dryacide can be recommended to protect both maize and cowpeas grain that is to be stored for four months or longer in the three areas of Zimbabwe studied during these trials. However, Dryacide does not appear to be effective in preventing damage to sorghum grain unless used at the relatively high concentration of 0.2% w/w. Therefore Protect 0.1% w/w is a more effective grain protectant and recommended for registration.

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