CROP POST HARVEST PROGRAMME

Grain Storage Pest Management using Inert Dusts

R7034

FINAL TECHNICAL REPORT

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Acronyms and Abbreviations

AEW    Agricultural Extension Workers
AGRITEX  Department of Agricultural Technical and Extension Services
CPHP    Crop Post Harvest Programme
CTH    Constant Temperature and Humidity
DE    Diatomaceous Earths
DFID    Department for International Development
DR&SS    Department of Research and Specialist Services
IAE    Institute of Agricultural Engineering
mc    moisture content
NRI    Natural Resources Institute
rep    replicate
rh    relative humidity
UZ    University of Zimbabwe

Acknowledgements

The authors would like to thank the farmers and AGRITEX staff from Binga and Buhera districts, for their active participation in the field trials and for their generous hospitality. Particular thanks go to Andrew Tseurayi and the Guwa family of Buhera, Gibson Tokotore and Shadrick Muleya of Binga. During the course of this project a huge number of samples were analysed and several million insects were counted. This could not have been achieved without the skill and support of Ngoni Shonhiwa, Rodrick Kuseri, Munyaradzi Chavhunduka and Tawanda Chisango, at the IAE Post-harvest laboratory in Zimbabwe and Matt Denniff, Caroline Talbot and Peter Spencer at the NRI laboratory in UK. The authors are grateful to the management of AGRITEX (through IAE) and NRI (through Food Systems Department) for providing an enabling environment during the implementation of this project. Thanks also go to David Jeffries, Denash Giga and Czech Conroy for their advice on specific aspects of the work.

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Executive Summary

Farmers and traders in sub-Saharan Africa incur serious losses to stored produce and are frequently forced to sell prematurely, because of insect damage. Although synthetic chemical pesticides can control insect damage in stored produce, many producers fear mixing them with their food. Inert dusts, particularly diatomaceous earths (DE) offer a safer alternative to synthetic chemicals, but information on their efficacy under small scale farming conditions is limited.

Diatomaceous earths consist of the fossils of phytoplanktons (diatoms), which are mainly composed of amorphous hydrated silicates. When insects come into contact with the DE particles, the waxy fat and lipids are adsorbed from their cuticles resulting in water loss, dehydration, and death. DEs have extremely low toxicity to mammals, and are commonly used in cattle, poultry, and dog feeds to combat internal parasites.

A collaborative project between the Natural Resources Institute and the Institute of Agricultural Engineering in Zimbabwe was developed to study the potential of DEs as alternative grain protectants to organophosphates. This research was funded by the UK Department for International Development’s Crop Post-Harvest Programme.

The project aimed to develop methods for treating grain and storage structures with DEs.

Laboratory trials found the DEs Protect-it™ and Dryacide® were persistent in protecting stored maize, cowpeas and beans against insect damage. DE efficacy increased at lower relative humidities, and insect species differed in their susceptibility to the DEs. Studies that subjected insect species to sub-lethal doses of DEs and then exposed survivors to increasing concentrations, suggested the development of tolerance by *Sitophilus zeamais* but not by *Prostephanus truncatus*.

On-farm trials in three districts in Zimbabwe demonstrated that DEs are extremely effective and persistent grain protectants against the major insect pests attacking sorghum, maize and cowpeas in storage.

During the first season’s trials, the treatments included the DEs, Protect-it™ and Dryacide® at two concentrations (0.1% and 0.2% w/w) and a synthetic conventional insecticide, Actellic Super dust. Damage levels remained very low in the treatments throughout the 40 weeks storage period, in contrast to the untreated controls. No significant difference was found between damage levels in grain treated with Actellic Super dust and the DE treatments, with the exception of the lower concentrations of Dryacide® on sorghum.

In the second season’s trials, a lower concentration (0.05% w/w) of the DEs was used and the 0.1% concentration repeated. Damage levels on maize and sorghum remained low in both concentrations for the first 24 weeks of storage, after which damage increased in the 0.05% w/w treatments. However, after 24 weeks, sorghum damage in 0.05% w/w treatments was significantly higher than that in the untreated controls. This increased damage may have been the result of the loss of natural enemy insect populations, coupled with less effective control of *Rhyzopertha dominica*.

During evaluations of the farmer-managed inert dust trials in Binga and Buhera districts, the DE treated grain outscored the control/traditionally treated grain for all the farmers’ parameters, including an estimated purchase price. As DEs are not registered for use as grain protectants in Zimbabwe, information on any effects of the DEs on taste/quality could not be gained. Many of the farmers asked where they could purchase Protect-it™.

A simple method of applying liquid suspensions of DEs to surfaces of storage structures, using a paintbrush, was developed. Further experiments found that applications to steel surfaces caused much higher insect mortality than applications to mud surfaces. Even the lower DE aqueous slurry concentration of 3g/m² on steel caused higher mortality than 12g/m² on mud.

The project found the use of DEs to be effective in controlling post-harvest insect pests in maize, sorghum and cowpeas stored under small-scale farmer conditions in Zimbabwe. DEs were as effective
as the locally recommended insecticide, Actellic Super Dust, and provided farmers with a safer and more environmentally sustainable control method. Preliminary studies were conducted on local sources of DE, which were found to control storage pests. Locally available DEs may provide a sustainable and low cost source of DE. Once temporary registration is completed, further work will be needed to assess consumer acceptability and any socio-economic factors influencing the use of DEs by small-scale farmers. Laboratory studies have shown that higher concentrations of DEs are required to control the Bostrichid beetles, *R. dominica* and *Prostephanus truncatus*. Field trials in a *P. truncatus* infested area are needed to ascertain optimum rates and application methods of DEs against this devastating storage pest.

**Background**

Farmers in sub-Saharan Africa are frequently forced to sell stored produce prematurely because of the deterioration due to insect damage which would occur if the storage period was extended (Golob *et al*., 1996; Brice *et al*., 1996; Marsland & Golob, 1996; Donaldson *et al*., 1996). These farmers expressed a desire to be able to maintain grain quality by reducing insect damage, they wanted a method that was not only relatively cheap, but was also not inherently dangerous. Many producers do not use conventional insecticides whether approved for use as a food additive or not, because they are afraid of the toxicity of all such chemicals (Golob *et al*., 1996).

Currently, the best method for protecting grain during storage against insect attack is to apply synthetic organo-phosphate insecticides. Most developing countries have to import the active ingredient needed to formulate the chemicals, using valuable foreign exchange. Nevertheless, these insecticides are frequently unavailable, adulterated or too expensive for farmers, and their misuse can be a health hazard. Although synthetic pesticides can work well, constraints regarding human and environmental safety and insect resistance, have led to increased international regulation that has reduced the number of 'safe' pesticides available for use. One solution to these problems is to introduce more sustainable methods of pest management through low-cost techniques that are more in tune with the needs of both the population and the environment. Inert dusts, particularly diatomaceous earths, offer a safer alternative to synthetic organophosphate insecticides for grain protection, but information of their efficacy under tropical small-scale farming conditions is lacking (Golob, 1997).

Grain market liberalisation has resulted in a burgeoning private trade sector in many sub-Saharan countries. Traders, often small-scale, are taking over storage functions previously the responsibility of para-statal marketing boards. Golob *et al*., (1996), highlighted the storage problems facing Ghanaian traders and their need to maintain a high quality product in order to maximise selling prices. A lack of both training and resources often results in traders being poorly equipped to deal with pest problems. In many instances, Ghanaian traders’ stores were not suitable for fumigation, but could accommodate the application of inert dusts.

**Inert dusts**

The use of inert dusts as grain protectants is not new. Observations of birds and mammals taking dust baths to rid themselves of mites and parasites is believed to have led the Chinese to start using diatomaceous earths in pest control more than 4000 years ago (Allen, 1972). The Aztecs of ancient Mexico are said to have mixed maize with lime to preserve their grain (Golob, 1997). In the Philippines, farmers layer lime with maize cobs to protect against insect damage, while in Honduras lime is mixed directly with the grain (Golob & Webley, 1980). Small-scale farmers in the developing world still use traditional methods of mixing sand, kaolin, paddy husk ash, wood ash and clays with grain as a protectant. However, despite these materials being locally available, the large quantities (>20% by weight) which are characteristically required to exert an effect (Golob & Webley, 1980), puts many farmers off. They are not keen on this level of adulteration of their grain and the cleaning of these huge quantities of ash and sand from the grain is tedious and time consuming.

Inert dusts are dry powders of different origins that are chemically unreactive in nature. They can be divided into five categories differentiated by their chemical composition or level of activity (Golob, 1997).
• Non-silica dusts (includes katelsous (rock phosphate and ground sulphur), lime (calcium hydroxide), limestone (calcium carbonate) and common salt (sodium chloride)).
• Sand, kaolin, paddy husk ash, wood ash and clays.
• Diatomaceous earths (or diatomite)
• Synthetic silicates and precipitated silicates
• Silica aerogels

Synthetic silicates and diatomaceous earths are active at much lower rates of application than the traditionally used grain protectants (sand, ash, lime etc.). However, synthetic silicates are manufactured for industrial uses, have a very high silicon dioxide content, and are very expensive and therefore inappropriate for use as grain protectants.

**Diatomaceous earths**

Diatomaceous earths (DE) consist of the fossils of tiny phytoplanktons (diatoms) that are mainly composed of amorphous hydrated silicates. Diatoms which populate much of the surface layers of the ocean and freshwater lakes, remove silica from the water to make their exoskeletons, which are an amorphous form of silica (Quarles & Winn, 1996; Press & Siever, 1985). When diatoms die, they sink to the bottom and accumulate into a sedimentary layer, which over the centuries builds up and becomes compressed and fossilised into a soft chalky rock called diatomaceous earth. The DE deposit can be quarried, dried and ground reducing both particle size and moisture content. DE is a porous material and is used: in filters to help clarify fruit juices, beers, wine, pharmaceuticals, swimming pool waste, dry cleaning solvents amongst others (Subramanyam & Roesli, 2000); as fillers in paints, plastics, asphalt, as coating agents in fertilisers, as carriers for pesticides (Jefferson & Eads, 1951); as a mild abrasive; as a particle aggregate in industrial absorbents; and as insecticides. Much of the DE being used today originated more than 20 million years ago in the lakes and seas of the Miocene.

DEs exert their effect on insects through physical means. When insects come into contact with the DE particles, waxes are absorbed from the cuticle of the insect resulting in water loss, dehydration, and death (Ebeling, 1971). Early work found that death occurred when 28-35% of the body weight (~60% of the water content) was lost (Ebeling, 1971).

**DEs and safety**

DEs have extremely low toxicity to mammals (e.g. DE rat oral LD$_{50}$, >5000 mg/kg (Subramanyam et al., 1994)), and are considered ‘Generally Regarded As Safe’ by the USA Environmental Protection Authority (Anon., 1991). The US Food and Drug Agency has exempted DE from requirements of fixed residue levels when added to stored grain (Anon,1961). Cattle, poultry and dog owners commonly use DEs as a feed mix to combat internal parasites (Allen, 1972). Since protective amounts of DE on grain are often less than 0.1%w/w, and as 98% of DE is removed during processing (Quarles & Winn, 1996; Desmarchelier & Allen, 1999), DE is not likely to become a health problem for consumers. The only possible health effect comes from long-term chronic exposure to quantities of inhaled dust, and safety precautions need to be taken by workers during DE application. The factors that effect toxicity are the amount of dust inhaled, its particle size and crystalline silica content. During the process of sedimentation, geological forces can convert amorphous silica into forms of crystalline silica including the highly dangerous cristobalite. Crystalline silica is a known carcinogen and cause of lung disease. The US Occupational Safety and Health Administration (OSHA) have established limits for DE, cristobalite and quartz suspended in air. Above these limits workers are required to wear dust masks (OSHA, 1995). Typically DEs must contain <1% crystalline silica. Safety precautions include reducing the amount of dust in the work place, and wearing masks to prevent inhalation. In broad terms, exposure safety limits for amorphous DEs are similar to those for such common materials as cement and lime (Desmarchelier & Allen, 1999).

**Commercial use of DEs**

Many DE dusts are now commercially available, and are registered for use as grain protectants in the following countries: Australia, Brazil, Canada, Croatia, China, Germany, Indonesia, Japan, Philippines, Saudi Arabia, United Arab Emirates and USA. DEs are used for managing stored product insects and mites (Korunic, 1998; Cook & Armitage, 1999; Ling et al., 1999; Mewis & Reichmuth, 1999),
improving fumigation efficiency and for structural treatment (Bridgemann, 1994; Fields et al., 1996). As DEs are natural substances they are approved for organic processing (Quarles & Winn, 1996). They can be applied to empty facilities for disinfection purposes as dry powders or wet aqueous slurries (Bridgemann, 1994), and can also be used in conjunction with aeration and fumigation (Nickson et al., 1994; Bridgemann, 1999). The use of DE as a dust to cap the grain surface in low flow phosphine fumigations is industry practice in bulk handling companies in Eastern Australia (Bridgemann, 1999). The DE layer improves phosphine retention enabling insect-free and residue-free storage in poorly sealed structures (Bridgemann & Collins, 1994).

**DEs as grain protectants**

Insect species differ in their sensitivity to the various DEs (Fields & Korunic, 2000). The most susceptible tend to be those with, large surface to volume ratios, body hair (DE particles collect on the hair) (Carlson & Ball, 1962), thin cuticles (Bartlett, 1951), are protected by low-melting point grease as opposed to a hardened waxy cuticle (Ebeling, 1971), and those that feed on dry grain as opposed to sucking insects (Flanders, 1941). Although there are conflicting results, there is a general consensus that the most sensitive stored product species are in the genus *Cryptolestes*; *Sitophilus* spp. are less susceptible, followed by *Oryzaephilus*, *Rhyzopertha* and *Tribolium* spp., which appear most resistant (Maceljski & Korunic, 1972b; Desmarchelier & Dines, 1987; Korunic & Fields, 1995; Fields & Muir, 1996). Other factors such as climatic conditions and adherence of the DE to the commodity also affect efficacy. La Hue (1972) found that DEs did not adhere as well to maize as to wheat or sorghum.

In small-scale laboratory trials, the admixing of Dryacide 0.1% w/w with wheat led to 100% mortality and 100% progeny control of *Rhyzopertha dominica*, *Tribolium castaneum* and *Sitophilus oryzae* at 25°C and 65% rh (Desmarchelier and Dines, 1987). The same Dryacide concentration admixed with beans controlled the bean bruchids *Acanthoscelides obtectus* and *Zabrotes subfasciatus* in laboratory studies in Zimbabwe (Giga & Chinwanda, 1994). A series of precipitated and fumed silicas were screened at NRI and found to be effective in causing adult mortality and reduced progeny emergence of *Prostephanus truncatus* and were shown to be persistent for a 40 week storage period (Barbosa et al., 1994). DEs and silica aerogels provided long-term protection of maize and wheat stored in metal silos during field trials in the US (Quinlan & Berndt, 1966; La Hue, 1977). More thorough reviews of DE use against stored product pests are provided by Subramanyam & Roesli, 2000; Korunic, 1998; Golob, 1997; Quarles, 1992; and Quarles & Winn, 1996.

The addition of a 100g layer of wheat admixed with Dryacide at 0.1% w/w to the top of 900g of untreated *Ephestia cautella* infested wheat effectively ‘moth proofed’ the wheat by preventing adult development of 97% of the population (Desmarchelier & Dines, 1987). However, this top dressing method was less effective against *T. castaneum*, *S. oryzae* and *R. dominica*.

During on-station field trials in Malawi both Dryacide (1-3g/kg) and Protect-it (0.1-5g/kg) failed to protect shelled or cob maize against insect damage (Gudrups et al, 1999). However, very little information exists on the efficacy of DEs for insect pest control in farm stores in developing countries.

In recent years, the effectiveness of conventional insecticides as fabric treatments for grain stores has been called into question (Gudrups et al., 1994). In Australia, Dryacide has replaced these compounds and is widely used for structural treatment in wheat and rice stores (Desmarchelier et al., 1993). It is applied either as a dust at 2g/m² or as a 10% aqueous slurry to provide 6 g/m². The use of DE slurries reduces worker exposure to inhaling DE particles during application. Although Dryacide remains sufficiently active to exert control when applied as an aqueous suspension, other inert dusts lose their efficacy when applied in this way (Maceljski & Korunic, 1972a; McLaughlin, 1994).

It is frequently stated that the development of insect resistance to DE is unlikely, due to the physical as opposed to chemical mode of action of DE insecticides (Quarles & Winn, 1996; Ebeling, 1971). However, little investigation into this subject has occurred.

Most of the work undertaken to investigate insect response to inert dusts has been conducted to observe acute effects on adult mortality under rigidly controlled experimental conditions in the laboratory. There is little information on: the effect on insect fecundity; the persistence of the treatments; or the effects on mixed populations of insects, particularly where moths, such as *Sitotroga cerealella*, occur in sorghum and maize.
Despite the efficacy of DEs, and the ever-increasing emphasis on reduction of environmental contamination, current regulations mean the future use of DEs directly applied to grain remains limited (Korunic, 1998). These regulations (present in many countries) limit the addition of any dust to grain intended for export to other countries. Moreover, the grains are often graded for quality on the basis of bulk density (test weight). DE treatment reduces the bulk density as DE particles get between grains increasing the volume of the stored grain, resulting in a lower test weight and price (Quarles, 1992). DE treatment also alters the angle of repose and flowability of grain, which has implications for large-scale grain handling. However, for small-scale storage of grain intended for home consumption or local trade DEs offer a realistic alternative to organophosphates. Compounds such as Dryacide are cost-competitive with organophosphate insecticides and are effective for many farm-storage requirements (Golob, 1997). Furthermore, if DE deposits occur locally, they could potentially be exploited to provide a low-cost source of grain protection.

In 1996 and 1997, farmers in four districts in Zimbabwe (Buhera, Binga, Mutoko and Chivi) ranked the need for improved methods of storage pest control as a priority issue during post-harvest needs assessment exercises (Donaldson et al., 1996; Boyd et al., 1997; Donaldson et al., 1997; Marange et al., 1997; Douglass et al., 1997). In response to these findings a collaborative project between the UK Natural Resources Institute (NRI), the Institute of Agricultural Engineering (IAE), University of Zimbabwe (UZ) and the Plant Protection Research Institute (PPRI) in Zimbabwe was developed to study the potential of DEs as alternative grain protectants to organophosphates. The two DEs used in this project were Protect-it™ (Hedley Technologies Inc., 2600 Skymark Avenue, Suite 101, Building 4, Mississauga, Ontario, L4W 5B2, Canada), and Dryacide® (Dryacide Australia Pty Ltd., P.O.Box 38, Scarborough 6019, Western Australia). Both these DEs are enhanced DEs containing silica aerogel, which increases their efficacy against insects (Korunic & Ormesher, 1999). This report describes the activities and findings of this project.

**Project Purpose**

Environmentally sustainable and safe post-harvest pest and pathogen control methods and procedures developed and promoted.

Specifically, the project purpose was to develop environmentally sustainable and safe post-harvest pest control methods, by working towards the replacement of conventional synthetic organophosphate insecticides with inert dusts for use in small and medium scale storage. The project addressed the identified constraint through a series of trials using the diatomaceous earths Protect-it™ and Dryacide®.
Research Activities

1.1 Laboratory assessment on the persistence of Dryacide® and Protect-it™ admixed with commodity against four beetles.

Introduction

Much of the work undertaken to investigate insect response to inert dust has been conducted to observe acute effects on adult mortality under rigidly controlled experimental conditions in the laboratory. Little information exists on the effect on insect fecundity or on the persistence of the DE treatments. A need was identified to add to the information already accrued concerning inert dusts as grain protectants, particularly against tropical storage pests on a range of commodities. Laboratory trials using diatomaceous earths (DEs) against *Sitophilus zeamais*, *Prostephanus truncatus*, *Callosobruchus maculatus*, *Acanthoscelides obtectus* and *Rhyzopertha dominica* would be used to both estimate appropriate field trial DE application rates and persistence (Trial a). The DEs used were Dryacide® and Protect-it™. During 1998, the production site of Protect-it™ was changed from Canada to the US. As a result, further trials were required to ensure a similar level of efficacy between the different sources of Protect-it™ (Trial b). Field and laboratory results suggested that DEs were less effective against the Bostrichid beetles *P. truncatus* and *R. dominica*. This was thought likely to be due to their behavioural characteristics of boring and tunnelling, and because they develop internally and are protected from direct exposure to the DEs. Subramanyam & Roesli (2000), also found *P. truncatus* and *R. dominica* suffered only low mortality when exposed to corn treated with another DE, Insecto, at 1g/kg. Further work was initiated to investigate the effect of a range of increased DE application rates on these beetles (Trial c).

Materials and Methods

Insects

Trial insects (*P. truncatus*, *S. zeamais*, *C. maculatus*, *A. obtectus* and *R. dominica*) were cultured in three litre glass jars under controlled conditions (CTH room at 27±5°C, 60±5%rh, 12:12 light:dark). *P. truncatus* and *S. zeamais* were reared on maize (*Zea mays*), *C. maculatus* on cowpea (*Vigna unguiculata*), *A. obtectus* on red kidney bean (*Phaseolus vulgaris*) and *R. dominica* on sorghum (*Sorghum vulgare*). Known age insects were collected by removing adults from a culture by sieving 4-5 weeks after it was set up. Seven days later, the culture was sieved again to remove any 0-7 day old adults that had emerged since the previous sieving. These 0-7 day old adults were placed on fresh commodity for a further 7 days, by which time all insects were known to be 7-14 days old. These insects were counted and used in the trials. Due to their relatively short adult life, 0-3 day old *A. obtectus* and *C. maculatus* insects were used in the trials.

Admixture trials

The three sets of admixture trials conducted were:

a) Efficacy and persistency of Protect-it (Canadian) and Dryacide (Australian) against four stored product pests attacking maize, cowpeas and kidney beans stored.

b) Comparative efficacy and persistency of Protect-it from two different origins (Canada and US) against stored product pests attacking maize and cowpeas stored.

c) Efficacy of different application rates of diatomaceous earths against the Bostrichid beetles *P. truncatus* and *R. dominica* on maize and sorghum respectively.

For all trials, pre-equilibrated commodity (100g, 27±5°C, 60±5%rh) was placed in 250 ml glass jars, three replicates per treatment were used except for the *R. dominica* trial c) where four replicates per treatment were used. Experimental dosages, target insect species, and commodities are shown in Table 1.1.1. The DEs Protect-it™ (Canadian and US origin) and Dryacide® (Australian origin) were obtained from Hedley Technologies Inc. and Dryacide Australia Pty Ltd. respectively, and were stored at 22°C. The required quantity of DE was added to the weighed commodity in each jar, and shaken by hand for exactly one minute. These trials were also used to assess the persistence of the DEs by exposing insects to treated grain at different intervals (0, 3, & 6 months) after the DE was applied. Forty
unsexed known age insects of one of the four test species were added to each jar. The jars were then sealed with filter paper and molten wax and placed in constant temperature and humidity (CTH) rooms at either 50%rh or 60%rh.

The timing of the adult mortality count differed between trials and for insect species. In trials a) and b), adult mortality counts were made for *A. obtectus* and *C. maculatus* after 72 hours, and for *P. truncatus* and *S. zeamais* after 7 days. In trial c), adult mortality counts were made for *P. truncatus* and *R. dominica* after 2, 7 and 15 days. Adult mortality counts were conducted by gently pouring the contents of each jar onto a tray, counting the live and dead insects and then replacing the contents of each jar. The final count of the number of dead and alive insects in the F1 population was conducted at 49 days for all trials and all insects.

The DE application rates used in each trial are shown in Table 1.1.1.

### Table 1.1.1 Diatomaceous earth application rates used in laboratory trials a), b) and c).

<table>
<thead>
<tr>
<th>Trial</th>
<th>Insects</th>
<th>Commodity</th>
<th>Diatomaceous earth application rates (% w/w)</th>
<th>Humidity % rh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Protect-it (Canadian)</td>
<td>Dryacide (Australian)</td>
</tr>
<tr>
<td>a)</td>
<td><em>P. truncatus</em></td>
<td>Maize</td>
<td>0, 0.1 &amp; 0.15</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td><em>S. zeamais</em></td>
<td>Maize</td>
<td>0, 0.05 &amp; 0.1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td><em>C. maculatus</em></td>
<td>Cowpea</td>
<td>0, 0.02 &amp; 0.03</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td><em>A. obtectus</em></td>
<td>Red Kidney Bean</td>
<td>0, 0.02 &amp; 0.03</td>
<td>0.1</td>
</tr>
<tr>
<td>b)</td>
<td><em>P. truncatus</em></td>
<td>Maize</td>
<td>0, 0.1 &amp; 0.15</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td><em>S. zeamais</em></td>
<td>Maize</td>
<td>0, 0.05 &amp; 0.1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td><em>C. maculatus</em></td>
<td>Cowpea</td>
<td>0, 0.05 &amp; 0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>c)</td>
<td><em>P. truncatus</em></td>
<td>Maize</td>
<td>0, 0.15, 0.25, 0.5, 0.75 &amp; 1</td>
<td>0, 0.15, 0.25, 0.5, 0.75 &amp; 1</td>
</tr>
<tr>
<td></td>
<td><em>R. dominica</em></td>
<td>Sorghum</td>
<td>0, 0.1, 0.125, 0.15, 0.175, 0.2</td>
<td>0, 0.1, 0.125, 0.15, 0.175, 0.2</td>
</tr>
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### Results

#### Trial a) Efficacy and persistence of Protect-it™ (Canadian) and Dryacide® (Australian)

The data for each humidity condition was analysed separately using GENSTAT, a split-plot analysis of variance and orthogonal contrasts were used to compare the Control with the DE treatments; the Dryacide® with the Protect-it™ treatments; and the two Protect-it™ application rates.

The results showed that both DEs increased parental mortality and reduced progeny emergence in all species in comparison with untreated controls at both humidities and for all dust ages (Figs. 1.1.1a-d, 1.1.2a-d). Both DEs were more effective at 50% rh than 60% rh.

*P. truncatus*

At both relative humidities Protect-it™ at either dosage caused higher mortality than Dryacide® (p<0.005) (Fig 1.1.1a). At 50% rh, the effectiveness of Protect-it™ was dose dependent (p=0.023) but not at 60% rh. At the lower rh the effect on mortality persisted throughout the experiment but at 60% the activity had diminished even in the three-month-old treatments.

Progeny production was much lower at 50% rh than at 60% rh (Fig 1.1.2a). At the lower humidity the DE treatments significantly restricted the appearance of progeny throughout the experimental period in comparison with controls (p<0.005). However, at 60% rh the storage period affected numbers which emerged, as after 3 and 6 months fewer adults emerged than at the beginning of the experiment even in controls, suggesting that the commodity itself had become less suitable during this storage period. At the higher humidity, it was only the DE treatments applied 0 and 3 months previously that restricted the appearance of progeny in comparison with controls (p=0.002 and 0.043 respectively).
S. zeamais
At both relative humidities the DE treatments increased mortality in comparison with the untreated controls (p<0.001) (Fig 1.1.1b). At the lower rh the effect on mortality persisted throughout the experiment but at 60% the activity diminished in the three and six-month-old treatments (p<0.001). In general, Dryacide® performed more effectively against S. zeamais than against P. truncatus, however when applied at the same application rates (0.1%w/w) Protect-it™ caused higher mortality than Dryacide®. At both relative humidities the effect of Protect-it™ was dose dependent (p<0.016).

At 50%rh, very few insects emerged from any of the treatments including the controls (Fig 1.1.2b). At 60% rh, treatment age did not affect progeny emergence, and all DE treatments significantly contained F1 emergence to fewer than 40 insects. The DE treatments did not differ in efficacy.

C. maculatus
The DE treatments resulted in increased mortality at both humidity levels in comparison to the untreated controls (p<0.001) (Fig. 1.1.1c).

At 50% rh, all DE treatments significantly reduced progeny emergence (p=0.008). Although the 50% rh progeny emergence data (Fig. 1.1.2c) suggests that the DE treatments were less effective when applied 6 months before, this was not significant. However at 60% rh, the storage period affected numbers that emerged, as after 3 and 6 months fewer adults emerged than at the beginning of the experiment even in controls suggesting that the cowpeas had become less suitable for bruchid development during this storage period. At the higher humidity Protect-it™ was more effective at restricting the appearance of progeny than Dryacide® (p=0.005).

A. obtectus
At both humidity levels the DE treatments resulted in increased mortality in comparison to the untreated controls (p<0.001) (Fig. 1.1.1d). Mortality was affected by the storage period at both humidity levels, although it is uncertain why lower mortality occurred at 60% rh in the 3 months old treatments than in the commodity treated 0 or 6 months previously.

At both humidity levels the DE treatments restricted mean progeny emergence to less than three adult insects, which was significantly lower than the control (p<0.001) (Fig. 1.1.2d).
Fig 1.1.1a  Efficacy and persistence of different diatomaceous earth treatments admixed with maize on the survival of 40 P.truncatus adults after 7 days exposure at two relative humidities (n=3).

Fig 1.1.1b  Efficacy and persistence of different diatomaceous earth treatments admixed with maize on the survival of 40 S.zeamais adults after 7 days exposure at two relative humidities (n=3).

Fig 1.1.1c  Efficacy and persistence of different diatomaceous earth treatments admixed with cowpeas on the survival of 40 C. maculatus adults after 3 days exposure at two relative humidities (n=3).

Fig 1.1.1d  Efficacy and persistence of different diatomaceous earth treatments admixed with red kidney bean on the survival of 40 A.obtectus adults after 3 days exposure at two relative humidities (n=3).
Fig 1.1.2a  Persistency and efficacy of different diatomaceous earth treatments admixed with maize on the F1 emergence from 40 P. truncatus at two humidities (n=3).

Fig 1.1.2b  Persistency and efficacy of different diatomaceous earth treatments admixed with maize on the F1 emergence from 40 S. zeamais at two humidities (n=3).

Fig 1.1.2c  Persistency and efficacy of different diatomaceous earth treatments admixed with cowpeas on the F1 emergence from 40 C. maculatus at two humidities (n=3).

Fig 1.1.2d  Persistency and efficacy of different diatomaceous earth treatments admixed with red kidney bean on the F1 emergence from 40 A. obtectus at two humidities (n=3).
**Trial b) Comparative efficacy and persistency of Protect-it™ from two different origins (Canada and US)**

The data was analysed using GENSTAT, a split-plot analysis of variance and orthogonal contrasts compared: Control vs DE treatments; US vs Can Protect-it™ treatments; Higher vs Lower US Protect-it™ application rates; High vs Lower Canadian Protect-it™ application rates.

Mortality was generally higher and F1 emergence lower at 50% rh in comparison to 60% rh, with the exception of the *C. maculatus* studies (Figs 1.1.3a-c & 1.1.4a-c).

**P. truncatus**
At both humidity levels mortality was higher in the DE treatments than the untreated controls (p≤0.003) (Fig. 1.1.3a). The 0.15%w/w application rate of both US and Canadian Protect-it™ caused greater mortality than 0.1%w/w (p≤0.003) at both humidities. There were no differences in mortality or progeny emergence between the US and Canadian Protect-it™ treatments at either relative humidity.

At the lower humidity level progeny emergence was restricted by the DE treatments in comparison to the untreated control (p<0.001), however at 60%rh this did not occur (Fig 1.1.4a). Progeny emergence was dose dependent for US Protect-it™ at 50% rh (p<0.005). The storage period affected progeny emergence at 60%rh but not at 50%rh.

**S. zeamais**
At both humidities the DE treatments caused greater mortality than the controls (p<0.001) and were dose dependent (p≤0.005) (Fig 1.1.3b). No differences in mortality or progeny emergence occurred between the US and Canadian Protect-it™ at either humidity.

Progeny production was much lower at 50% rh than at 60% rh (Fig. 1.1.4b). At both humidity levels all DE treatments significantly restricted the appearance of progeny compared to the controls (p<0.001), but were only dose dependent at the higher humidity level (p≤0.06). However the storage period also affected adult emergence, suggesting the commodity became less suitable for *S. zeamais* development during this storage period.

**C. maculatus**
At both relative humidities the DE treatments caused greater mortality than the controls (p<0.001), but were only dose dependent at 60% rh (p≤0.027) (Fig 1.1.3c). No differences in mortality occurred between the US and Canadian Protect-it™.

None of the DE treatments significantly restricted progeny emergence in comparison to controls at either relative humidity, and at least 180 adults emerged in all treatments (Fig. 1.1.4c).
Fig 1.1.3a  Efficacy and persistence of US vs Canadian Protect-it admixed with maize on the survival of 40 *P. truncatus* adults after 7 days exposure at two relative humidities (n=3).

Fig 1.1.3b  Efficacy and persistence of US vs Canadian Protect-it admixed with maize on the survival of 40 *S.zeamais* adults after 7 days exposure at two relative humidities (n=3).

Fig 1.1.3c  Efficacy and persistence of US vs Canadian Protect-it admixed with cowpea on the survival of 40 *C.maculatus* adults after 3 days exposure at two relative humidities (n=3).
**Fig 1.1.4a** Persistency and efficacy of US vs Canadian Protect-it admixed with maize on the F1 emergence from 40 *P. truncatus* at two humidities.

**Fig 1.1.4b** Persistency and efficacy of US vs Canadian Protect-it admixed with maize on the F1 emergence from 40 *S.zeamais* at two humidities.

**Fig 1.1.4c** Persistency and efficacy of US vs Canadian Protect-it admixed with cowpeas on the F1 emergence from 40 *C.maculatus* at two humidities.
**Trial c) Efficacy of different application rates of diatomaceous earths against the Bostrichid beetles* P. truncatus and R. dominica on maize and sorghum respectively.**

The data was analysed using GENSTAT an analysis of variance was conducted and eight orthogonal contrasts were used to compare the treatments used in the *P. truncatus* concentration trials.

The DE treatments led to increased mortality compared to the untreated controls (*p* <0.001) (Fig. 1.1.5). Protect-it™ treatments caused significantly greater and more rapid adult mortality than Dryacide® treatments (*p*=0.001). Percentage mortality in the Protect-it™ treatments hardly increased in the period between the 2 and 15-day counts. The third contrast confirmed that the % mortality response to the different application rates of Protect-it™ followed a linear relationship (*p*=0.018). The fourth contrast testing whether the application rate of Protect-it™ followed a quadratic relationship was significant at the 10% level, showing there was a slight curvature in the relationship between the application rates. The orthogonal contrasts also confirmed that the application rates of Dryacide® followed a linear relationship. At the 2 day count, the % mortality for the Dryacide® application rates ranged widely from 8.33% to 60.83% and from 20.83% to 93.33% by the 15 day count.

The DE treatments significantly restricted the appearance of progeny compared to the untreated controls (*p*=0.001), the highest mean number of insects to emerge in the DE treated grain was 88.67 compared to 402.33 in the untreated control (Fig 1.1.5). Adult emergence numbers did not differ between the Dryacide® and Protect-it™ treatments, and for both DEs decreased with increasing concentration following a linear relationship.

![Fig 1.1.5](image)

The effect of a range of US Protect-it and Dryacide concentrations on the percentage mortality and F1 emergence of 40 *P. truncatus* at 27C, 60% rh (n=3).

As field trials in Zimbabwe (see section 1.3) found that DE concentrations of 0.2%w/w were more effective in reducing *R. dominica* damage to sorghum than 0.1%w/w, lower DE application rates were used against *R. dominica* than *P. truncatus* during these trials. Results of the *R. dominica* trials showed all DE application rates caused less than 20% mortality within a 14 day period, with the exception of the Protect-it™ 0.2%w/w treatment which resulted in 26% and 42% mortality after 7 and 14 days exposure respectively (Fig. 1.1.6). Although control mortality was not significantly lower than DE treatments. Further post-hoc contrasts showed mortality in the Protect-it™ treatments was significantly different at all counts (*P*≤0.043).

Progeny emergence was lower in the Protect-it™ treatments than the Dryacide™ (*p*<0.001) and the untreated control (*p*<0.001). Analysis confirmed a linear relationship between Protect-it™ dose and
mortality at all three counts and progeny emergence (p<0.001). No relationship was found for Dryacide®.

Fig. 1.1.6 The effect of a range of US Protect-it and Dryacide concentrations on the percentage mortality and F1 emergence of 40 *R. dominica* at 27°C, 60%rh (n=4).

Discussion

Trial a) Efficacy and persistency of Protect-it (Canadian) and Dryacide (Australian)

This trial showed that DEs could be successfully used against *P. truncatus*, *S. zeamais*, *C. maculatus* and *A. obtectus* to protect stored maize, cowpeas and red kidney beans. The results confirmed earlier findings that DE grain protection was more effective at the lower relative humidity level of 50% rh than 60% rh. Relative humidity affects the rate of water loss and therefore determines the effectiveness of inert dusts. Le Patourel (1986) found a 37-fold increase in silica dust dosage was required on wheat grain at 16%m c, compared to 11%m c in order to obtain the same seven-day LD<sub>50</sub> of *Sitophilus granarius*. DEs are likely to be of less practical use in high humidity locations and in commodities stored during months experiencing high humidity conditions.

At 60% rh, progeny emergence of *S. zeamais* and *A. obtectus* were controlled by the application rates used. However the high progeny emergence of *C. maculatus* and *P. truncatus* suggests that higher DE concentrations should be tested. Insects differ in their susceptibility to inert dusts due to a number of factors described in the main introduction of this report, and as a result different DE application rates are required to control different species. In the field mixed populations of insects are almost always encountered, and it is therefore important to have some idea of the spectrum of pests likely to develop throughout the storage season, to ensure that DEs are applied at adequate application rates.

The results suggest that over the duration of the trial the host commodity became less suitable for insect development and the DE treatments became less effective. This might be due to the DE absorbing moisture during the storage period, so that the DE on grain treated 6 months previously was rendered less effective at absorbing lipids from the insects cuticles when they were added. Another explanation might be that over time the DE absorbed oils from the commodity, inhibiting its action against insects when they were eventually added. Sorption of oils from DE treated rice has been reported (McGaughy, 1972). Lower mortality of *Sitophilus oryzae* and *Tribolium castaneum* was seen by Nielsen (1998) in DE treated milled and brown rice compared to rough rice, and was believed to be due to saturation of the DE by oils from the surface. Similarly, aged deposits of the DE Perma Guard on
milled and brown rice were reported to be less effective than fresh deposits (McGaughey, 1972). Further study of long-term persistence of DEs applied to commodity is needed, and might have important implications for storage conditions of DEs prior to application. The quantity and storage method (e.g. bulk or bag) is likely to effect the efficacy of the DE over time, the moisture content of 100g commodity in a small jar, will change much more rapidly than that of a large bulk of grain.

**Trial b** Comparative efficacy and persistency of Protect-it™ from two different origins (Canada and US) against stored product pests attacking maize and cowpeas at 50 and 60% rh.

The results showed no significant differences between the efficacy of the Canadian and US Protect-it™ sources. As with trial a), the DEs were more effective at 50% rh than 60% rh. In general, doses needed to be increased at the higher humidity level to achieve the same level of control. High progeny emergence of *C. maculatus* occurred despite the increased application rates compared to trial a). At 60% rh, high numbers of *P. truncatus* also emerged from both the 0.1% and 0.15% w/w application rates, suggesting still higher rates are required to control this beetle.

**Trial c** Efficacy of different application rates of diatomaceous earths against the Bostrichid beetles *P. truncatus* and *R. dominica* on maize and sorghum respectively.

This trial showed that these higher concentrations of DE can effectively control *P. truncatus* by increasing adult mortality and reducing progeny emergence, the relationship between these parameters and DE concentration was found to be linear. Protect-it™ was found to be more effective than Dryacide® in causing *P. truncatus* adult mortality, however this did not result in any significant difference in the number of progeny emerging from the two DEs. At concentrations of 0.25% w/w, both Dryacide® and Protect-it™ contained *P. truncatus* F1 emergence. Further studies of a range of concentrations around this application rate would provide more detail on optimal application rates against *P. truncatus*, although these are likely to be effected by climatic conditions. *P. truncatus* is likely to come into contact with DE on the surface of the grain only while searching for a host or mate, as feeding, oviposition and larval development occur within the grain, this may explain its ability to survive at higher DE concentrations than other stored product pests.

None of the DE treatments against *R. dominica* caused more than 50% adult mortality or effectively contained F1 emergence, in fact higher numbers of progeny emerged from the lower Dryacide® treatments than the untreated control. In other trials with adult *R. dominica* and five different DEs (Super Insecolo, Dryacide, Insecto, Insectigone, and Permaguard) at an application rate of 1g/kg, the highest mortality achieved after 14 days was <10% (Subramanyam, unpubl. data). It would be interesting to see if higher DE concentrations could contain progeny emergence. Higher DE application rates will affect the economics of the pest control activities. Bostrichid beetles are known to be sensitive to pyrethroid insecticides (Golob et al., 1985), and it would be interesting to study whether lower DE concentrations can be used if combined with pyrethroids, and whether this could potentially reduce the cost of pest control activities.
1.2 Assessment of the resistance potential of insects to inert dusts

Introduction

Due to the physical as opposed to chemical mode of action of inert dusts, and the fact they reduce insect mobility, researchers have suggested that genetic selection for resistance was unlikely to develop (Quarles & Winn, 1996; Ebeling, 1971), although insects might develop a behavioural response to avoid contact (Golob, 1997; Ebeling, 1971). However little investigation into this subject has occurred. These trials were undertaken to determine the potential for insects to develop resistance to DEs when admixed with the grain and continually exposed to low doses.

Materials and Methods

Resistance potential was assessed by subjecting three storage pest species to sub-lethal doses of the diatomaceous earths Protect-it™ and Dryacide® (Australian), and then exposing the survivors to increasing concentrations of these same dusts. The methodology used was based on that reported by Dyte and Blackman (1967) and Golob et al. (1990) during the assessment of stored product beetles development of resistance to insecticides.

The insect species used were Prostephanus truncatus, Sitophilus zeamais and Callasobruchus maculatus. 80 unsexed adult insects (7-14 days old in the case of P. truncatus and S. zeamais, 1-3 days old in the case of C. maculatus) were added to 200g of commodity admixed with the initial concentration of either Protect-it™ or Dryacide® (see Tables 1.2.1a,b&c for details). Four replicates of each treatment were set up. (Note: P. truncatus and S. zeamais were tested on maize, C. maculatus was tested on cowpeas).

Insect mortality was assessed after 18 days for P. truncatus and S. zeamais, and after 2, 4 and 11 days for C. maculatus, at the final assessment period the 80 adult insects were removed. The number of progeny emerged was recorded 5 weeks after the initial addition of the adult insects for C. maculatus and after 7 weeks for P. truncatus and S. zeamais. The progeny were used to set up the next set of exposure concentrations, again 80 adult insects were added to each replicate. This process was repeated with insects being exposed to increasing dosages, until the number of progeny emerging became too low to obtain the 80 insects required to set up the next set of exposure concentrations.

When this occurred, the emerged progeny (Fx) were placed onto clean commodity, adults were removed after 18 days and the progeny (Fx+1) collected after 7 weeks for use in the tolerance assessment studies. (To avoid confusion, these progeny are referred to as the Fx+1 generation, indicating that they had passed one generation in clean flour after x generations of exposure to diatomaceous earths). A control (never exposed to DE) culture of the same insect strains was also set up, in order to assess whether a change in tolerance of the insect populations which survived exposure to treated grain had occurred. The (Fx+1) progeny and the control progeny were then exposed to a range of concentrations (0-6g/m²) of aqueous DE slurry on 22*44cm steel slabs, to observe whether tolerance had developed. Insects that had been exposed over time to Protect-it™, were exposed to aqueous Protect-it™ slurry concentrations on steel slabs, and those that had been exposed to Dryacide® were exposed to Dryacide® slurry concentrations, the control insects were tested on both the Protect-it™ and Dryacide® treated steel slabs. Control insects and those exposed over time to both Protect-it™ and Dryacide® were also tested on water treated (control) steel slabs.

Bioassays were conducted by exposing 40 adults to the aqueous DE slurry concentrations, and observing mortality between 24-168 hours at 27°C and 60%RH. The insects were exposed to the aqueous DE slurry concentrations, by placing them inside fluon treated glass rings (50mm diameter; 15mm height) secured to the steel slabs with blue tack, escape was prevented by using a petri dish lid with airholes.
Table 1.2.1a. Details of *Prostephanus truncatus* resistance potential to DE exposure concentrations

<table>
<thead>
<tr>
<th>Set up date</th>
<th>Generation</th>
<th>Dryacide® Admix concentration (%w/w)</th>
<th>Protect-it™ Admix concentration (%w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>02/11/98</td>
<td>0.025</td>
</tr>
<tr>
<td>21/12/98</td>
<td>F1</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>08/02/99</td>
<td>F2</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>29/03/99</td>
<td>F3</td>
<td>0.10</td>
<td>0.125</td>
</tr>
<tr>
<td>17/05/99</td>
<td>F4</td>
<td>0.125</td>
<td>0.175</td>
</tr>
<tr>
<td>05/07/99</td>
<td>F5</td>
<td>Put onto untreated maize</td>
<td>Put onto untreated maize</td>
</tr>
<tr>
<td></td>
<td>F5+1</td>
<td>Used for tolerance tests</td>
<td>Used for tolerance tests</td>
</tr>
</tbody>
</table>

Note: Shaded boxes indicate the insects used to set up the next generation of insects for exposure to admixed DE at the same and a higher concentration. At each generation an 18 day mortality count was conducted and the adults were removed to prevent confusion with the emerging progeny.

Table 1.2.1b. Details of *Sitophilus zeamais* resistance potential to DE exposure concentrations

<table>
<thead>
<tr>
<th>Set up date</th>
<th>Generation</th>
<th>Dryacide® Admix concentration (%w/w)</th>
<th>Protect-it™ Admix concentration (%w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/03/99</td>
<td>P</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>30/04/99</td>
<td>F1</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>18/06/99</td>
<td>F2</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>06/08/99</td>
<td>F3</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>24/09/99</td>
<td>F4</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>11/11/99</td>
<td>F5</td>
<td>0.035</td>
<td>0.035</td>
</tr>
<tr>
<td>31/12/99</td>
<td>F6</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>17/02/00</td>
<td>F7</td>
<td>Put onto untreated maize</td>
<td>Put onto untreated maize</td>
</tr>
<tr>
<td>13/04/00</td>
<td>F8 or F7+1</td>
<td>Used for tolerance tests</td>
<td>Too few emerged</td>
</tr>
</tbody>
</table>

Note: Shaded boxes indicate the insects used to set up the next generation of insects for exposure to admixed DE at the same and a higher concentration. At each generation an 18 day mortality count was conducted and the adults were removed to prevent confusion with the emerging progeny.

Table 1.2.1c. Details of *Callosobruchus maculatus* resistance potential to DE exposure concentrations

<table>
<thead>
<tr>
<th>Set up date</th>
<th>Generation</th>
<th>Dryacide® Admix concentration (%w/w)</th>
<th>Protect-it™ Admix concentration (%w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19/10/98</td>
<td>P</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>23/11/98</td>
<td>F1</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>23/12/98</td>
<td>F2</td>
<td>Too few emerged</td>
<td>Too few emerged</td>
</tr>
</tbody>
</table>

Note: Shaded boxes indicate the insects used to set up the next generation of insects for exposure to admixed DE at the same and a higher concentration. At each generation mortality counts were conducted 48, 96 and 264 hours after set up, the adults were removed following the 264 hour count to prevent confusion with the emerging progeny.

Results

Adult mortality counts and number of offspring per pair of adults are shown for each of the test insects at each generation in Tables 1.2.2a-c.

Table 1.2.2a. *P. truncatus* adult mortality and number of offspring per pair of adults following continuing exposure to increasing application rates of DEs admixed with maize.

<table>
<thead>
<tr>
<th>% w/w</th>
<th>Dryacide®</th>
<th>Protect-it™</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P</td>
<td>F1</td>
</tr>
<tr>
<td>0.025</td>
<td>16.3 (5.8)</td>
<td>19.4 (8.1)</td>
</tr>
<tr>
<td>0.05</td>
<td>4.1 (6.9)</td>
<td>10.5 (10.2)</td>
</tr>
<tr>
<td>0.1</td>
<td>12.5 (7.8)</td>
<td>6.6 (6.6)</td>
</tr>
<tr>
<td>0.125</td>
<td>6.9 (3.8)</td>
<td>33.6 (2.2)</td>
</tr>
<tr>
<td>0.175</td>
<td>56.7 (1.1)</td>
<td>77.5 (0.3)</td>
</tr>
</tbody>
</table>

In each cell the first number is mean % mortality of 80 adult insects after 18 days exposure, the number in brackets is the mean number of offspring per pair of adults after 7 weeks.
Table 1.2.2b. *S. zeamais* adult mortality and number of offspring per pair of adults following continuing exposure to increasing application rates of DEs admixed with maize.

<table>
<thead>
<tr>
<th>Dryacide®</th>
<th>Protect-it™</th>
</tr>
</thead>
<tbody>
<tr>
<td>% w/w</td>
<td>P</td>
</tr>
<tr>
<td>0.01</td>
<td>2.8 (3.8)</td>
</tr>
<tr>
<td>0.015</td>
<td>3.8 (4.8)</td>
</tr>
<tr>
<td>0.025</td>
<td>2.8 (2.7)</td>
</tr>
<tr>
<td>0.03</td>
<td>3.4 (5.2)</td>
</tr>
<tr>
<td>0.035</td>
<td>1.9 (4.6)</td>
</tr>
<tr>
<td>0.04</td>
<td>2.8 (3.7)</td>
</tr>
<tr>
<td>0.05</td>
<td>3.8 (2.1)</td>
</tr>
</tbody>
</table>

In each cell the top number is mean % mortality of 80 adult insects after 18 days exposure, the number in brackets is the mean number of offspring per pair of adults after 7 weeks.

Table 1.2.2c. *C. maculatus* adult mortality and number of offspring per pair of adults following continuing exposure to increasing application rates of DEs admixed with cowpeas.

<table>
<thead>
<tr>
<th>Dryacide®</th>
<th>Protect-it™</th>
</tr>
</thead>
<tbody>
<tr>
<td>% w/w</td>
<td>P</td>
</tr>
<tr>
<td>0.01</td>
<td>16.9 (17.5)</td>
</tr>
<tr>
<td>0.025</td>
<td>23.1 (17.2)</td>
</tr>
<tr>
<td>0.035</td>
<td>82.5 (4.0)</td>
</tr>
</tbody>
</table>

In each cell the first number is mean % mortality of 80 adult insects after 48 hours, the number in brackets is the mean number of offspring per pair of adults after 3 weeks.

Tolerance testing

The results of the tolerance testing showed that both *P. truncatus* and *S. zeamais* mortality increased with exposure time and DE slurry concentration whether insects had been reared from those exposed to DEs previously or not (Figs 1.2.1a-e & 1.2.2a-d). Dryacide® slurry caused more rapid *P. truncatus* mortality than Protect-it™ at the higher concentrations of 3 and 6 g/m2.

The data for each exposure time was analysed using a split plot analysis of variance using insect origin (e.g. control or ex DE) as the whole plots and slurry concentration as the sub plots. Orthogonal contrasts were used to compare mortality between never exposed insects (control) with ex DE reared insects; never exposed insects with ex Dryacide® reared insects; never exposed insects with ex Protect-it™ reared insects; and in the *P. truncatus* trial insects reared through 0.125%w/w Dryacide® with those reared through 0.175%w/w Dryacide®.

In the *P. truncatus* trial no significant differences were found for any of the contrasts at any of the exposure times. In the *S. zeamais* trial, mortality levels of the control (never exposed to DE) insects were significantly higher than those of the DE exposed insects at 24 (p<0.007), 48 (p<0.001), 72 (p<0.001), and 96 (p<0.001) hours, however after 96 hours no difference in mortality occurred. This difference in mortality occurred for both DEs.
Fig 1.2.1a
Percentage mortality of 40 Prostephanus truncatus adults never previously exposed to diatomaceous earths on steel plates treated with different Dryacide slurry concentrations (n=3).

Fig. 1.2.1b
Percentage mortality of 40 Prostephanus truncatus adults previously exposed for 5 generations to increasing Dryacide admix concentrations (final conc. being 0.125% w/w) on steel plates treated with different Dryacide slurry concentrations (n=3).

Fig. 1.2.1c
Percentage mortality of 40 Prostephanus truncatus adults previously exposed for 5 generations to increasing Dryacide admix concentrations (final concentration being 0.175%w/w) on steel plates treated with different Dryacide slurry concentrations (n=3).
Fig 1.2.1d  Percentage mortality of 40 Prostephanus truncatus adults never previously exposed to diatomaceous earths on steel plates treated with different Protect-it slurry concentrations (n=3).

Fig 1.2.1e  Percentage mortality of 40 Prostephanus truncatus adults previously exposed for 5 generations to increasing Protec-it admix concentrations (final concentration being 0.125% w/w) on steel plates treated with different Protect-it slurry concentrations (n=3).
Fig 1.2.2a
Percentage mortality of 40 Sitophilus zeamais adults never previously exposed to diatomaceous earths on steel plates treated with different Dryacide slurry concentrations (n=3).

Fig 1.2.2c
Percentage mortality of 40 Sitophilus zeamais adults never previously exposed to diatomaceous earths on steel plates treated with different Protect-it slurry concentrations (n=3).

Fig 1.2.2b
Percentage mortality of 40 Sitophilus zeamais adults previously exposed for 7 generations to increasing Dryacide admix concentrations (final concentration being 0.04% w/w) on steel plates treated with different Dryacide slurry concentrations (n=3).

Fig 1.2.2d
Percentage mortality of 40 Sitophilus zeamais adults previously exposed for 7 generations to increasing Protect-it admix concentrations (final concentration being 0.04%) on steel plates treated with different Protect-it slurry concentrations (n=3).
Discussion

Prior exposure of *P. truncatus* insects to increasing DE concentrations for five generations did not affect mortality when exposed to a range of DE slurries in comparison to *P. truncatus* insects that had never been exposed to DE. However, *S. zeamais* insects exposed for seven generations to increasing DE concentrations took longer to die from exposure to a range of DE slurry concentrations than *S. zeamais* insects that had never been exposed to DE. This delayed response suggests that these *S. zeamais* insects have developed a degree of tolerance to DEs, although the exposure studies did not indicate any increase in progeny numbers. This delayed response might enable greater oviposition and feeding damage to occur prior to death. However further work is needed to explore what behaviour is possible in these DE coated insects prior to their delayed death. During the tolerance tests insects could not escape from the DE treated steel slabs, this is an artificial situation and in reality insects might crawl or fly away after encountering DEs, further work is also needed on behavioural responses of insects to DEs.

It was thought that due to the physical nature of the mode of action of these DE, resistance would not develop. These trials and recent work with *Tribolium castaneum*, *R. dominica* and *Cryptolestes ferrugineus* where reduced mortality during DE exposure occurred in insects reared for several generations in DE admixed commodity (Korunic, 1998), suggest that there is potential for insects to develop tolerance to DEs. Further work is needed to investigate whether insects, if given the choice actually avoid DE treated commodities and areas, which might delay the development of resistance among a population, and whether insects such as the *S. zeamais* in these trials have developed a tolerance to DE and if so is this due to the production of thicker cuticle, or changed metabolism etc? Because of the very different mode of action of DEs to the synthetic chemical insecticides, cross resistance is unlikely to occur.
1.3 Field trials to assess the efficacy and persistence of dust admixture to protect stored sorghum, maize and cowpeas in three agro-ecological zones in Zimbabwe

Introduction

In 1996 and 1997 during post-harvest needs assessment exercises 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 cereals 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; Marsland & Golob, 1996). 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 some of the major Zimbabwean storage insect pests, under constant climatic conditions (Carlson & Ball, 1962; Desmarchelier & Dines, 1987; Giga & Chinwanda, 1994; Appel et al., 1999; & see section 1.1). The objectives of the field trials were to determine whether these diatomaceous earths could control the whole spectrum of 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 to determine the most appropriate dosage rates.

Materials & Methods

Field trials were set up in three districts in Zimbabwe (Fig 1.3.1). The areas were selected in collaboration with the AGRITEX field staff, and covered Natural Regions IIIa (Harare), III (Buhera) and V (Binga). In Binga and Buhera districts the trials were conducted on-farm and managed by researchers. In Harare the trials were conducted on-station at IAE.

Figure 1.3.1 Geographical location of the field trials
As the quantity of grain to be treated during the trials was too large to be accommodated in the farmer's own store in addition to the household's grain, additional granaries were constructed. These were built as part of a training course for local artisans, which both localised the construction knowledge involved and reduced the labour costs. Additional stores were also constructed on-station at IAE in Harare. Four stores were built in each of the three districts, each store was used as a separate replicate.

The Binga stores used the model developed during project R6685 "Improved design of indigenous stores - including minimising the use of hardwood resources”. This was a cylindrical improved traditional wood structure located on a wooden platform raised one metre about the ground on PVC pipe legs filled with cement and reinforced with wire (Plate 1.3.1). The single compartment of the store was plastered with mud on both its internal and external surfaces. The small entrance hole was closed with a wooden door. A traditional overhanging thatched grass roof was placed on the top of the structure, to insulate the store and protect the top and sides from rain damage.

Plate 1.3.1. Trial store - Binga district

Plate 1.3.2 Trial store - Buhera district

Both the Buhera and IAE store designs were brick structures based on an improved model of the traditional pole and mud structure (Plate 1.3.2). The structure was raised ~40 cm off the ground, on small brick columns, the base and ceilings were made of cement slabs, while the exterior and interior walls were built of bricks. The stores have three compartments on either side of a main corridor. The interior of the six compartments and the walls of the corridor were plastered with a termite-soil based mud mixture. Normally, each compartment is covered by a cement slab lid but these were omitted to facilitate sampling. A small close fitting wooden door was fitted to each compartment. The roof was made of traditional poles and thatched with grass.

The trials were conducted over a 40 week period during each of two storage seasons (1998/99 and 1999/00), starting in July or August each season.

Treatments included the two diatomaceous earths, Dryacide® and Protect-it™ admixed at different dosage rates, Actellic Super Dust, and an untreated control. Different dosage rates of the DEs were used in the two seasons (Table 1.3.1).
Table 1.3.1. Grain protectant treatments applied during researcher managed field trials.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryacide® 0.1% w/w</td>
<td>Dryacide® 0.05% w/w</td>
<td></td>
</tr>
<tr>
<td>Dryacide® 0.2% w/w</td>
<td>Dryacide® 0.1% w/w</td>
<td></td>
</tr>
<tr>
<td>Protect-it™ 0.1% w/w</td>
<td>Protect-it™ 0.05% w/w</td>
<td></td>
</tr>
<tr>
<td>Protect-it™ 0.2% w/w</td>
<td>Protect-it™ 0.1% w/w</td>
<td></td>
</tr>
<tr>
<td>Actellic Super Dust™ 0.05% w/w</td>
<td>Actellic Super Dust 0.05% w/w</td>
<td></td>
</tr>
<tr>
<td>Untreated control</td>
<td>Untreated control</td>
<td></td>
</tr>
</tbody>
</table>

The commodity was treated by thorough admixing on polythene sheets using a clean shovel. In Binga, the commodity used was threshed sorghum grain (50kg/rep.) which, following treatment, was loaded into a polypropylene sack, labelled and randomly placed inside the single compartment store. In Buhera, both maize grain (180kg/rep.) and cowpea grain (10kg/rep.) were used in 1998/99; while in 1999/2000 only maize grain (200kg/rep.) was used due to difficulties in obtaining sufficient quantities of cowpeas. Maize grain (165kg/rep. in 1998/99 and 130kg/rep. in 99/00) was also used at IAE. Following treatment, maize was loaded in bulk into the compartments of the store whereas cowpeas were placed in small woven jute sacks, which were stored in the central corridor of three of the stores in Buhera.

Samples of 1.5kg of maize and sorghum, were collected every eight weeks using a multi-compartmented probe, 500g samples of cowpeas were collected using bag spears. The sample was then divided into three sub-samples for the analysis of damaged grain. The sample weight, number of damaged grains, and the live and dead adult insect populations, and moisture content were recorded.

Data analysis

Data was analysed using GENSTAT under the guidance of the biometrician David Jeffries (University of Greenwich). 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 the different treatments, the four contrasts used were: Untreated control vs Treatments; Actellic Super dust vs DEs; Dryacide vs Protect-it; 0.1% w/w vs 0.2% w/w (in 1998/99) and 0.05% w/w vs 0.1% w/w (in 1999/2000). 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.

Participatory analysis (1989/99 storage season)

A field day was held in Buhera at the end of the first season storage trial a field day was held (at the request of and partial organisation/ funding from the local farming community). During the field day, the researchers requested farmers interested in evaluating the different treatments to stay behind. Two groups of women (Groups 1&2) and one group of men (Group 3) were formed, each group had 7-8 people.

Each group was given six transparent plastic bags labelled A-F, containing samples of maize treated with the different grain protectant treatments and the untreated control, along with six bags labelled A-F with samples of treated cowpeas and the untreated control. The groups were told that they could open the bags and take out a handful of grains if they wished.

Each group was asked:
1. How they would differentiate between the samples of grain (A-F)? The parameters they mentioned were visualised using symbols on the ground.
2. To rank the different parameters they had mentioned in terms of importance.
3. Using the parameters they had mentioned, to score each of the grain samples (A-F) on a matrix, using a 1-10 scale (where 10=good, 0 = bad).
(Note: Questions 1-3 were asked first for maize and then for cowpeas)
4. What were the main criteria they considered when choosing a grain protectant?

The activities were carried out using sticks and symbols to mark the ground, and stones and maize kernels and beans for scoring.
**Results**

*First storage season 1998/99 - Dryacide and Protect-it applied at 0.1% and 0.2% w/w.*

**Maize - Buhera - 1998/99**

Throughout the 40 week storage period, no significant differences were found between Actellic Super and the DEs, or between either of the two DEs or the two dosage rates (0.1% and 0.2% w/w) used (Fig 1.3.2a). From 16 weeks storage onwards the differences in damage levels between the untreated control and all the protectant treatments were highly significant (p <0.001).

The predominant insect species 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 controls, *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 per 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 DEs, or between the two dosage rates (0.1% and 0.2% w/w) used (Fig 1.3.2b). From 8 weeks storage onwards damage in the untreated control was significantly higher than in all the protectant treatments (p< 0.001). Damage incidence was lower in the Actellic Super dust treatments than in the DEs, this difference was significant from 8 weeks storage onwards (p =0.042).

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 Dryacide® 0.1%w/w treatments had increased. This sudden increase may be a reflection of the difficulty in controlling *Rhyzopertha dominica* (Fig 1.3.3c). 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 no more effective than the DE treatments apart from Dryacide 0.1%w/w.

At the start of the storage season *Sitophilus 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 (Fig 1.3.3c). In both the untreated control and the Dryacide® 0.1% w/w treatments, large populations of *R. dominica* began to develop from 24 weeks. The *R. dominica* populations in the Dryacide® 0.1%w/w treatments exceeded those in the control from 32 weeks onwards, reaching a mean population of 900 insects/kg by week 40. However, there was large variation in the size of the *R. dominica* populations between sites (reps), the standard error of the mean for the Dryacide® 0.1%w/w at week 40 = 626.80 insects/kg.

**Cowpeas - Buhera - 1998/99**

Throughout the 40 week storage period, damage levels between the two DEs and between the different dosage rates (0.1% and 0.2% w/w) were not significantly different (Fig 1.3.2d). Insect damage in the untreated control began to rise steeply from 16 weeks, and was significantly different from all other treatments from week 8 (p≤0.035). At week 32, damage in the Actellic Super dust treatment 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 Hymenopteran parasite *Dinarma basalis* was also found in the untreated cowpea samples from week 24.
Figure 1.3.2a. Insect damage to maize grain treated with diatomaceous earth or Actellic Super dust during the 1998/99 storage season in Buhera district, Zimbabwe (n=4).

Figure 1.3.2b. Insect damage to maize grain treated with diatomaceous earth or Actellic Super dust during the 1998/99 storage season at IAE, Harare, Zimbabwe (n=4).
Figure 1.3.2c. Insect damage to sorghum grain treated with diatomaceous earth or Actellic Super dust during the 1998/99 storage season in Binga district, Zimbabwe (n=4).

Figure 1.3.2d. Insect damage to cowpeas treated with diatomaceous earth or Actellic Super dust during the 1998/99 storage season in Buhera district, Zimbabwe (n=3).
Figure 1.3.3a. Comparison of mean total number of adult 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 adult 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 adult 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 adult Callosobruchus rhodesianus per kg of cowpeas in treated and untreated 0.5 kg samples during the 1998/99 storage season in Buhera district, Zimbabwe (n=3).
Second storage season 1999/2000 - Dryacide® and Protect-it™ applied at 0.05% and 0.1% w/w.

Maize - Buhera -1999/2000
As during the first storage season, insect damage in the untreated control began to increase rapidly from 16 weeks, becoming significantly higher than the treatments (Fig 1.3.4a). By week 32, a difference also appeared between the two DEs, 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. The population increase was most rapid in the untreated control and Dryacide® 0.05% w/w, mainly due to S. zeamais, with a smaller population of T. castaneum appearing by week 40 (Fig 1.3.5a).

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 greater damage occurred in the 0.05% w/w DE treatments than in the 0.1% w/w. This difference between the dosage rates 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 between Actellic Super dust and the DEs (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 season (Figs. 1.3.2b&1.3.4b).

S. zeamais populations began to increase rapidly in the untreated control from 16 weeks, 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 DEs also increased rapidly and exceeded that of the untreated control from 24 weeks onwards. During the first storage season (1998/99) a similar observation was made for the 0.1% w/w Dryacide® treatment. This effect of the Dryacide® 0.1% w/w was repeated during the second season, and the reduction of the dosage rate magnified the effect. 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 DE treatments from 16 weeks.

Total insect numbers correlate well with damage levels for all treatments (r = 0.7801; df =136). Damage levels increased most rapidly in treatments with large R. dominica populations (r = 0.8031; df =136). 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.

32
Fig. 1.3.4a. Insect damage to maize grain treated with diatomaceous earth or Actellic Super dust during the 1999/2000 storage season in Buhera district, Zimbabwe (n=4).

Fig. 1.3.4b Insect damage to maize grain treated with diatomaceous earth or Actellic Super dust during the 1999/2000 storage season at IAE, Harare, Zimbabwe (n=3).
Figure 1.3.4c. Insect damage to sorghum grain treated with diatomaceous earth or Actellic Super dust during the 1999/2000 storage season in Binga district, Zimbabwe (n=4).

Figure 1.3.5a. Comparison of mean total number of adult 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 adult 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 adult insects per kg of sorghum in treated and untreated 1.5kg samples during the 1999/2000 storage season in Binga district, Zimbabwe (n=4).
Participatory analysis of the first seasons field trials

The parameters mentioned as important for differentiating between the trial maize samples (A-F) were ranked by each of group, and are presented in Table 1.3.2.

Table 1.3.2. Parameters used by the different groups for distinguishing between maize samples and their relative importance.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rank of each parameters (1 = most important)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 (female)</td>
</tr>
<tr>
<td>Presence of insect dust</td>
<td>1</td>
</tr>
<tr>
<td>Presence of weevils</td>
<td>2</td>
</tr>
<tr>
<td>Presence of larvae</td>
<td>3</td>
</tr>
<tr>
<td>Insect damage holes in grain</td>
<td>4</td>
</tr>
<tr>
<td>Presence of trash</td>
<td>5</td>
</tr>
<tr>
<td>Broken grains</td>
<td>6</td>
</tr>
<tr>
<td>Bad smell</td>
<td>7</td>
</tr>
<tr>
<td>Poor taste</td>
<td>8</td>
</tr>
<tr>
<td>Physical damage</td>
<td>9</td>
</tr>
<tr>
<td>Grain structure</td>
<td>10</td>
</tr>
<tr>
<td>Grain size</td>
<td>10</td>
</tr>
<tr>
<td>Grain fullness</td>
<td>10</td>
</tr>
<tr>
<td>Grain weight</td>
<td>10</td>
</tr>
</tbody>
</table>

The farmers of Group 1 used the same parameters for scoring both the cowpea samples and the maize, Group 2 included an additional seed viability parameter for the cowpeas. Group 3 mentioned only the damage level and size of the cowpeas as important criteria for differentiating between the samples.

When each of the samples (A-F) was scored against the Groups important parameters (Table 1.3.2) the following results were obtained for the maize (Table 1.3.3) and the cowpeas (Table 1.3.4).

Table 1.3.3. Scoring of maize samples by the three groups.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>A Dryacid 0.1%</th>
<th>B Dryacid 0.2%</th>
<th>C Protect-it 0.1%</th>
<th>D Protect-it 0.2%</th>
<th>E Actellic Super dust</th>
<th>F Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence of insect dust</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Presence of weevils</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Presence of larvae</td>
<td>8</td>
<td>10</td>
<td>5</td>
<td>7</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Insect damage holes in grain</td>
<td>10</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Presence of trash</td>
<td>10</td>
<td>8</td>
<td>4</td>
<td>8</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Broken grains</td>
<td>9</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total - Group 1</strong></td>
<td><strong>56</strong></td>
<td><strong>45</strong></td>
<td><strong>24</strong></td>
<td><strong>40</strong></td>
<td><strong>53</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>

| Presence of insects            | 10             | 8              | 7                 | 8                 | 9                     | 0         |
| Presence of trash              | 7              | 6              | 8                 | 7                 | 10                    | 0         |
| Insect damage                  | 3              | 7              | 6                 | 6                 | 10                    | 0         |
| Weight of grain                | 5              | 7              | 5                 | 5                 | 10                    | 2         |
| Smell of grain                 | 10             | 7              | 8                 | 4                 | 6                     | 0         |
| **Total - Group 2**            | **35**         | **35**         | **34**            | **29**            | **45**                | **2**     |

| Presence of insect dust        | 10             | 9              | 7                 | 5                 | 7                     | 0         |
| Grain structure                | 10             | 9              | 7                 | 5                 | 4                     | 6         |
| Grain size                     | 8              | 9              | 6                 | 7                 | 4                     | 10        |
| Grain fullness                 | 10             | 7              | 8                 | 6                 | 6                     | 6         |
| Weight of grain                | 10             | 8              | 6                 | 7                 | 5                     | 1         |
| **Total - Group 3**            | **48**         | **42**         | **34**            | **30**            | **26**                | **23**    |
Table 1.3.4. Scoring of cowpea samples by the three groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Score given for each sample (10 = good, 0 = bad)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A Dryacide 0.1%</td>
</tr>
<tr>
<td>Presence of insect dust</td>
<td>5 8 10 7 10 0</td>
</tr>
<tr>
<td>Presence of insect dust</td>
<td>5 8 10 7 10 0</td>
</tr>
<tr>
<td>Presence of insect damage in grain</td>
<td>6 10 2 8 8 0</td>
</tr>
<tr>
<td>Presence of insect damage in grain</td>
<td>6 10 2 8 8 0</td>
</tr>
<tr>
<td>Presence of trash</td>
<td>4 6 5 1 9 0</td>
</tr>
<tr>
<td>Presence of trash</td>
<td>4 6 5 1 9 0</td>
</tr>
<tr>
<td>Insect damage</td>
<td>7 10 10 9 8 1</td>
</tr>
<tr>
<td>Weight of grain</td>
<td>9 10 10 9 8 1</td>
</tr>
<tr>
<td>Total - Group 1</td>
<td>27 50 34 36 56 1</td>
</tr>
<tr>
<td></td>
<td>Group 2</td>
</tr>
</tbody>
</table>

For those parameters directly linked to insect damage it can be seen that the grain protectant treatments outscored the untreated control for both maize and cowpeas, and by all groups.

Plate 1.3.3 & 1.3.4 Farmers evaluating grain protectant treatments

Only two of the groups discussed what factors were considered important in choosing a grain protectant.

Group 1 said the only factor they considered was its efficacy in controlling weevils.
Group 3 said the first factor they considered was the price. They mentioned that they often could not afford sufficient chemical to treat all the grain in the store, and that they lacked knowledge on how to use the grain protectants correctly, giving the example of how they often sprinkle them on top without mixing them in. The persistence of the chemical was also important, as was the recommended safety period between grain treatment and consumption (e.g. 30 days for pirimiphos methyl in Zimbabwe due to local registration requirements). Visits to view friends stores who have treated their grain with a protectant was also mentioned as an important validation of the efficacy of the grain protectant, although the farmers were quick to point out that because people use different application techniques and concentrations, the effect may differ between granaries. The farmers also mentioned that there was an overall fear of using chemicals on food within the community, this related to the vegetable patch in particular as children often suffer stomach-ache after eating vegetables treated with chemicals. The farmers also mentioned that there was a conflict of interest due to the fact that each household has only one storage structure, and they don't want to mix food that they will be eating immediately with food treated with a grain protectant.

**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 DEs is closely linked to the dosage rates, and can be seen to differ between commodities.

During the first season, both application rates (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 application rate (0.05% w/w) of these two DEs was included during the second seasons trials. This lower dosage rate of both Protect-it™ and Dryacide® was not effective at 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 appeared to be highly location specific. Higher grain moisture content is known to reduce the efficacy of admixed DEs against storage pests (Le Patourel, 1986). Throughout the trial the moisture content of the maize grain at Harare was higher than that at Buhera.

It is of concern 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* (described in lab experiments see 1.1) coupled with their negative effect on the natural enemy population. Perez-Mendoza et al., (1999) found the hymenopteran parasitoid *Anisopteromalus calandrae* was very sensitive to DEs, and spent an increased amount of time grooming in an attempt to remove DE particles from the cuticle surface. The same study found *A. calandrae* avoided DE treated wheat, resulting in significantly more weevils emerging from the DE treated wheat as compared to the untreated wheat. Further studies would be needed in order to better understand the relationships. 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 with farmers.

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, unless pre-harvest infestation was high.

These results suggest that an application rate of 0.1% w/w of either Protect-it of 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 treatment if protection is considered necessary. These results may have important implications for other semi-arid regions in Africa.
Once temporary registration of diatomaceous earths as grain protectants is completed, further work will be needed to assess consumer acceptability and any socio-economic factors influencing the use of DE by small scale farmers.

The farmers' comments during the participatory analysis regarding lack of knowledge of correct pesticide application techniques, support the findings of a earlier survey on maize post-production practices (Mvumi et al., 1995). More than 50% of the 2121 farmers interviewed during that survey were not applying synthetic insecticides as detailed in the product's instructions. If diatomaceous earths are registered for use as grain protectants in Zimbabwe, it is important that comprehensive information on their application method is widely available.

It was interesting to note during the participatory analysis of the first seasons trials, how different the parameters mentioned by men and women were. The women's parameters suggested a much more detailed analysis of insect damage including parameters such as presence of: feeding dust (meaning the grain had been destroyed); larvae (which spoil the taste of the mealie meal); adult insects; and smell (which the groups discussed as being possibly linked to either insect activity or chemical treatment), these are food characteristics. Whilst the men's criteria were mainly related to physical characteristics of the grain size, structure, grain fullness, weight etc, characteristics important for sale.

All three groups involved in the participatory analysis of the treatments were very impressed with the grain treatments considering that they had been applied 40 weeks previously. Many farmers both after the field day and following the participatory evaluation asked whether they could purchase any of the protectants from us or be involved in any future trials of these grain protectants.

It is surprising that Group 1 gave Protect-it™ 0.1% such low scores for insect damage linked parameters in comparison to the other samples. Particularly as this evaluation was done at the 40 week storage period when damage levels counted during the laboratory analysis for Protect-it™ 0.1% were less than 20%, and not significantly different than any of the other treatments.

It is interesting that the men of Group 3 found such a difference in grain size and structure between the samples, considering the original maize was all from the same batch, this suggests that the men may have been looking for more differentiating characteristics than actually existed. A long argument occurred about the relationship between damaged grain and its weight. Group 2 women also mentioned grain size as an important parameter, but decided not to include it in the scoring exercise as there was no difference in grain size between the samples.

Note: A similar evaluation was done with farmers in Binga district in April (Mvumi et al., 2000). 25-30 farmers were divided into three groups, in each group the host farmer (whose homestead had been used to house one of the model stores during the experiment) acted as a resource person for the other farmers. The discussion focussed on both the store design and the grain protectants. Farmers used criteria including webbing, insect presence, insect trash and damage to rank the samples (threshed sorghum grain treated with different protectants and stored for 40 weeks). Overall, the farmers rated Actellic Super Dust as the most effective sorghum grain protectant and Protect-it™ 0.2%w/w as the second most effective (one group rated the two protectants equally). The farmers, considered Protect-it™ 0.1%w/w was more effective than Dryacide® 0.2%w/w. Dryacide® 0.1%w/w was ranked the lowest of all the treatments, as farmers felt it provided no additional control in comparison to untreated sorghum grain.
1.4 On-farm participatory trials to develop optimum methods of application and assess the socio-economic factors influencing dust usage

Introduction

During the first storage seasons trials (1998/99) it was established that the diatomaceous earths (DE) Protect-it™ and Dryacid® were highly effective at reducing insect damage to stored commodities (maize, sorghum and cowpeas) during a 40 week storage period (see Section 1.3). Farmers involved in blind evaluations of these trials during field days ranked the DE treatments highly. However, although they were carried out on-farm (at two of the three sites) under typical climatic conditions, these first storage seasons field trials were predominantly researcher managed.

During the second storage seasons (1999/2000) in addition to the researcher-managed trials, an additional set of farmer managed DE trials were set up. These trials focused on observing the performance of one of the DEs (Protect-it™ 0.1% w/w), in farmers’ own stores, and from farmers’ perspectives in order to learn about farmers perceptions of the DEs as grain protectants. Unfortunately, no DEs are yet registered for use as grain protectants in Zimbabwe and so the grain treated with DEs during these trials could not be consumed. As a result of this no information could be collected on the effect of DE on factors such as cooking properties, flavour, brewing characteristics etc.

Materials and Methods

Field days at the request of the two communities involved in the researcher managed DE trials were held in March and May 1999 in Binga and Buhera districts respectively (see 1.3 for further details). During these field days, many farmers came forward asking whether they could be provided with samples of the DE to test at their own homesteads. The project team explained to the two communities that this season, in addition to the researcher-managed trials, we hoped farmers would also set up, manage and evaluate a concurrent set of trials. In these trials they would use their own grain (purchased by the project as the grain could not be consumed following the trials) and their own granaries.

Further meetings were arranged with farmers in the communities through the Agricultural Extension Workers (AEWs) and the field days. At these meetings, grain protection was discussed, the results of the first year's researcher managed trials were described and the need for independent farmer evaluation of the DEs was explained. Following these meetings, at the request of the farmers, their homesteads and storage structures were visited and the arrangements for the trials finalised.

In Binga district, 11 farmers (5 women) from two wards (Sinampande and Manjolo) conducted the trial. The DE and grain admixture procedure was demonstrated to the two groups, (the procedure is similar to that of admixing grain with the synthetic chemical protectant pirimiphos-methyl (Cooper Shumba), except for the quantity of the grain protectant required). Following the demonstration each farmer collected a pre-measured 50g sample of Protect-it™. At their homesteads, the farmers observed by project staff or AEWs then admixed the 50g of Protect-it™ with 50kg of threshed sorghum grain. The Protect-it™ 0.1% w/w treated grain was placed into a sack and stored in their granary (Plate 1.4.1) along with a comparison sack of 50kg of sorghum grain treated in the farmers traditional way. The term “traditional” is used throughout this trial to describe the method of grain protection the farmer normally applies to his/her grain, hence traditional may imply: no treatment at all; admixture with botanicals; or admixture with synthetic chemical protectants.

In Buhera district, 10 farmers (5 women) from Ward 6 conducted the trial. Here, maize grain is typically stored in bulk in a multi-compartmental mud and pole storage structure. Those farmers involved provided one compartment of their store for the DE treated grain, and their traditionally treated grain in one of the other compartments was used as the comparison. Following a group demonstration on the DE admixture procedure, each farmer collected a pre-measured 100g sample of Protect-it™. At their homesteads, the farmers observed by project staff and the AEW, admixed the 100g of Protect-it™ with 100kg of shelled maize. The Protect-it™ 0.1% w/w treated grain was loaded into one compartment of the storage structure (Plate 1.4.2).
Samples of 1.5kg were taken at 0, 5 and 7 months storage, for laboratory analysis of insect damage, insect presence and moisture content. At 5 and 7 months storage the farmers and other household members in the presence of project staff and AEWs evaluated samples of the Protect-it™ treated and traditionally treated control grain, and used their own parameters to compare the two samples (Plates 1.4.3a-c).

**Plate 1.4.1. Typical storage structures in Binga district, Zimbabwe**

**Plate 1.4.2. Typical storage structures in Buhera district, Zimbabwe**
Plates 1.4.3a-d. Evaluation and scoring of the Protect-it™ and 'traditionally' treated samples.

During the initial group meetings in Binga district, both the project staff and the AEWs felt that a thorough understanding of post-harvest sorghum practices in Binga district was lacking. As a result a questionnaire survey was designed, which would be carried out with 31 households in the district. Details of the survey and the findings are given in the results section, the full survey findings are presented in a separate report (Stathers et al., 2000).

Results

Buhera - Maize
The most commonly used parameters for the comparison of the Protect-it treated and traditionally treated grain samples at both the 5 and 7 month storage evaluations were: insect damage to grain, colour of grain; presence of protectant dust; presence of insects. The full list of parameters mentioned by the Buhera households involved in the trial is shown in Table 1.4.1.
Table 1.4.1 Parameters mentioned by households in Buhera for assessing the value of farm stored shelled maize at 5 and 7 months storage.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Number of households mentioning this parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At 5 month evaluation (n=10)</td>
</tr>
<tr>
<td>Insect damaged grain</td>
<td>10</td>
</tr>
<tr>
<td>Colour of grain</td>
<td>10</td>
</tr>
<tr>
<td>Presence of protectant dust</td>
<td>9</td>
</tr>
<tr>
<td>Presence of insects</td>
<td>3</td>
</tr>
<tr>
<td>Size and structure of kernels</td>
<td>5</td>
</tr>
<tr>
<td>Texture of the grain (by hand feeling)</td>
<td>3</td>
</tr>
<tr>
<td>Presence of rotting/ mould</td>
<td>1</td>
</tr>
<tr>
<td>Weight of grain</td>
<td>1</td>
</tr>
<tr>
<td>Presence of insect feeding dust</td>
<td>2</td>
</tr>
<tr>
<td>Expected meal yield</td>
<td></td>
</tr>
<tr>
<td>Expected <em>sadza</em> colour and quality</td>
<td>1</td>
</tr>
</tbody>
</table>

Using the ranked position of each parameter in conjunction with the frequency the households mentioned it a score was obtained. This score suggested that at both 5 and 7 months the most important parameters for differentiating between grain samples were (in decreasing order of importance): insect damage; colour of grain; presence of protectant dust; presence of insects; size and structure of grain; texture of grain. It is interesting that the following parameters: presence of insect feeding dust; evidence of rotting; resulting mealie meal yield and quality became more important at the 7 month evaluation, presumably when insect damage had started to become really noticeable and food might be becoming more scarce.

Of the ten households involved in the Buhera trial, nine had treated their own grain with pirimiphos methyl 2% dust (Cooper Shumba), and the remaining household had used malathion dust (Haku). A number of different application methods were described.

At both the 5 and 7 month Buhera evaluations, the Protect-it™ treated maize scored higher than the traditionally (e.g. Cooper Shumba or Haku dust) treated maize, for every parameter mentioned. The mean scores given to both the Protect-it™ and traditionally treated grain for the different parameters are shown in Figs 1.4.1 a&b.
After examining the samples at both 5 and 7 months, all the households involved expected that the Protect-it™ treated grain would be sold and bought at a higher price than the traditionally treated grain (Fig 1.4.2).
Figure 1.4.2. Comparison of farmer perceived price of their Protect-it treated and traditionally treated grain in Buhera and Binga districts, Zimbabwe (1999/2000).

The households also compared the Protect-it™ treated and traditionally treated grain during processing, the actual and expected processing differences are listed in Table 1.4.2.

**Table 1.4.2** Processing differences between Protect-it™ treated and traditionally treated maize grain, as mentioned by Buhera households.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Frequency the parameters were mentioned during farmer evaluations at 5 months storage</th>
<th>Frequency the parameters were mentioned during farmer evaluations at 7 months storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protect-it treated grain takes longer to grind</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Protect-it treated grain gives more meal</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Protect-it treated grain produces whiter mealie meal</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Protect-it treated grain produces heavier meal</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Protect-it treated grain produces finer meal</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Untreated grain will produce smelly sadza due to insect waste matter</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Untreated grain takes longer to grind and produces more meal</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Sadza produced from damaged grain would not have the stiffness that people like because the insects have eaten the inside of the grain.</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Protect-it treated grain produces less mealie meal</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated grain will be heavier to carry to the mill than the damaged grain</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Protect-it treated grain will taste better</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated grain will be better for beer brewing (as the grain needs to germinate when placed in water)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated grain will be better to use as seed because it will germinate</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Conflicting views were expressed as regards the quantity of meal obtained from the Protect-it™ treated and traditionally treated grain. However, 11 households felt more meal would be obtained from the Protect-it™ treated grain than the traditionally treated grain, and only one thought the opposite.
The most commonly used parameters for the comparison of the Protect-it™ treated and traditionally treated grain samples at both the 5 and 7+ month storage evaluations in Binga were: insect damage to grain; presence of insects; presence of insect webbing; and colour of grain. The full list of parameters mentioned by the Binga households involved in the trial is shown in Table 1.4.3.

Table 1.4.3 Parameters mentioned by households in Binga for assessing the value of farm stored threshed sorghum grain at 5 and 7+ months storage.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>At 5 month evaluation (n=9)</th>
<th>At 7+ month evaluation (n=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insect damaged grain</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Colour of grain</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Presence of protectant dust</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Presence of insects</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Presence of insect webbing</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Size and structure of grains</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Presence of rotting/mould</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Moisture content</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Weight of grain</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Presence of insect feeding dust</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Numbers of different types of insects</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Freshness of grain</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Using the ranked position of each parameter in conjunction with the frequency that households mentioned it, a score was obtained. This score suggested that at both 5 and 7+ months the most important parameters for differentiating between grain samples were (in decreasing order of importance): insect damage; presence of insects; presence of insect webbing; colour of grain. All the parameters received higher scores at the 7+ month evaluation, as insect damage had increased. Several parameters were only mentioned at the 7+ month evaluation including: presence of insect feeding dust; look of freshness of the grain; size and structure of the grain; evidence of rotting/mould. At the 5 months evaluation one household mentioned that the Protect-it™ treated and traditionally (untreated) stored grain had different moisture contents. The farmer explained that swollen grain was an indication of high moisture content and thought that the untreated grain had higher moisture content than the Protect-it™ treated grain. The number of different types of insect present in a sample was also felt to be important as an indicator of potential damage severity (i.e. more insect species results in more damaged grain).

Of the eleven households involved in the Binga trial, two had treated their sorghum grain with the plant soswe (*Maerua edulis*), the other nine had not treated their grain with any form of protectant. Soswe leaves are typically applied as whole fresh leaves or pounded and dried then mixed with the grain in layers.

At both the 5 and 7+ month farmer evaluations, the Protect-it™ treated maize samples performed better than the traditionally (untreated or soswe) treated sorghum, for all the parameters mentioned by the farmers. The mean scores given to both the Protect-it™ and traditionally treated grain for the different parameters are shown in Figs 1.4.3 a&amp;b. Unfortunately the scores for the parameters marked with a star at the 5 months evaluation were used the wrong way around during the evaluation but have been transposed for presentation in Fig 1.4.3a.
Figure 1.4.3a. Farmers’ comparison of their Protect-it treated and traditionally treated threshed sorghum after 5 months storage in Binga district, Zimbabwe (1999/2000)

After examining the samples at both 5 and 7+ months, all the households involved expected that the Protect-it™ treated grain would be sold and bought at a higher price than the traditionally treated grain (Fig 1.4.2).

The households also compared the Protect-it™ treated and traditionally treated grain during processing, the actual and expected differences are listed in Table 1.4.3.
Table 1.4.3 Processing differences between Protect-it™ treated and traditionally treated threshed sorghum grain, as mentioned by households in Binga.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Frequency the parameters were mentioned during farmers evaluations at 5 months storage</th>
<th>7+ months storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protect-it treated grain takes longer to pound</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Protect-it treated grain gives more meal</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Protect-it treated grain produces whiter mealie meal</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated grain produces heavier meal</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Untreated grain will produce smelly sadza due to insect waste matter</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Untreated sorghum absorbs more water</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated grain absorbed water faster than damaged grain</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Untreated grain crushes easily into powder, instead of removing the seed coat, after winnowing there is very little left.</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Untreated sorghum yields more meal because the insects are also part of it</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated sadza is stiffer to pound, because it was not damaged by weevils</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated sorghum turns brown, and they like it brown</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated sorghum took less time to hull</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Untreated sorghum meal is sour</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Protect-it treated sorghum more nutritious that untreated</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

As with the Buhera trials there were conflicting views expressed regarding the quantity of meal obtained from the Protect-it™ treated and traditionally treated grain. Only one household felt the untreated sorghum would yield more meal, and justified this by explaining that the insects which had damaged this untreated grain, would become part of the meal too.

**Laboratory analysis on farmer participatory trial samples**

**Buhera**

The mean percentage of damaged grains in the Protect-it™ treated and traditionally treated maize at 0, 5 and 7 months storage in Buhera district is shown in Fig 1.4.4. Insect damage in both the traditionally treated and Protect-it™ treated samples remained relatively low throughout the duration of the trial. Although mean damage was higher in the traditionally treated samples than the Protect-it™ treated samples, statistical analysis showed that this was not significant at any of the storage periods. High variation in damage occurred between farms.

Mean insect population was below 8 insects/kg at the start of the trial, the specimens found were *S. zeamais* and *S. cerealella*. At the 5 month sampling period mean insect populations had increased with 33 insects/kg and 197 insects/kg in the Protect-it™ and traditionally treated maize samples respectively. At the final 7 months sampling period insect populations were 32 insects/kg and 241 insects/kg in the Protect-it and traditionally treated maize samples respectively. The most dominant species was *S. zeamais* followed by *S. cerealella*. Although insect populations were lower in the Protect-it™ treated maize samples than the traditionally treated maize samples from 5 months onwards these differences were not significant.
**Binga**

The mean percentage of damaged grains in the Protect-it™ treated and traditionally treated sorghum at 0, 5 and 7+ months storage in Binga district is shown in Fig 1.4.5. Insect damage in both the traditionally treated and Protect-it™ treated samples remained relatively low throughout the first five months of the trial, but began to increase in the traditionally treated (predominantly untreated) samples after the five month sampling period. However, although mean damage was higher in the traditionally treated samples than the Protect-it™ treated samples, statistical analysis showed that this was not significant at any of the storage periods. High variation in damage was found between the farms.

At the start of the trial mean insect populations were approximately 100 insects/kg, mainly *Sitophilus oryzae* with a few *S. cerealella*, *Tribolium castaneum* and *Rhyzopertha dominica*. Mean populations had increased to approximately 300 insects/kg by the fifth month and to 439.25/kg and 709.46/kg in the Protect-it™ and traditionally treated grain samples respectively by the final sampling. However, statistical analysis revealed these differences were not significant. High variation occurred between farms and within treatments. In the final sampling period, *S. oryzae* remained the dominant species followed by *R. dominica*, and *T. castaneum*. Very high populations of *R. dominica* were present on one farm in both the Protect-it and traditionally treated grain samples at the final sampling period which was nine months after the start of the trial due to flooding damage preventing access at the seven month sampling period. This farmer was one who mentioned insect feeding dust as an important parameter.
During the course of the trials observations and discussions with members of the households involved revealed a number of important facts. During the scoring exercise many of the farmers mentioned that the grain had been damaged by insects in the field or prior to placement in store, and that this might account for some of the damage observed despite the application of a grain protectant.

Farmers found it easy to differentiate between the protectant dust and the insect feeding dust. In Buhera, presence of protectant on the grain was considered to increase the value of the grain, as it was believed that grain with visible protectant on the surface could be stored again without the need to add further protectant. However, one female farmer in Buhera felt that the presence of dust whether from the protectant or insect feeding activity was not desirable as it meant extra labour during winnowing.

One farmer in Buhera mentioned that the name Protect-it™ was difficult to remember, as it was not a Shona name, like Shumba (which means lion in Shona). However, during earlier field days other farmers had mentioned that they liked the name Protect-it™ and that it was easy to remember as there was also a condom on the market with the brand name Protector.

Many of the farmers wanted to know where they could purchase Protect-it™, and we explained that as it wasn't yet registered in Zimbabwe, it was not possible to purchase it. We explained again that these trials were part of the process, which might result in its registration, as it was important to understand what Zimbabwean farmers thought of it as well as researchers.

The Binga farmers mentioned the fact that the nearest store that sold grain protectants was in Gokwe (~180 km), and suggested that if this protectant was registered, attempts should be made to ensure that they could obtain supplies of it locally. An earlier report by Douglass et al., 1997 discussed this non-availability of grain protectants locally, and reported that the Zimbabwe Farmers Union (ZFU) is planning to open a warehouse at the Mola Centre with stocks of grain protectants to try and address this problem.

**Binga post-harvest sorghum practices questionnaire survey**

Full details of the post-harvest sorghum survey can be found in Stathers et al., (2000), the following is a summary of key findings. The main sources of household income were sale of livestock, beer, crops and crafts. All households kept some livestock. Goats and chickens were kept by >90% of respondents, cattle by 74.2%, guinea fowls by 45.2%, sheep by 35.5%, and donkeys by 6.5%.
The most frequently grown sorghum variety was SV2, which is perceived as being early maturing enabling it to escape both elephant and bird damage. Its low rainfall requirements, and good brewing characteristics enhanced its popularity. The traditional sorghum variety Kapila was also grown by a third of households surveyed its key characteristics include high yield and the production of good quality meal and beer, it is also considered to suffer only very low levels of insect damage during storage. Other less common sorghum varieties grown by the farmers included Kasili, Mukuwa, Red Swazi, Short variety and Super white.

Overall the most important use of sorghum is for sadza. However a few households considered the use of sorghum for payment of hired labour and production and sale of beer as more important than sadza. Poultry are commonly fed on the seed coat following dehulling, and any heavily damaged grain.

Farmers prioritised the following constraints encountered during the different sorghum activity phases:
- Production - damage by elephants, quelea birds, and crickets.
- Harvesting - damage by quelea birds and elephants, transport constraints from field to homesteads.
- Drying - unexpected heavy rainfall and subsequent rotting.
- Processing - shortage of labour, scattering, rodents and skin irritation from sorghum chaff.
- Treatment and storage - damage by insects, rodents and termites, protectant chemicals expensive and not locally available, shortage of thatching grass and danger from snakes.
- Marketing - lack of both market and transport to market.

Sorghum is typically stored threshed in a store. A wide variation in the plastering design (internal/external/both or neither) of stores was found both within and between homesteads. It should be noted that both monogamous and polygamous homesteads often had more than one store. In polygamous homesteads each wife typically had one store and then the husband often own one or two communal stores. 80% of the stores were raised more than 1 metre off the ground.

85% of respondents suffered from termite problems in their stores. Typical termite management strategies include: scraping off the termite tunnels; applying used oil to the posts; removing the outer part of the mopane posts leaving the more termite resistant heartwood exposed; applying ash; spraying with a mixture of pounded soswe in water; applying chemicals (not identified); and rebuilding the structure.

60% of respondents used protectants on their stored sorghum in order to reduce insect damage. The most common protectant used was soswe (*Maerua edulis*) (75%). This was applied in a number of ways including: mixing leaves in with the sorghum grain; placing the leaves in layers in the sorghum; pounding then mixing in the grain; pounding then mixing with water and spraying; crushing and then adding to mud used in plastering. Other farmers used Cooper Shumba (pirimiphos-methyl), damfin, mopane ash which were admixed with the grain. Admixed protectants were applied at the time of loading the grain into the store, usually between July - August. Protectants mixed with mud or cow dung for plastering were applied prior to loading.

**Discussion**

All the farmers involved in the trials made very positive comments about the grain protection qualities of Protect-it™ applied at 0.1% w/w, in comparison to their traditional grain protection method. It is interesting that the Buhera farmers considered the Protect-it™ to be a better protectant than the pirimiphos methyl 2% dust that they usually use. Since a comparison of insect damage in their pirimiphos methyl 2% dust treated maize with that in the untreated maize used during the researcher managed trials (see section 1.3 Fig 1.3.4a) reveals that their traditional treatment reduces damage compared to leaving the grain untreated. The comparison of prices of the Protect-it™ treated and traditionally treated grain in both Buhera and Binga, confirms the farmers’ parameter scorings, with Protect-it™ treated grain being given a higher value at both the 5 and 7 month evaluations.

The parameters listed by the farmers as important in comparing grain samples: insect damage to grain; and presence of insects and insect products, are similar to those recorded during laboratory analysis of differently treated samples. Other parameters mentioned by farmers as quite important included:
presence of protectant dust on the treated grain; and colour of grain. It might be worth using a scoring system developed in conjunction with farmers to also score treated grain samples for these parameters. In Binga, farmers frequently mentioned the presence of insect webbing as an important parameter. However, during the laboratory analysis only low numbers of *S. cerealella* were recorded, suggesting that the laboratory method used is not a good indicator of moth activity and numbers. The processing parameters mentioned by the farmers all suggest that Protect-it™ treated grain is viewed more positively in terms of the eventual sadza output: increased meal, whiter maize meal; heavier meal; finer meal; less smelly sadza. Although increased processing time suggests negative labour connotations for the women involved, when the issue was discussed, the women said it was a fact that the undamaged grain would take longer to process and require more labour. However, it would also yield more meal, because the insects had not consumed the inside of the grains.

It is difficult to analyse the results of these trials statistically because of the high levels of variation, which exist between each replicate (a farmer). The aim of these trials was to learn about farmers’ perceptions of diatomaceous earths (in this case Protect-it™) as grain protectants. It was therefore important that farmers used their own grain, which they knew the history of since harvest, and treated the grain themselves prior to storing it in their own granaries and managing it themselves. Naturally, this meant that the farmers would all start with grain grown under different conditions, possibly even different varieties of grain, and exposed to different levels of field infestation. The building styles, ages and maintenance levels of the granaries would also have differed between farms, as would the other contents, some of which contained already infested grain. All of the above will have led to variation between the replicates, however it is interesting that despite this variation all the farmers involved perceived Protect-it™ as a highly effective grain protectant. This high level of variation might have been reduced if the farmers had worked as a group. They could have treated one batch of well mixed (in order to try and increase the likelihood of even infestation) grain, and then split it into individual batches for storage in a central store, which they managed. However, this would have reduced the level of farmer ownership and control of the trials, and subsequently the relevance of the trials. It was unfortunate that due to Cyclone Eileen five of the Binga farms could not be visited at the seven months evaluation, and this was then delayed to a 9 months evaluation, making comparisons between these five farms and the other six farms difficult. As expected, insect populations were higher at the five farms where the final sampling took place after 9 months.

Increasing the number of replicates (farmers involved in the trials) may also reduce the variation but would have cost and time implications. However, this might be important in future trials following the temporary registration of Protect-it™ as a grain protectant where consumer parameters of taste, preparation qualities and brewing etc. are included with economic parameters to give a fuller picture of the acceptability and potential for this grain protection method. Farmer managed seed germination trials would also be included in further studies.

The traditional protectants used by the households involved in these trials, show that the use of grain protectants on maize by farmers in Buhera is common, while most farmers in Binga do not use grain protectants on sorghum with the exception of the few who use plant materials. This might suggest that Buhera maize farmers would be more likely to purchase a protectant, than Binga sorghum farmers, but may also be related to the problem of lack of availability of grain protectant outlets in Binga district.
1.5 Develop extension messages and literature

Due to the lack of registration of DEs for use as grain protectants in Zimbabwe, this activity was not completed during the life of the project. However, the project has generated sufficient information on application method and rate for admixture of DEs with maize, sorghum and cowpeas over different storage periods to produce a recommendation, which could be used as the basis for further extension messages. Safety recommendations to protect users from potential respiratory problems related to inhalation of DE particles would be the central part of this message. The admixture procedure (mixing a known quantity of DE thoroughly with a known quantity of commodity) is the same as that for applying grain protectant dusts currently available in Zimbabwe, which reduces the likelihood of user confusion. However, a survey in 1995 found that recommended grain protectant application procedures were rarely followed (Mvumi et al., 1995). A wide variation in dosages applied was reported, especially for insecticides sold without a measuring cup enclosed in the package. Farmers used spoons of various sizes and shapes, fertiliser cups, tea-cups or bare hands, or the perforations on the insecticide container to sprinkle the insecticidal dust onto the grain without measuring. These reports highlight the need for large-scale field testing of any printed material produced, with potential user groups with different literacy levels, vernacular languages, gender and well being categories prior to final printing of the material, to ensure optimum use of DEs by users.

To date the project trials have confirmed the efficacy of DEs against stored product pests in Zimbabwe, and farmers have ranked the admixing of DEs highly in comparison to their usual grain protection methods. However information on the effect of DEs on important consumer parameters such as taste, preparation qualities, brewing characteristics and cost benefit are required following temporary registration.

Farmers and extension staff have already learnt about the use of DEs as grain protectants in Zimbabwe, through a number of pathways including: direct involvement in the trials (~50 farmers & 10 extension staff); informal neighbourhood and community information networks; active participation at field days (both in the communities involved in the trials (~400 farmers) and at the IAE research station (~100 farmers) and agricultural shows (~300 farmers); field extension staff involved with the project; local newsletter articles and radio programmes.

2.1 Laboratory based assessment on the efficacy of Dryacide® and Protect-it™ dusts applied as aqueous slurries to concrete, metal and mud-plastered surfaces.

Introduction
In addition to admixing DE with commodities, the fabric of warehouses and grain handling machinery can be treated with aqueous DE slurries to improve long term protection against insect infestation (Anon, 1994). DE slurries also have an important role in the disinfestation of grain storage structures (Bridgeman, 1994). The slurry application technique practiced in Australia, involves atomising, and spraying or squirting the DE/water 10% w/v mixture onto the storage structure to achieve 6 to 10g/m² (Bridgeman, 1999). However, no information exists on the efficacy of surface application of aqueous DE formulations to mud surfaces such as those found in many traditional African stores. The effect of different concentrations of Protect-it™ and Dryacide®, applied as aqueous slurries to steel, concrete and mud surfaces on the mortality or Tribolium castaneum, Sitophilus zeamais, Prostephanus truncatus and Rhyzopertha dominica was studied in the laboratory.

Materials and Methods
A series of laboratory trials were conducted in which aqueous DE slurry was evenly applied to different surfaces at a range of different concentrations. The DE slurry was evenly applied using a 1.5-inch (~4cm) paintbrush, and left to dry for 24 hours, prior to the addition of insects. Forty unsexed 7-14 day old adult insects of each of the test species (T. castaneum, S. zeamais, P. truncatus and R. dominica) were added to glass rings (50mm diameter; 15mm height) secured to the surface of the treated slabs.
(22x44cms) and mortality was assessed after 24, 48, 72 and 168 hours. Mud, concrete, steel and painted mud surfaces were evaluated, using DE slurries at concentrations of 3, 6 and 12g/m². The mud surface was produced by spreading a mixture composed of: 20g milled hay; 1kg dried sieved earth (collected at the Natural Resources Institute, UK); and 700ml of water, onto a concrete slab to give a smooth layer ~5mm thick. A further trial evaluated the potential of adding DE to the mud prior to plastering.

**Results**

Application of DE slurry to concrete surfaces increased mortality of all insect species in comparison to an untreated control concrete surface (Fig. 2.1.1). However, even after 48 hours exposure, mortality on DE slurry treated concrete surfaces was still low ranging from 2-21% for all insect species.

Application of DE slurry to steel surfaces caused rapid mortality of all insect species in comparison to the untreated control steel surface (Fig 2.1.2a&b). At a DE slurry application rate of 6g/m², for Protect-it™ and Dryacide®, respectively, mortality ranged from 18-95% and 8-87% after 24 hours exposure, and 89-100% and 88-100% after 72 hours exposure (Fig 2.1.2a). When the application rate was reduced to 3g/m², mortality remained high for all test species (Fig 2.1.2b).

Application of 6g/m² DE slurry to mud surfaces resulted in only low levels (<10%) of mortality for all insect species after 96 hours exposure (Fig. 2.1.2c). When the DE slurry application rate was increased to 12g/m2, mortality remained low (<17%) for all insect species after 96 hours exposure (Fig. 2.1.2d).

The addition of a layer of gloss or emulsion paint to the top of the mud surface prior to DE slurry application, increased insect mortality (Fig 2.1.3a-c), but was still much lower than that achieved on steel surfaces. In general, mortality was higher on mud painted with emulsion as opposed to gloss paint.

The admixing of DE with mud prior to plastering did not increase insect mortality (Fig. 2.1.4).

**Fig. 2.1.1** Mortality of four stored product insect species on concrete surfaces treated with DE slurries at 6g/m² (n=3).
Mortality of four stored product insect species on steel surfaces treated with DE slurries at 6g/m² 
(n=3)

- Dry acid 6g/m²
- Protect-it 6g/m²
- Control

Insect species and treatment

Mortality of four stored product insect species on steel surfaces treated with DE slurries at 3g/m² 
(n=3)

- Dry acid 3g/m²
- Protect-it 3g/m²
- Control

Insect species and treatment

Mortality of four stored product insect species on mud surfaces treated with DE slurries at 6g/m² 
(n=3)

- Dry acid 6g/m²
- Protect-it 6g/m²
- Control

Insect species and treatment

Mortality of four stored product insect species on mud surfaces treated with DE slurries at 12g/m² 
(n=3)

- Dry acid 12g/m²
- Protect-it 12g/m²
- Control

Insect species and treatment
Fig 2.1.3a  Mortality of four stored product insect species on mud surfaces treated with DE slurries at 6g/m² (n=3)

Insect species and treatment

Fig 2.1.3b  Mortality of four stored product insect species on mud painted-with-emulsion surfaces treated with DE slurries at 6g/m² (n=3)

Insect species and treatment

Fig 2.1.3c  Mortality of four stored product insect species on mud painted-with-gloss surfaces treated with DE slurries at 6g/m² (n=3)

Insect species and treatment
Fig 2.1.4  
Mortality of four stored product insect species on mud surfaces treated with Protect-it slurry at 12g/m2 and mud/Protect-it admixed surfaces (n=3)

Discussion

DE slurry application was only really effective when applied to steel surfaces. Control was achieved even at the reduced dosage of 3g/m2. When applied to mud surfaces, insect mortality was low, and remained so even if the surface was painted with gloss or emulsion paint. There was a small increase in effectiveness when slurries were applied to concrete surfaces.

Following application, a fine coat of DE dust could be observed on the steel surfaces, which was not evident on the mud surfaces, and insects on the steel became quickly covered in dust particles. The mud may have been permeable to the slurry so making the dust particles unavailable to the insects. Although the mud surface was smoothed prior to drying, it was not as flat as the steel surface, this may have enabled insects falling onto their dorsal side to turn themselves over more easily than on the steel surface, which may have enhanced their survival. The origin and composition of the mud may also affect the efficacy of DE slurries. During these studies, insects were confined on the DE treated slurries. Enforced confinement is likely to lead to greater levels of mortality than would occur in the field. Further work is needed to investigate whether insects are repelled by the presence of DE slurries on mud surfaces, even if they are not killed.

The application of dry DE to storage structures is know to be more effective than wet DE (slurry). However, wet DE (slurry) application reduces worker exposures to the dust particles. Farmers in Zimbabwe commonly apply grain protectants dust (e.g. pirimiphos-methyl) to the internal surfaces of their granaries prior to loading grain. Further work could investigate the application of dry DE to mud surfaces, although if the results were successful, increased attention would need to be paid to minimising the health aspects of the technique.
2.2 Development of methods to apply slurries for small-scale application.

In Australia, the use of DE to disinfect grain, pulse and oilseed storage is widespread (Bridgeman, 1999). DE can be applied wet or dry to the surface of structures. The advantage of wet or aqueous slurry application is improved occupational safety, as the worker only comes into contact with DE dust during mixing and, for this reason, wet application is widespread in Australia. High-pressure slurry pumps or modified grain protectant spraying systems are used for application (Bridgeman, 1999). This equipment is inappropriate for most small-scale farmers in developing countries. A method was tested to enable small-scale producers and traders to easily apply DE slurries to the surfaces of storage structures.

The application method described in 2.1, using a 1.5 inch (~4cm) paintbrush (readily available in most developing countries), to apply a known quantity of aqueous DE slurry to a surface, was found to work well. During testing, the most important points in terms of efficacy of this application method were found to be the DE slurry concentration and the type of surface; DE slurries were shown to be more effective on steel than on mud or concrete. Admixing the DE with the mud during plastering was not effective, and the painting of the mud surface prior to DE slurry application did not increase efficacy.

The use of DEs are known to be less effective when applied as a wet slurry as opposed to a dry powder (Bridgeman, 1999). Application of dry DE on mud surfaces using a perforated container is likely to be more effective. However, this would increase worker exposure to DE particles in the atmosphere, especially within the enclosed space of a storage facility, and it would be difficult to apply evenly or to estimate coverage. In situations where producers or traders commonly use spraying equipment, this may form a highly effective means of application. Aqueous slurry could be added to the spray tank. It is important that the slurry is mixed well and the concentration and hence coverage is understood. Calculations for coverage are complicated and resources would need to be invested in user understanding, in order to reduce the chances of misapplication. Nozzles need to be carefully selected, as they can easily become blocked. The use of spraying equipment for DE application does accelerate wear and tear (Bridgeman, 1999).

For steel surfaces, the application of DE slurry with a paintbrush is a highly effective technique, however this technique is not effective on mud surfaces and therefore of little use to the majority of small-scale producers in developing countries.
Outputs

Output 1: Methods for treating grain with inert dusts to provide protection against insect pests in storage developed.

Laboratory trials found Dryacide® and Protect-it™ to be both effective and persistent in reducing insect damage to stored commodities. High application rates of diatomaceous earths were required to control the Bostrichid beetles *Prostephanus truncatus* and *Rhizopertha dominica*. The continuous exposure of seven generations of *Sitophilus zeamais* to low doses of DEs increased their tolerance to DE slurries, in comparison to *S. zeamais* never previously exposed to DEs. *Prostephanus truncatus* did not show this response.

On-farm trials in three Districts in Zimbabwe have demonstrated that diatomaceous earths (DE) are extremely effective and persistent grain protectants against the major insect species attacking stored sorghum, maize and cowpeas.

During the first season’s trials, the treatments included: the DEs, Protect-it™ and Dryacide®, at two concentrations (0.1% and 0.2% w/w); Actellic Super dust; and an untreated control. Damage levels remained very low in all the grain treatments throughout the 40-week storage period, in contrast to the untreated controls where damage levels increased rapidly from 24 weeks storage onwards. No significant difference was found between damage levels in the Actellic Super dust treatment and the DE treatments, with the exception of the lower concentrations of Dryacide® on sorghum, where damage levels increased suddenly after 24 weeks storage, which may be a reflection of the difficulty in controlling *Rhyzopertha dominica*.

During the second season’s trials, lower concentrations (0.1% and 0.05% w/w) of the DEs were used. Damage levels on maize remained low in both concentrations for the first 24 weeks of storage, after which stage damage levels increased in the 0.05% w/w treatments. On sorghum, a similar result was observed, with damage levels in the 0.05% w/w treatments increasing more rapidly than the 0.1% w/w treatments. From 24 weeks onwards, damage levels in the 0.05% w/w treatments were significantly higher than those in the untreated control, which may be a result of the loss of natural enemy populations coupled with ineffective control of *R. dominica* at this lower concentration.

During evaluations of the farmer-managed inert dust participatory trials in Binga and Buhera districts, the DE treated grain outscored the control/traditionally treated grain for all parameters, including an estimated purchase price. The most commonly used parameters, which the farmers selected for scoring were: insect damage; presence of live insects; presence of insect webbing (on sorghum in Binga only) and appearance of grain. Interestingly, farmers in Buhera liked the fact that the DE remained on the surface of the grain after 7 months in store. As DEs are not registered for use as grain protectants in Zimbabwe, information on any effects of the DEs on taste/quality could not be gained. Many of the farmers asked where they could purchase Protect-it™.

Output 2: Methods for treating storage structures with liquid suspensions of inert dusts developed.

A simple method of applying liquid suspensions of inert dusts to surfaces, using a paintbrush, was developed. Further experiments using this technique found that applications to steel surfaces caused much higher insect mortality than application to mud surfaces. Even the lower DE aqueous slurry concentration of 3g/m² on steel caused higher mortality than 12g/m² on mud. The low efficacy of DE slurries on mud surfaces suggests that this technique will not be effective in many farmers’ stores in Zimbabwe, where walls are traditionally plastered using a thin layer of mud. However the technique may have application in both farmers’ and traders’ stores made of other materials.
Contribution of Outputs

The application of diatomaceous earths (DEs) has been found to be an effective method of controlling post-harvest insect pests in maize, sorghum and cowpeas in Zimbabwe. Their use has the potential to reduce losses and maintain quality during storage. This will improve both the household food security of small-scale farmers and their ability to take advantage of price fluctuations in the market throughout the storage season. These findings may have implications for other semi-arid regions in Africa. DEs have been found to be as effective as the synthetic insecticide, Actellic Super Dust, providing farmers with a safer and more environmentally sustainable post-harvest pest control method.

During the project, preliminary studies were also carried out on local sources of DEs, a sample from northern Zimbabwe was found to have efficacy against storage pest insects, and deserves further attention. Natural deposits of DE are present throughout sub-Saharan Africa. Further investigation of DE deposits, currently being exploited for industrial purposes (e.g. DE is being mined in both Tanzania and Kenya) is required to ascertain whether any of them could provide a more sustainable and low cost source of DE for grain protection. Studies into the percentage crystalline silica and respirable dust of any effective local DEs would need to be determined to ensure user safety.

The trials in Zimbabwe have generated a great deal of interest from both farmers and private agrochemical companies. They have learnt about the potential of DEs as grain protectants in Zimbabwe through: direct involvement in the trials; informal neighbourhood and community information networks; active participation at field days (both in the communities involved in the trials and at the IAE research station) and agricultural shows; field extension staff involved with the project; local newsletter articles and radio programmes. However, until DEs are registered as grain protectants in Zimbabwe, more complete information on their acceptability to producers and consumers and the socio-economic factors influencing the use of DEs by small-scale farmers cannot be obtained. Temporary registration for use of DEs as grain protectants in Zimbabwe is currently being applied for. A local company (EcoMark) is keen to register and distribute the DE, Protect-it™, within Zimbabwe. During the project, strong links have been formed between AGRITEX field staff, researchers and farmers. AGRITEX field staff and researchers have become skilled at applying participatory methodologies and more knowledgeable about post-harvest practices and constraints in the localities where the project has been active. During the project, one of the IAE project staff has completed his fieldwork on 'The ecology of stored grain insect pests in Zimbabwe and their control using inert dusty with particular emphasis on the Angoumois grain moth, *Sitotroga cerealella* Olivier (Lepidoptera: Gelechiidae)' for PhD degree submission at the University of Greenwich. All these factors will help to improve both farmer-oriented post-harvest research capacity and food security in Zimbabwe.

The larger grain borer *Prostephanus truncatus*, one of the most serious pests of stored maize in Africa, is not yet endemic in Zimbabwe. Laboratory trials have shown that higher concentrations of DE are required to reduce damage by *P. truncatus*. *Rhizopertha dominica* (another Bostrichid beetle) was found to cause high levels of damage on sorghum in the lower DE concentrations used in the Zimbabwean field trials. Further study is needed on the efficacy of DEs against these devastating Bostrichid beetle pests. Initial laboratory studies should focus on the possibility of combining DEs with low doses of permethrin or deltamethrin to control *P. truncatus* and *R. dominica*. Following the outcome of these laboratory trials, field trials could be established in a country such as Tanzania where *P. truncatus* causes serious storage losses, and where farmers' desire for alternatives to Actellic Super dust was one of the main messages from the 1999 Dar es Salaam workshop on post-harvest problems in Tanzania. Researchers in the Plant Protection Division of the Tanzanian Ministry of Agriculture are keen to collaborate on field-trialing DEs, based on the findings of project R7034 in Zimbabwe and linking into project R7486 on the development of IPM techniques for the control of LGB.

The dissemination of knowledge about both the use of and efficacy of DEs for grain protection both within the countries involved (through existing agricultural knowledge information systems and innovative uptake pathways) and to other countries is a critical part of any further work on DEs. The information already collected, on application methods and producer acceptability, will be reinforced by further social and economic information once registration procedures enable producers to process and consume DE treated commodity. This additional information will strengthen the extension tools developed, and will facilitate a more focused monitoring of the impact of this alternative grain protection technology.
**Project publications and disseminations**


ANON. (1999) Use of Inert Dusts as Grain Protectants in Zimbabwe: Radio program based on The Zimbabwean Farmer article above. Radio 3 Zimbabwe, 10th and 11th May 1999 (on air 3 times each day), 10 minutes. Zimbabwe [national]. (Radio)


MVUMI, B. (1999) Inert Dusts as Grain Protectants. Shona and English. Institute of Agricultural Engineering, Borrowdale, Zimbabwe. 24 June. [Component of a Farmers Open day for ~1000 Farmers] (Open day)


MVUMI, B., MHUNDURU, J. and ZHOU, A. (1999) Inert Dusts as Grain Protectants [One day field day for ~40 farmers in Binga district]. Tonga and Shona. Mr Muzamba’s homestead, Binga district, Zimbabwe. March. (Open Day)


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i. Hedley Technologies Inc., 2600 Skymark Avenue, Suite 101, Building 4, Mississauga, Ontario, L4W 5B2, Canada

ii. Dryacide Australia Pty Ltd., P.O.Box 38, Scarborough 6019, Western Australia.

iii. Zimbabwe is divided into six Natural Regions (NR) mainly based on rainfall and its temporal distribution: NR I - 1000mm+; NR IIa 750-1000mm; NR IIb same as NR IIa but distribution less reliable; NR III 650-800mm; NR IV 450-650mm; NR V <600mm (Department of the Surveyor General, 1984)

iv. Actellic Super Dust is the trade name for a "cocktail" of pirimiphos-methyl 1.6% and permethrin 0.3%, it is a locally available grain protectant.