Diatomaceous earths as grain protectants in Tanzania:

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1 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 for 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). Many small-scale farmers in the developing world still use traditional methods of mixing sand, kaolin, paddy husk ash, wood and other sources of 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 (include 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

Unlike most synthetic insecticides, inert dusts function through their physical properties and are, therefore generally slower acting (Maceljski & Korunic, 1972). Synthetic silicates and diatomaceous earths are active at much lower rates of application than sand, ash, lime etc. traditionally used by small-scale farmers. However, synthetic silicates, which are manufactured for industrial uses, have very high silicon dioxide content, and are very expensive and therefore inappropriate for use as grain protectants. This report concentrates on the use of diatomaceous earths in stored grain protection and the findings of the 'Small-scale farmer utilisation of diatomaceous earths during storage' project. This is a collaborative project between the Plant Health and Post Harvest Management Services of the Tanzanian Ministry of Agriculture and Food Security, the UK Natural Resources Institute, the University of Zimbabwe, the Tropical Pesticide Research Institute, the Institute of Agricultural Engineering in Zimbabwe, AREX, EcoMark Ltd, and Diatom Research Consulting. The project field activities are located in Tanzania and Zimbabwe and the project is funded by the UK DFID Crop Post Harvest Programme from June 2002 – January 2005.

2 Diatomaceous earths

Diatomaceous earths (DEs) consist of the fossils of phytoplanktons (diatoms) (Plate 1), which are composed mainly of amorphous hydrated silica (~90% $SiO2$) and other minerals including aluminium, iron oxide, magnesium, sodium and lime. Diatoms are unicellular organisms found in both fresh and marine water. They extract silicic acid from the water and incorporate it into their shells. When they die they sink down into a sedimentary layer. Over many centuries a thick layer builds up, which becomes compressed and fossilised into a soft, chalky rock called diatomite. This layer of diatomite can be quarried, dried and ground in order to reduce both the particle size and moisture content, resulting in a fine talc-like dust (diatomaceous earth) considered to be non-toxic to mammals (Quarles, 1992). The high porosity of diatomite has resulted in its use: in filters to help clarify fruit juices, beers, wine, pharmaceuticals, swimming pool waste, dry cleaning solvents amongst others (Subramanyam & Roesli, 2000); as a filler in paints, plastics, asphalt, coating agent in fertilisers, carrier for pesticides (Jefferson & Eads, 1951); as a mild abrasive; and as a particle aggregate in industrial absorbents. Diatoms are the dominant phtyoplankton in areas where dissolved silicon concentrates, which are typically located at equatorial and subpolar latitudes as well as along the western continental margins (Libes, 1992). There are more than twenty five thousand species of diatoms, and as many as 7-8 billion diatoms can exist per sq metre of ocean (Round *et al*., 1992). Much of the DE being used today originated more than 20 million years ago in the lakes and seas of the Miocene and deposits are scattered around the globe.

Plate 1. Scanning electron micrograph of diatoms.

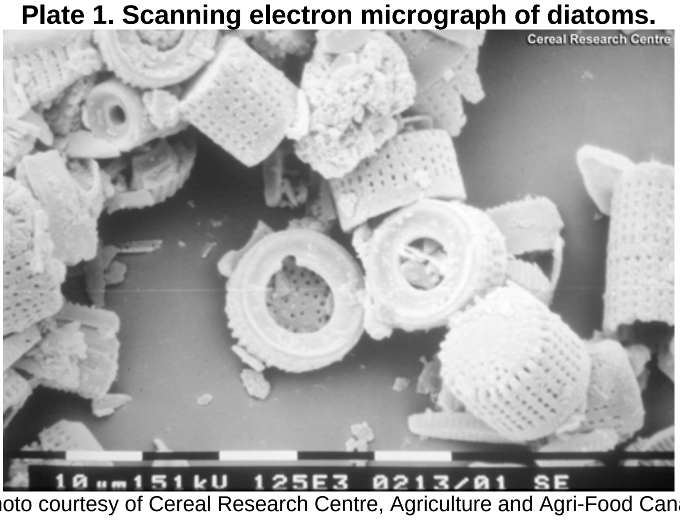


Photo courtesy of Cereal Research Centre, Agriculture and Agri-Food Canada.

3 Mode of action of diatomaceous earths

Diatomaceous earth also has insecticidal properties, exerting its effect through physical means and, although not affecting metabolic pathways by chemical action, may well be chemically active under some circumstances. When particles of DE come into contact with insects they absorb wax from the cuticle resulting in water loss, desiccation and death

(Ebeling, 1971). Death occurs when 28-35% of the body weight (about 60% of the water content is lost) (Ebeling, 1971). Many dusts including DEs have a repellent affect against insects (White *et al*., 1966) and it has been suggested, against rodents as very low numbers of rodent hairs and faecal matter were found in grains, cereals and dried fruits treated with DE (cited by Allen, 1972).

Stored product species show variation in their susceptibility to DE (Carlson & Ball, 1962; Desmarchelier & Dines, 1987; Korunic, 1998; Subramanyam *et al*., 1998; Fields & Korunic, 2000). The most susceptible tend to be those:

- with large surface to volume ratios (small insects);
- with body hair (DE particles collect on the hair) (Carlson & Ball, 1962);
- with thin cuticles (Bartlett, 1991);
- protected by low-melting 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 results are conflicting, 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). However, much of the DE research work has focused on a very limited number of insect species important in large-scale storage but has tended to ignore insects such as *Prostephanus truncatus*, the larger grain borer and moth species devastating to small-scale farmers in developing countries.

The different insect life-stages also vary in their susceptibility to DE. First instars of *Plodia interpunctella* were more susceptible to the DE 'Insecto' than 3rd and 5th instars (Subramanyam *et al*., 1998). *T. confusum* larvae, survived seven times as long as *T. confusum* adults on wheat admixed with DEs (Mewis & Reichmuth, 1999). This larval tolerance might be linked to the ability of the larvae to regenerate their cuticle frequently, preventing the DE particles from breaking the water barrier of the continuously growing new wax layers (Mewis & Reichmuth, 1999). Those insects which develop and feed internally within grains are less likely to come into contact with DE particles applied to the surface of grains than insects which develop externally, or are highly mobile within commodities. This fact necessitates the need for DE treatment of grain either prior to infestation or immediately following the destruction of insect populations by fumigation or solarisation, particularly in commodities commonly attacked by boring beetles such as the bostrichids *P. truncatus* and *Rhyzopertha dominica*.

4 Commercial uses of diatomaceous earth products

During the 1960's and 1970's researchers in the USA worked with DEs (Quinlan and Berndt, 1966; Redlinger and Womack, 1966; Strong and Sbur, 1963; La Hue, 1965, 1967, 1977; White *et al*., 1966) but it was the development of organophosphate resistance in stored product insects that led to a serious appraisal of DEs. In 1984 the US Environmental Protection Agency registered Insecto, a new DE which could be effectively applied to grain at dosages as low as 0.05-0.1% (w/w) (Subramanyam *et al*., 1994).

Many DE dusts are now commercially available, and are registered for use as grain protectants in Australia, Brazil, Canada, Croatia, China, Germany, Indonesia, Japan, Philippines, Saudi Arabia, United Arab Emirates, UK[1] and the USA. DEs from different sources vary in their efficacy against insects (Snetsinger, 1988; Katz, 1991; McLaughlin, 1994). This variation is due mainly to the different physical and morphological characteristics of the diatoms rather than their origin (Korunic, 1998), and helps to explain why some registered DEs are more effective than others.

Diatomaceous earths can be used for the treatment of both grain and structures.

4.1 Grain treatment

Diatomaceous earths can be applied directly to dry grain. Historically high dosages were required; however improved formulations which are effective at dosages between 0.5 and 1 kg/t grains (Insecto, USA; Dryacide, Australia) or from 0.1 to 1 kg/t grains (Protect-it, USA) and innovative combinations with other grain management practices enable reduced dosages to be used.

The simplest application method is to admix the DE with the small quantities of grain or seed using a shovel, prior to storage. Uneven mixing and distribution of the DE within the commodity can enable pockets of insect populations to develop. Larger quantities of grain can be treated while on auger hoppers, belt conveyors or bucket elevators using a dust applicator for dry DE or a spray system for aqueous DE slurries.

However many of the present regulations defining quality parameters prohibit the addition of any dust to grain intended either for export to other countries or for large scale handling. The presence of DE creates greater friction between grains, which reduces the bulk density and flowability of the grain and the evidence of visible residues on the grains also affects the quality assessment (Quarles, 1992; Johnson & Kozak, 1966; Quinlan & Berndt, 1966; LaHue,

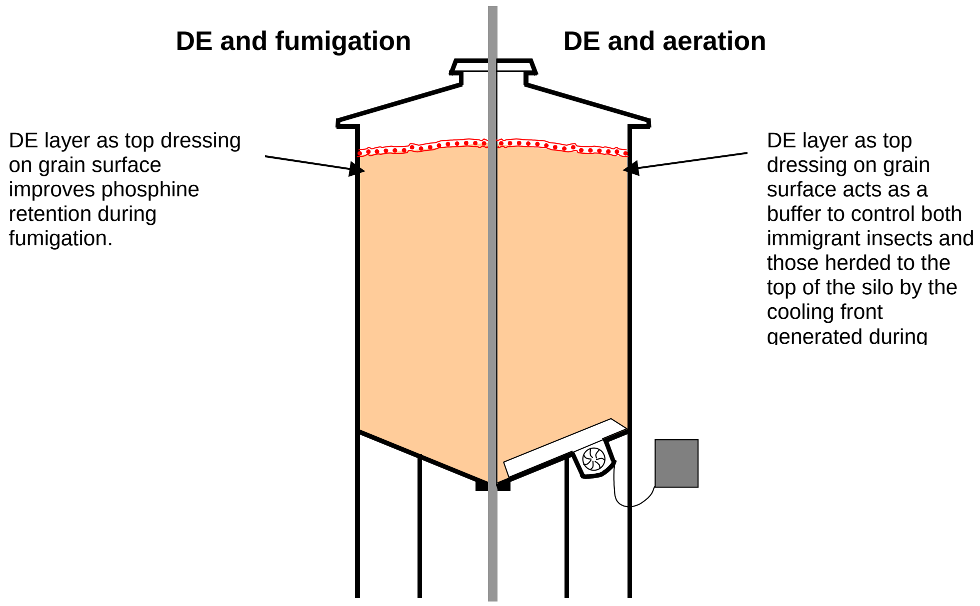
[1] The DE SilicoSec is now being promoted as a grain protectant in the UK but due to DEs having a physical as opposed to chemical mode of action they do not need to be registered in the UK. The home grown cereals authority has published two topic sheets (62 & 79) on DE use see http://www.hgca.com

1970; Desmarchelier & Dines, 1987; Jackson & Webley, 1994; Korunic, 1997; Korunic *et al*., 1998). Until such regulations are changed the future of large-scale direct application of DE to grain remains limited. Investigations into the alteration of the regulations to enable DE treated grain to be assessed fairly and further research into reduced DE dosages are ongoing.

An alternative protection system favoured by bulk grain handlers in Australia is to apply the enhanced DE Dryacide® as a top dressing and fumigate with phosphine every two to three months (Figure 1). The use of DE as a dust to cap the grain surface in low flow phosphine fumigations is industry practices in bulk handling companies in Eastern Australia (Bridgeman, 1999). The DE layer improves phosphine retention enabling insect-free and residue-free storage in poorly or unsealed structures (Bridgeman & Collins, 1994). In this practice Dryacide is dusted onto the level surface of the grain at a rate of 100g/sq m. Trials have indicated that the use of DE in this manner gives superior results when compared to covering the grain surface with a PVC cover (Winks & Russell, 1994).

Controlling insect populations with aeration alone is not completely effective, the addition of DE to the surface layer of the grain can reduce insect populations still further (Figure 1) (Nickson *et al*., 1994; Bridgeman, 1999). Insects which move to the top of the silo as a result of the cooling front and immigrating insects are controlled by the DE layer (Bridgeman, 1999).

Figure 1: Diagram of a silo with the grain surface top dressed with DE to enhance both fumigation and aeration practices



4.2 Structural treatment

DEs can also be applied as dry powders or wet aqueous slurries to empty storage facilities and grain handling equipment such as trucks, headers, augers and combines for disinfestation and long-term protection purposes (Bridgeman, 1994; Anon, 1994). Before empty storage facilities or grain handling equipment are treated with DE they must be cleaned of grain dusts and residues.

The surfaces of silos and other storage facilities can be sprayed with aqueous DE slurry; in Australia, this is now a popular practice and has been shown to provide protection for up to 12 months (Bridgeman, 1991, 1994; Desmarchelier & Dines, 1987). Laboratory studies have shown that DE slurries are more effective when applied to metal surfaces than to concrete or mud surfaces (Stathers & Denniff, unpublished). Dryacide recommend a slurry application rate of 6 grams/ square metre (1.2lb per 1,000 sq ft) which is higher than the recommended Dryacide dust application rate of 2 g/sq metre (0.4lb per 1,000 sq ft of surface area). As application rates differ between DE formulations, individual label recommendations must be followed. Slurry application of DEs gives more even coverage than dusts and occupational safety is improved as DE dust is only generated during tank mixing. In response to consumer pressure to reduce both chemical treatment of food commodities and pesticide residues in food, the use of DEs that are approved for organic processing, for structural treatment of cracks and crevices in buildings or as a top dressing in grain stores is likely to increase in the future (Quarles & Winn, 1996).

The application procedure chosen will effect the cost of treatment, as the admixture of DE with commodity will require larger quantities of DE than a layer of DE applied as a top dressing for combined use with fumigation or aeration. Similarly due to different dosage recommendation wet and dry structural treatments will differ in cost.

Diatomaceous earth can be used not only against storage pests but also against domestic and field pests. DE is effective against pests that live in close association with humans such as cockroaches, silverfish, mites, ants, houseflies, spiders, bedbugs, fleas and crickets (St Aubin, 1991). It can be used to treat cracks, wall crevices, wall voids and attics to repel insects and deny harbourage in these areas (Quarles, 1992). Of the 44 DEs registered in the United States, 8 are registered for household use (Subramanyam & Roesli, 2000). There are claims that DE is deadly to a wide range of field pests including: gypsy moth; codling moth; pink boll weevil; lygus bug; twig borer; thrips; mites; slugs; snails; nematodes; mildew (Allen, 1972). DE can be applied directly to the soil, or to moist foliage using an electrostatic appplicator (Quarles, 1992). However, there is little published or accessible data to support the effective use of DEs against domestic or field pests.

5 Safe use of diatomaceous earths in storage

When considering health and safety aspects of DE use in storage, there are two main areas: consumer safety and worker safety.

5.1 Consumer safety

Diatomaceous earths have extremely low toxicity to mammals (e.g. the DE Insecto® has a rat oral LD_{50}, >5000 mg/kg (Subramanyam *et al*., 1994), silicon dioxide (the major constituent of DE) has a rat oral LC_{50} = 3,160 mg/kg (NIOSH, 1977)). DEs are considered 'Generally Regarded As Safe' by the USA Environmental Protection Authority (Anon., 1991). The Food and Drug authority 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). Silica occurs naturally in vegetables and grains such as rice, and the average human intake from natural sources is about 200mg per day (Quarles & Winn, 1996). Silica does not accumulate in mammals as it is excreted as silicate in the urine (Desmarchelier & Allen, 1999). Silica is used as a thickener in ointments and suppositories, as a filler in tablets, as an anti-caking agent in processed foods, in toothpaste, and to prevent clogging in hygroscopic powders (FDA, 1995; Budavari, 1989; Martindale, 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, DE is not likely to become a health problem for consumers (Quarles & Winn, 1996; Desmarchelier *et al*., 1996). The traditional method of cleaning grain by rinsing with water is also effective in removing DE (Desmarchelier & Paine, 1988).

5.2 Worker safety

The only possible negative health effect comes from long-term chronic exposure to quantities of inhaled dust and workers involved in DE application and/or handling of DE treated grain should take appropriate safety precautions. The important issues include the amount of dust, its particle size and the crystalline silica content of the DE (Desmarchelier & Allen, 1999). During the process of sedimentation, geological forces can convert amorphous silica into forms of crystalline silica including the highly dangerous cristabolite. Exposure to crystalline silica dust is a known cause of lung disease (Hughes *et al*., 1998) and in 1997 the International Agency for Research on Cancer (IARC) classified it as a group 1, human carcinogen. This recent decision has caused much debate, details of which can be found in Goldsmith (1999) and Hessel *et al*. (2000). Fortunately, most DEs are mainly composed of amorphous (non-crystalline) silica which is classified by the IARC as group 3, not carcinogenic (Korunic, 1998), and average <3% crystalline silica (Quarles & Winn, 1996). It should be noted that DE used in swimming pool filters can contain up to 60% crystalline silica and only DE's specifically registered for use as grain protectants should be used on stored grain or in storage structures.

The US Occupational Safety and Health Administration (OSHA) established limit for DE containing < 1% of crystalline silica is 6mg m^{-3}, above these limits workers are required to wear dust masks (OSHA, 1991). Why exposure standards vary between countries is not clear. A comparison of the Australian Time Weighted Average (TWA) maximum exposure levels of workers for different dusts based on continuous exposure during an 8 hour day for 5 days per week are shown in Table 1. These figures suggest that DEs are potentially less hazardous to workers than lime, wood or cotton dusts. However, in order to minimise risk anyone involved in handling or applying any quantity of DEs should wear protective dust masks.

Table 1. A comparison of Australian TWA maximum exposure levels for a range of dusts.

Material	**TWA maximum exposure levels (8 hour day/ 5 days per week)**
Uncalcined DE	10 mg m^{-3}
Silica gel	10 mg m^{-3}
Kaolin	10 mg m^{-3}
Starch	10 mg m^{-3}
Lime	5 mg m^{-3}
Wood dust	1-5 mg m^{-3} (*depending on type*)
Cotton dust	0.2 mg m^{-3}
White asbestos	1.0 fibre per mL of air
Blue asbestos	0.1 fibre per mL of air

Source: Adapted from National Occupational Health and Safety Commission (NOHSC, 1995) cited by Desmarchelier & Allen (1999).

Safety precautions include reducing the amount of dust in the work place, wearing masks to prevent inhalation, and ensuring the DE meets the regulatory specifications in terms of particle size and absence of crystalline silica. In broad terms exposure safety limits for amorphous DEs are similar to those for such common materials as cement and lime (Desmarchelier & Allen, 1999). Interestingly, Desmarchelier and Allen (1999) also reported preliminary information that the use of DEs could reduce worker exposure to grain dust. They had observed that small respirable particles of grain dust could attach themselves to a non-respirable particle of DE, actually reducing the amount of respirable dust in the workspace.

Protective clothing (hats, overalls and gloves) should also be worn to prevent DEs from drying out the skin (Desmarchelier & Allen, 1999). A moisturiser with sun block should be worn if working outside. Safety glasses are also advisable to protect the eyes. Protective clothing can be washed in water to remove DE particles. If a person is exposed to excessive concentrations of dust, they should be removed from the dusty atmosphere into fresh air, and should then wash their nose, face and exposed skin with clean water (McDonald, 1989; Miles, 1990).

6 Research on diatomaceous earths in Tanzania

6.1 Introduction

Farmers throughout sub-Saharan Africa suffer serious losses to their stored produce due to insect damage. For many people these losses threaten household food security or undermine market returns, driving them to seek options for protecting their grain during storage. In addition to many of the traditional storage protectant practices such as admixing with ash or plant materials, and funds allowing they can purchase synthetic chemical pesticides. The main one is Actellic Super dust, an organophosphate-pyrethroid cocktail, but many other similar cocktails have recently entered the market. Unfortunately, since the distribution of these products was privatised, farmers have experienced widespread adulteration problems. In response to farmers' demands for alternative grain protectants, CPHP funded research in Zimbabwe from 1998 -2000 which found that DEs were effective grain protectants against insect damage for small-scale on-farm storage systems (Stathers et al., 2002a, 2002b). On learning about the Zimbabwean DE studies Mr Riwa of the Plant Health Services of the Ministry of Agriculture and Food Security contacted the NRI researchers involved and they collaborated to develop a proposal for a 3 year research project which was funded by the UK DFID Crop Post Harvest Programme in August 2002. Further work to evaluate these fossil dusts was then initiated in Tanzania where the devastating larger grain borer (LGB, *Prostephanus truncatus*) is already widespread, the proposal also included exploration of the potential of African deposits of diatomaceous earths. The project has developed a website http://www.nri.org/de/ to help share the information that is being generated with other stakeholders.

6.2 Materials and methods

6.2.1 Trial sites and timing

Researcher managed field trials were set up in five villages in three regions in Tanzania (Dodoma, Shinyanga and Manyara). The trials were conducted over a 40 week storage period during each of two consecutive storage seasons (2002/2003 and 2003/2004) starting in July or August each year. In the 2004/2005 storage season these researcher managed trials were only set up in Dodoma and Manyara regions. The three regions fall within different agro-ecological zones.

6.2.2 Storage facilities

Grain storage facilities differ from house to house, however the main practices seem to be the use of either a woven basket (*kihenge*) or polypropylene sacks. Whichever of these methods is used, the grain is usually kept inside the house often in the kitchen, store room or bedroom. In Shinyanga and Manyara regions mini vihenge were constructed by some of the villagers and used to store the trial maize and sorghum grain, while in Dodoma polypropylene sacks were used to store the maize grain. As the number of vihenge needed to store the different treatments were too many to be accommodated in an individual farmer's house in addition to the households' grain, sheltered raised platforms large enough to hold vihenge containing all the different treatments each replicated four times were constructed in both Mwataga and Mwamakaranga villages in Shinyanga region. While in Arri and Singe villages, Manyara region the village executive officers offered the use of the small village warehouses (go-down) situated in the centre of the villages near the few shops and businesses. In Mlali village, four farmers identified by the extension officer offered to house the sacks of the different treatments in their homes, each farmer acted as a separate replicate.

Table 2: Treatments and commodities used in the different trials

Location	Grain type (quantity/ treatment replicate)	Treatments used in 2002/2003 storage season (4 reps. of each treatment set up)	Treatments used in 2003/2004 storage season (4 reps. of each treatment set up)	Storage structure
Mlali village, Kongwa district, Dodoma region	Maize (100 kg)	A= Protect-It 0.1%w/w (100g/100kg) B= Protect-It 0.25%w/w (250g/100kg) C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w (250g/100kg) F=Traditional protectant (unwinnowed grain + animal dung ash (1.5kg/ 100kg)) G=Untreated control	A= Protect-It 0.1%w/w (100g/100kg) B= Protect-It 0.25%w/w (250g/100kg) C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w (250g/100kg) F=Traditional protectant (unwinnowed grain + sunflower ash (1.7kg/100kg)) G=Untreated control H=Stocal Super dust (111g/100kg) I=Tanzanian (Kagera) DE (250g/100kg)	Polypropylene sacks stored on raised wooden post platforms in four farmers households. Randomised block design. (Each farmers house acting as a rep.)
Mwamakaranga village, West Shinyanga district, Shinyanga region	Maize (100kg)	A= Protect-It 0.1%w/w B= Protect-It 0.25%w/w C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w F=Traditional protectant (unwinnowed grain + rice husk ash (8kg/100kg)) G=Untreated control	A= Protect-It 0.1%w/w B= Protect-It 0.25%w/w C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w F=Traditional protectant (unwinnowed grain + mkalya (100g/100kg)) G=Untreated control	Mini vihenges (woven baskets, plastered with cowdung and earth mixture) on wooden post platform at the Mangondis homestead as selected by village. Randomised block design.
Mwataga village, Kishapu district, Shinyanga region	Sorghum in 2002/03 50kg in 2003/04 100kg all treatments except traditional where 70kg used	A= Protect-It 0.1%w/w B= Protect-It 0.25%w/w C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w F=Traditional protectant (mixed ash 4kg/100kg)) G=Untreated control	A= Protect-It 0.1%w/w B= Protect-It 0.25%w/w C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w F=Traditional protectant (women hand mixed marumba (*Ocimum*) in kihenge 50-100g/70kg)) G=Untreated control	Mini vihenges (woven baskets, plastered with cowdung and earth mixture) on wooden post platform at the ShijaMahona homestead as selected by village. Randomised block design.
Arri village, Babati district, Manyara region	Maize (100kg)	A= Protect-It 0.1%w/w B= Protect-It 0.25%w/w C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w F=Traditional protectant -unwinnowed grain (1:1 mixture of cowdung ash and giri giri mo (pounded and dried plant leaves) 18 matchboxes per 100kg) G=Untreated control	A= Protect-It 0.1%w/w B= Protect-It 0.25%w/w C=Protect-It 0.1%w/w plus permethrin at 2mg/kg D=Actellic Super dust (111g/100kg) E=Dryacide 0.25%w/w F=Traditional protectant -winnowed grain (1:1 mixture of cowdung ash and giri giri mo (pounded and dried plant leaves) 18 matchboxes per 100kg) - G=Untreated control	Mini vihenges (woven baskets, plastered with cowdung and earth mixture) on wooden post platform at the village godown Randomised block design.
Singe village, Babati district, Manyara region	Beans (10kg)	A= Protect-It 0.02%w/w B= Protect-It 0.05%w/w C=Protect-It 0.1%w/w D=Actellic Super dust (11g/10kg) E=Dryacide 0.1%w/w F= Untreated control	A= Protect-It 0.02%w/w; B= Protect-It 0.05%w/w C=Protect-It 0.1%w/w; D=Actellic Super dust (11g/10kg) E=Dryacide 0.1%w/w; F= Untreated control	Mini jute sacks on platform in godown first season and then at godown workers home in 2nd season. Completely randomised design.

6.2.3 Grain treatments

The treatments and commodities used in the different trials are shown in table 2 above. The DE application rates used were based on the results obtained in previous laboratory and field studies (Stathers et al, 2002a; Stathers, 2003; Stathers et al, 2004).

The commodity was purchased from local farmers. The grain was then bulked and thoroughly mixed together to try and reduce its heterogeneity as much as possible and then placed into clean sacks and weighed to ensure each sack contained the same weight, the quantities of grain used in each trial are shown in table 2. It was then treated by thorough admixing with grain protectants on polythene sheets using a clean shovel. Following treatment the commodity was loaded into a polypropylene sack and labelled clearly. In those trials where mini vihenge were used to store the grain, following treatment all sacks were carried to the go-down or shelter and then unloaded into the appropriate labelled kihenges. At all sites a randomised block design layout was used with the exception of the bean trials at Singe village where a completely randomised trial design was used.

6.2.4 Grain sampling and sample analysis

Samples of 1kg of maize and 500g of sorghum and beans were collected from the respective trials every 8 weeks. A multi-compartmented probe was used to take the samples from the mini vihenge. While a bag spear was used to collect the samples from the maize and beans stored in polypropylene sacks and small jute bags respectively. The sample was then sieved and randomly divided into three sub-samples using a Riffle divider for the analysis of damaged grain. The sample weight, number of damaged grains and total live and dead adult insect population were recorded.

6.3 Results

6.3.1 First storage season – 2002/2003

Maize

Maize grain damage by natural infestations of insect storage pests started to increase in the untreated control grain and the grain protected with ‘traditional’ protectants after 16 weeks of storage (~mid October – early November), and continued to increase rapidly at all three trial sites (Figs. 1a-c). However in the DE and Actellic Super dust treatments damage was significantly lower, not exceeding 10% of grains throughout the 40 week storage period in either Mlali or Mwamakaranga villages, and only in the lower application rate of Protect-It (0.1%w/w) and Dryacide in Arri village.

The main insects found in the samples were *Sitophilus zeamais* and *Tribolium* spp., with a few *Oryzaephilus* sp., *Rhyzopertha dominica, Cryptolestes ferrugineus* and *Prostephanus truncatus* appearing after 32 weeks of storage. The mean total and dead and live numbers of each of the insect species present in the different treatments at Mlali at each sampling are shown in figures 2a-c. Significantly higher numbers of insects were found in the untreated control and traditional protectant treatments. It is also interesting to note that very few of the live insects were found in the DE or Actellic Super dust treatments.

Sorghum

In the sorghum grain, only the higher application rate of Protect-It (0.25%w/w), the Protect-It permethrin combination and the Actellic Super dust treatments managed to prevent insect damage from rapidly increasing during the 40 week storage period (Fig 1d).

The main insect pests were *Sitophilus oryzae*, *Tribolium castaneum*, *Rhyzopertha dominica* and *Sitotroga cerealella*.

Beans
Insect damage in the untreated beans had begun to increase by the 24 week sampling and continued to increase rapidly (Fig. 1e). However, insect damage remained below 5% in all the protectant treatments used throughout the 40 week storage period.

Acanthoscelides obtectus populations began to appear in the untreated control sample at the 16 week storage sampling period, and increased rapidly. A few *A. obtectus* also began to appear in the lowest Protect-It application rate of 0.02%w/w after 32 weeks storage.

6.3.2 Second storage season – 2003/2004

Maize
As in the first storage season, it was only at the 16 week sampling that insect damage started to increase in the untreated control grain and the grain protected with 'traditional' protectants at Mlali and Mwamakaranga villages (Figs. 3a&b). The DE treatments and Actellic Super dust did not suffer from insect damage levels of >5% throughout the 40 week storage period. Damage increased suddenly between the 32 and 40 week sampling times in the Stocal super dust treatment at Mlali, but there were large variations in the amount of damage observed in four replicates of this treatment. The Tanzanian DE used in the Mlali trial kept damage levels below 10% throughout the 40 weeks of storage. However in Arri village, where high numbers of insects had been winnowed from the grain at set up, damage had reached >30% in all treatments except Actellic Super dust by 8 weeks of storage and continued to increase rapidly in all treatments except Actellic Super dust (Fig. 3c).

As in the first storage season the main insect pests at all three sites were *Sitophilus zeamais* and *Tribolium* spp. Higher numbers of *P. truncatus* occurred in Mlali towards the end of the storage season than during the first season, with the largest *P. truncatus* developing in the Stocal Super dust, traditional protectant and Actellic Super dust treatments by the end of the trial (Figs. 4a-c).

Sorghum
Insect damage to the sorghum grain was generally lower during the second storage season than the first. It was only in the untreated control and 'traditional' protectant treatments that damage was higher than 10% of grains (Fig. 3d). No significant differences were seen between the different application rates of Protect-It or between the DEs and the Actellic Super dust treatments.

As in the first storage season the main insect pests were *Sitophilus zeamais*, *Tribolium castaneum* and *Rhyzopertha dominica*.

Beans
Insect damage in the untreated beans and the lowest application rate of Protect-It (0.02%w/w) began to increase by the 24 week sampling and continued to increase rapidly (Fig. 3e). However, in the other treatments damage did not begin to increase until the 32 week sampling and remained below 30% during the 40 week storage period. The Actellic Super dust treatment was most effective maintaining damage below 10% throughout the 40 week storage period.

As in the first storage season the main insect pest was *Acanthoscelides obtectus*. High populations of parasitic wasps were found in the untreated control from 32 weeks storage onwards.

6.3.3 Third storage season – 2004/2005

The third storage seasons trials were set up in mid August 2004, so no data is yet presented, trials have only been set up using maize at Mlali and Arri villages, the treatments used are the same as those used in the 2003/2004 storage season.

6.4 Discussion

The results demonstrate that Protect-It and Dryacide can be extremely effective and persistent grain protectants, against the major insect storage pests attacking maize, sorghum and beans, for storage periods of 40 weeks in the climatic conditions found in the three agro-ecosystems of the trial sites in Tanzania. However, it is concerning that all maize treatments were so heavily damaged in the second storage season at Arri village, Babati district, Manyara region. It is likely that this was as a result of using heavily infested grain to set up the trials. As DEs are effective when insects come into direct contact with them, they should be used on freshly harvested, dry, non infested grain only. In these trials no differences in efficacy between the 0.1% and 0.25% w/w application rates were evident with the exception of the Arri maize trial and the Mwataga sorghum trial in the second storage season. Further work using *P. truncatus* seeded on-station trials is underway to investigate whether during years with high incidences of *P. truncatus* the higher application rate is necessary.

Only low damage levels were encountered in all the protectants treatments and the untreated control during the first 16 weeks of storage (when clean, dry grain was used), indicating that the addition of grain protectants in these areas of Tanzania would be unnecessary for any grain which is to be stored for 4 months or less, unless pre-harvest infestation was high. However any grain that it to be stored for longer than 4 months should be treated immediately after harvest and drying to protect it against insect damage.

The Tanzanian DE obtained from the Kagera deposit applied at 0.25%w/w effectively protected maize grain for 40 weeks of storage. This local DE has been used again in the third seasons trials, and although it is too early to speculate, there could be potential economic advantages in using a local source of DE to protect grain during storage. Studies into the percentage crystalline silica and respirable dust of any effective local DEs are needed to ensure user safety.

At the end of each storage season, groups of disaggregated farmers at each trial site blindly assessed the different treatments. Throughout the trial sites the results of the evaluations of the different grain protectant treatments by the different farmer groups were very consistent. With the DE and Actellic Super dust treatments all scoring higher than the traditional protectants and the untreated control. The criteria that the farmers involved used for assessing quality of stored maize grain didn't vary much between trial sites or among wealth groups. Absence/ degree of storage insect damage and general damage to grain (which could include insect feeding damage) were frequently perceived as the most important criteria. A report of this work from the first storage season is available.

The project has also been supporting farmer-managed trials, where farmers are testing the DE Protect-It at an application rate of 0.25%w/w against their typical grain protection practice. They have been very impressed with the efficacy of Protect-It, and through regular visits to these farmers the project is hoping to learn more about what factors affect these farmers post-harvest decision making.

Figure 1a.

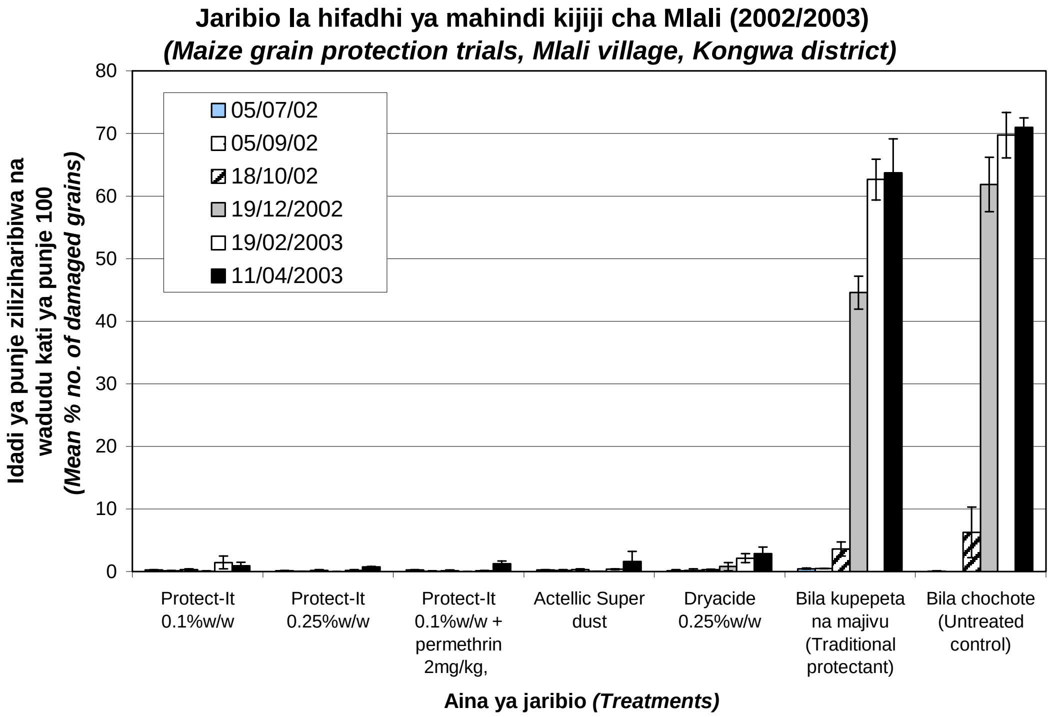


Figure 1b.

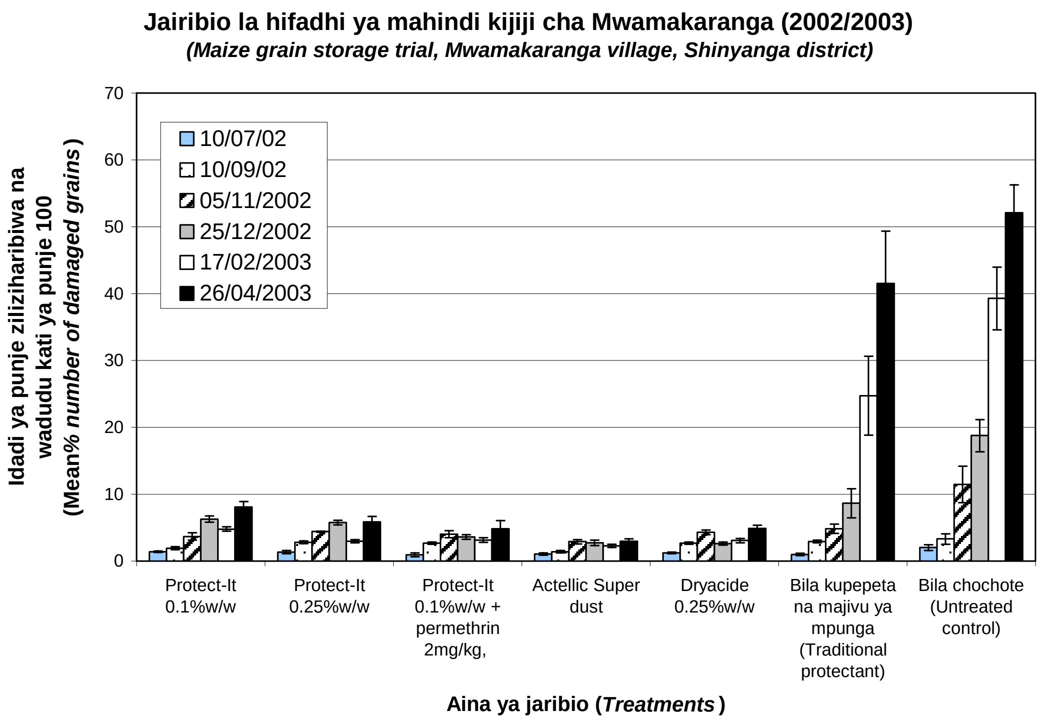


Figure 1c.

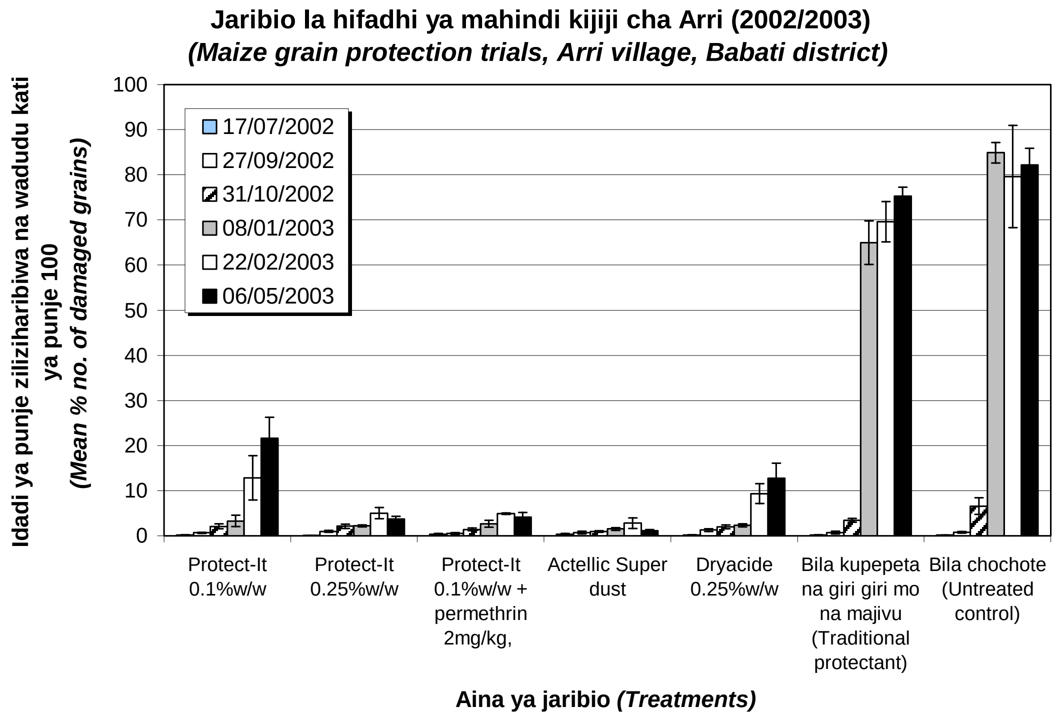


Figure 1d.

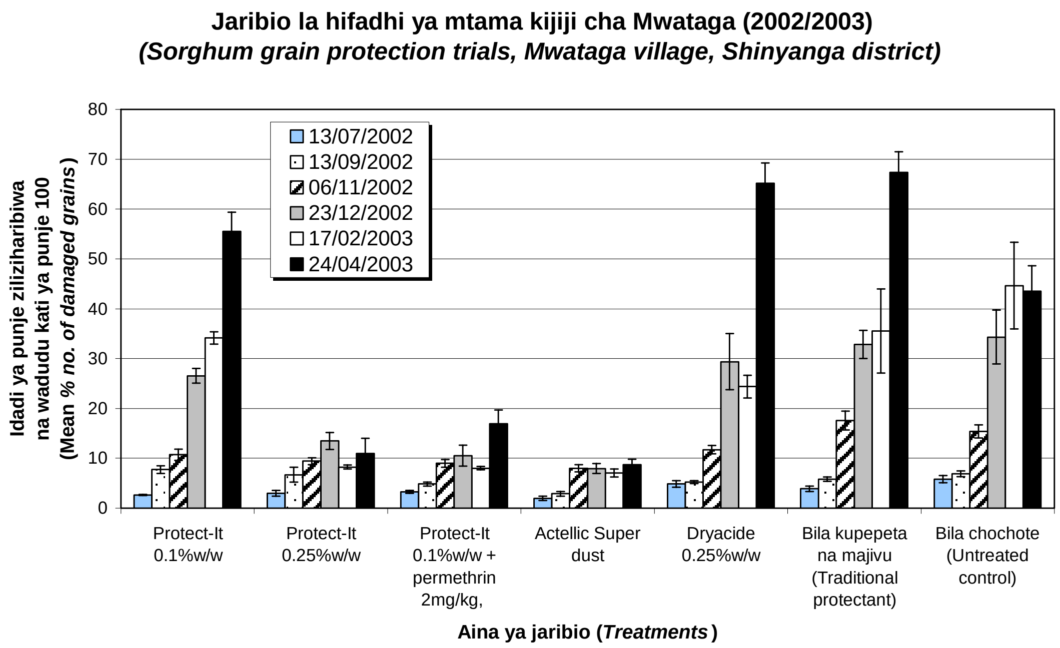


Figure 1e.

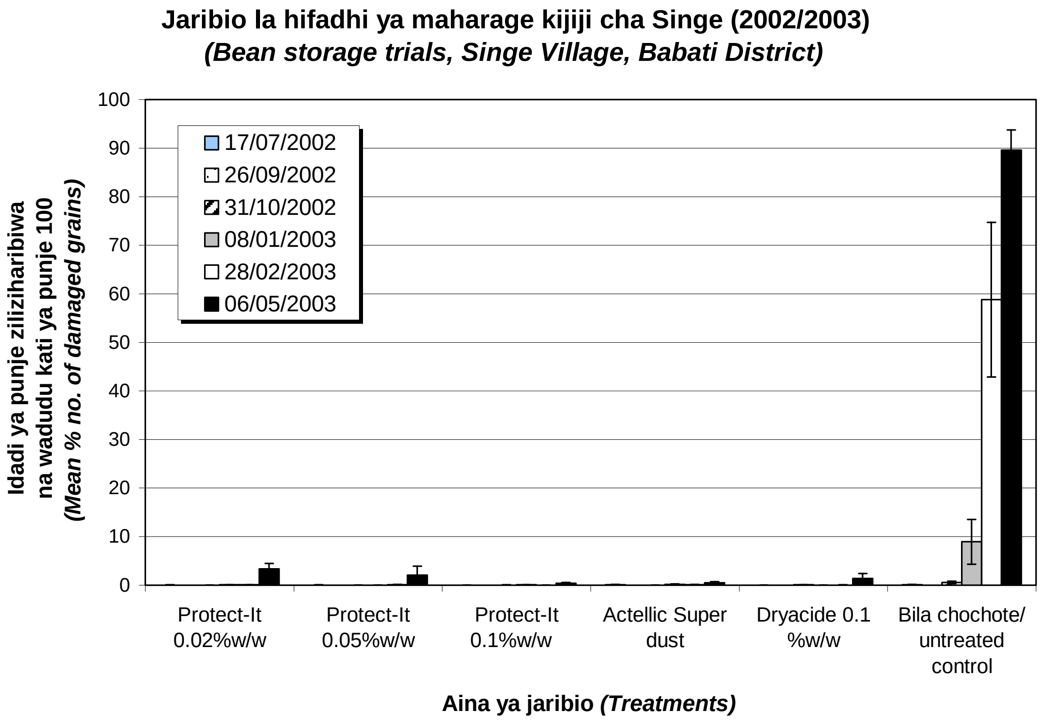


Figure 2a. Comparison of mean total number of adult insects/ kg per species on maize grain treated with different protectants during 2002/03 storage season at Mlali village, Kongwa district, Dodoma region, Tanzania.

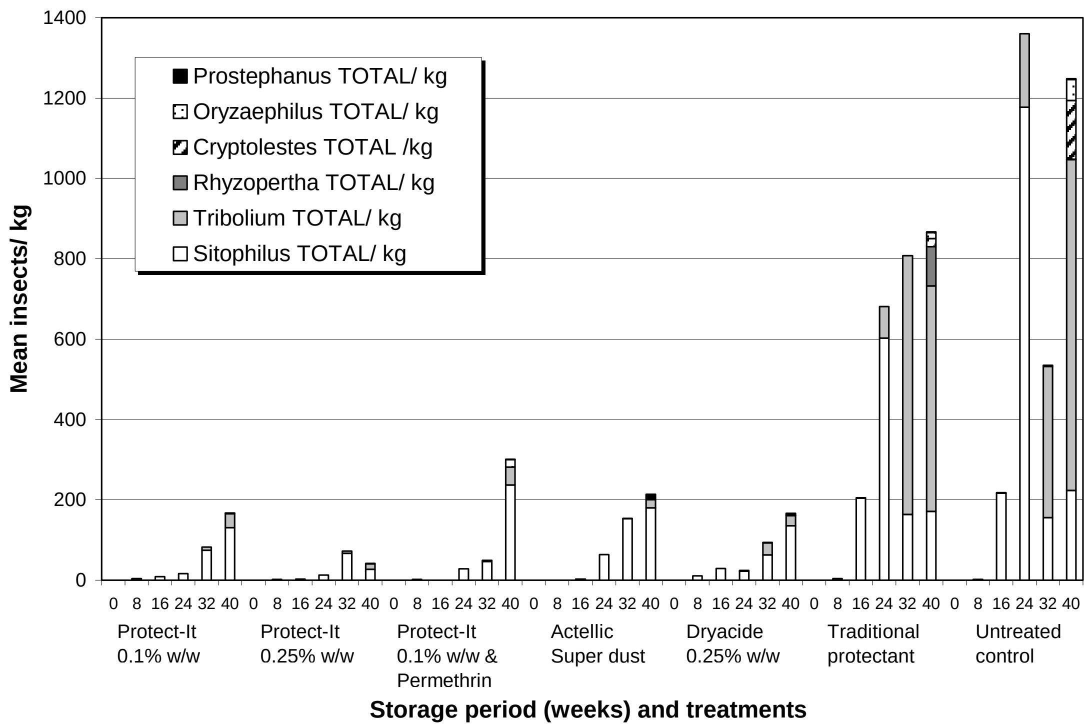


Figure 2b. Comparison of mean number of live adult insects/ kg per species on maize grain treated with different protectants during 2002/03 storage season at Mlali village.

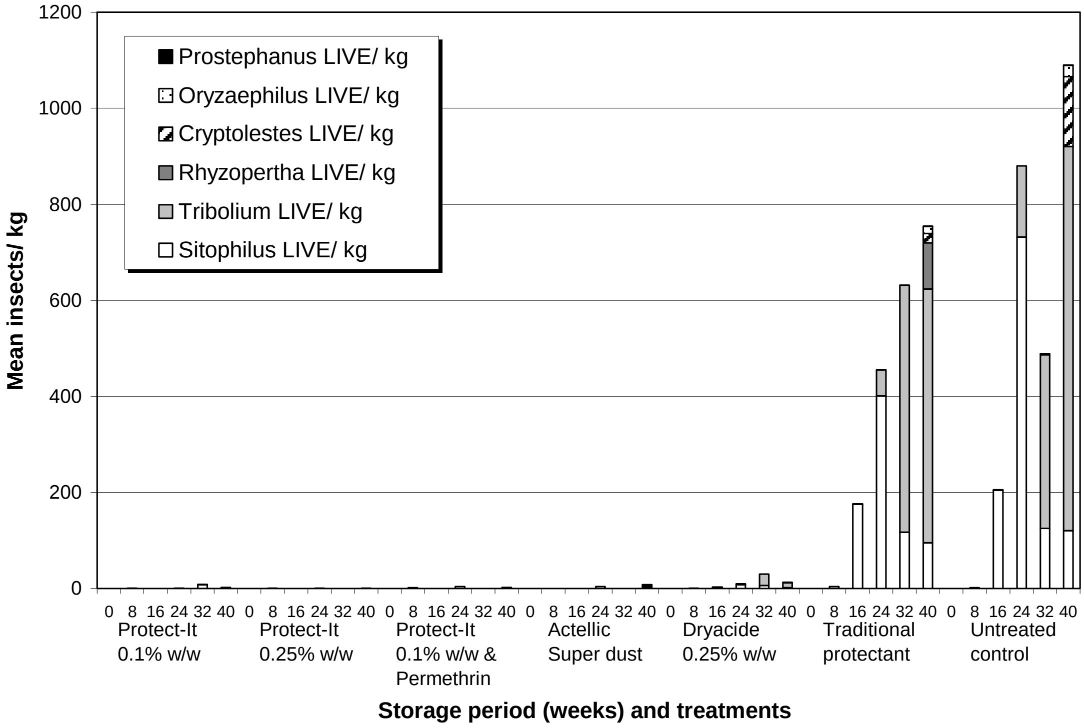


Figure 2c. Comparison of mean number of dead adult insects/ kg per species on maize grain treated with different protectants during 2002/03 storage season at Mlali village.

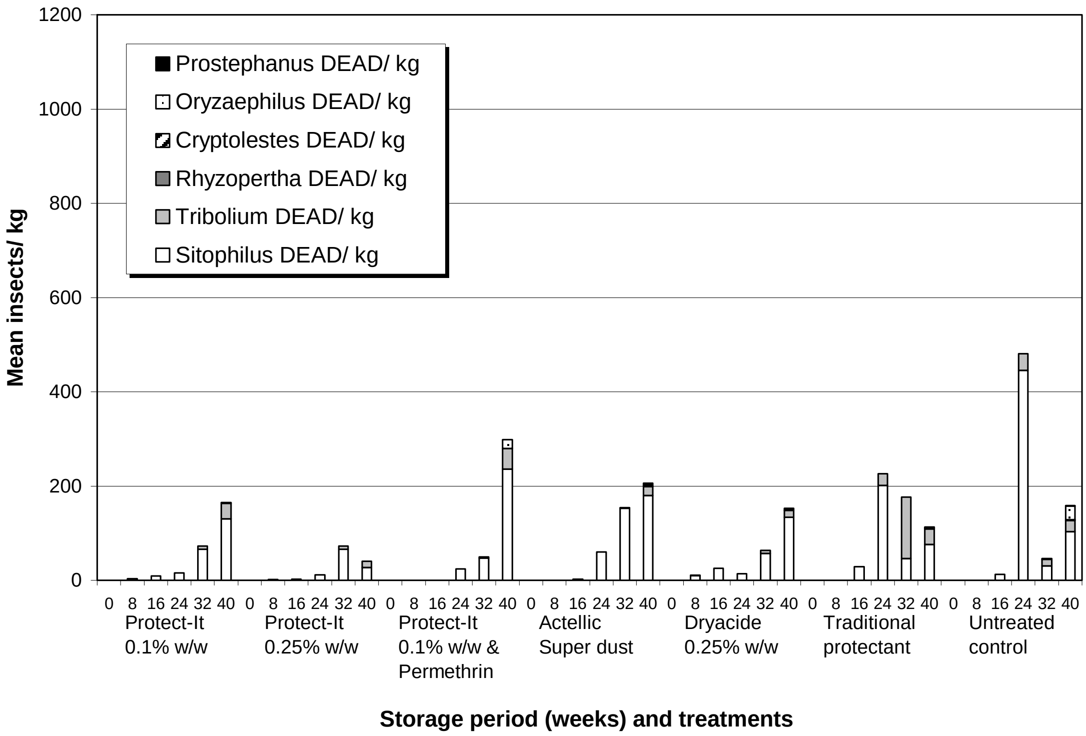


Figure 3a.

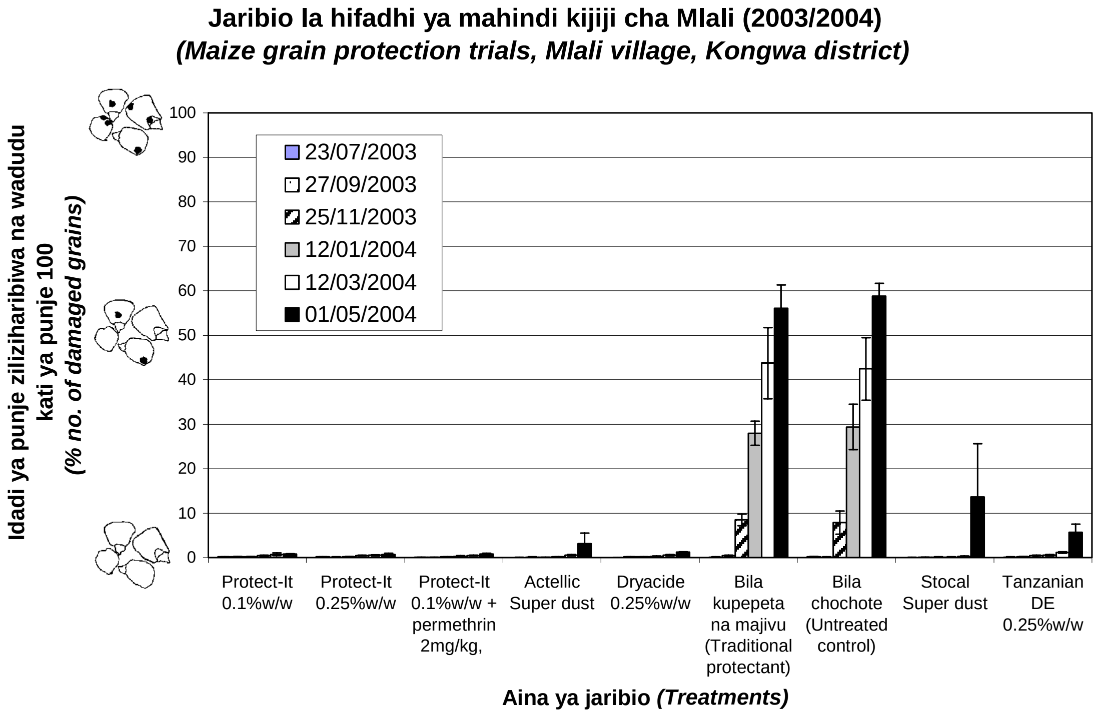


Figure 3b.

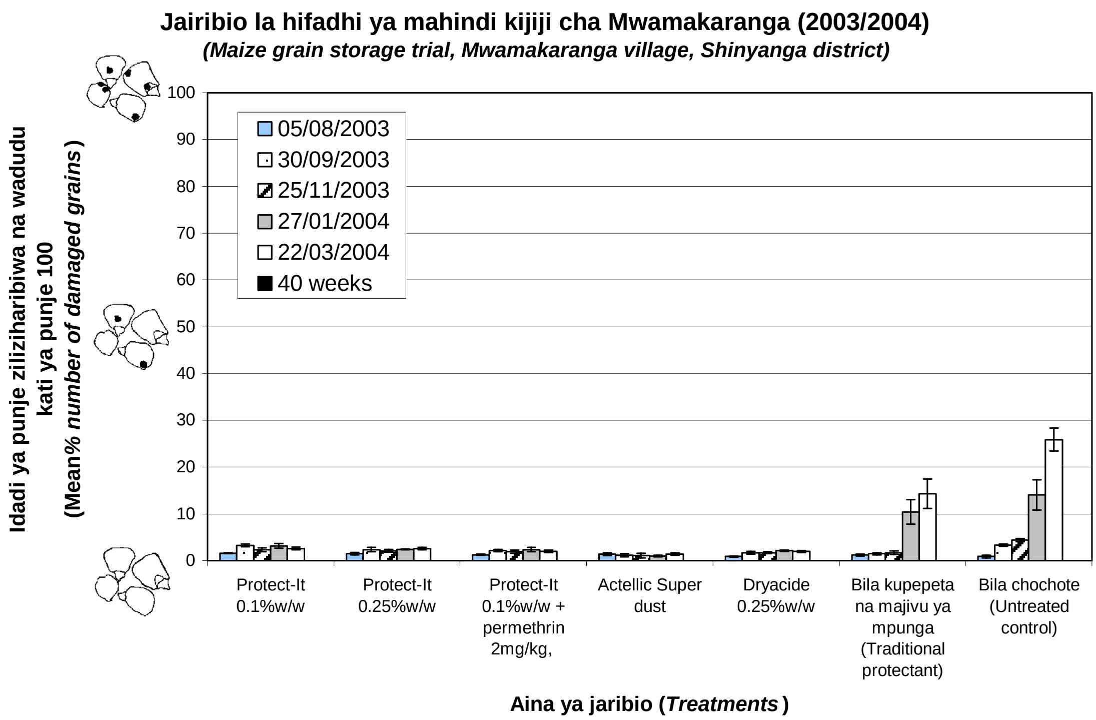


Figure 3c.

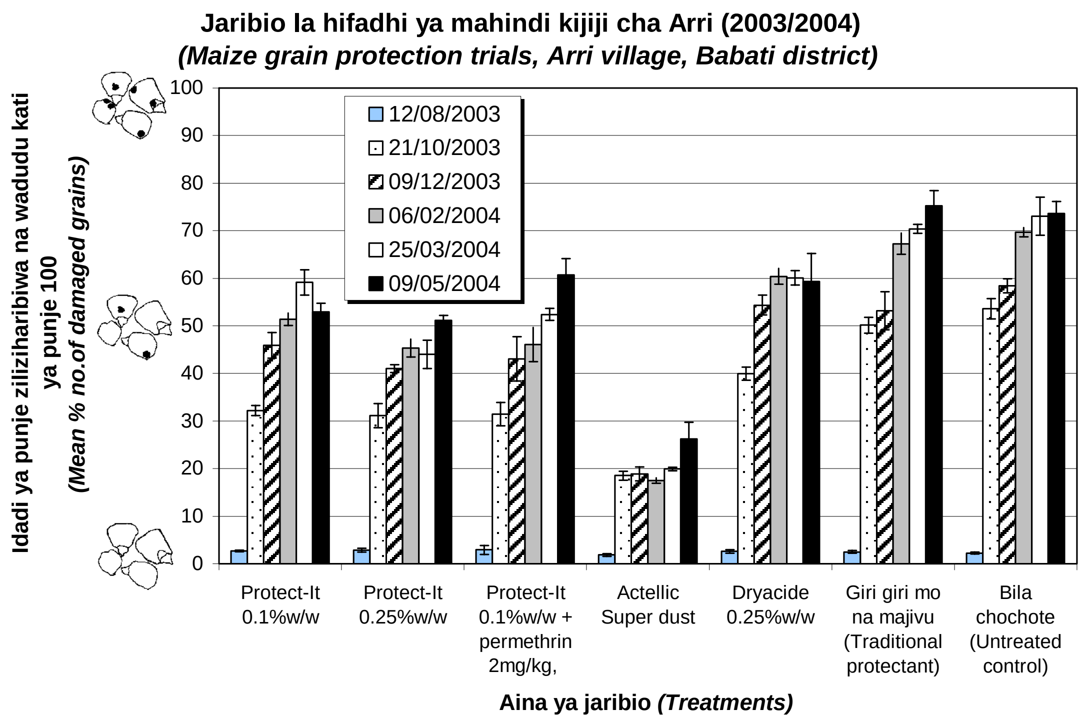


Figure 3d.

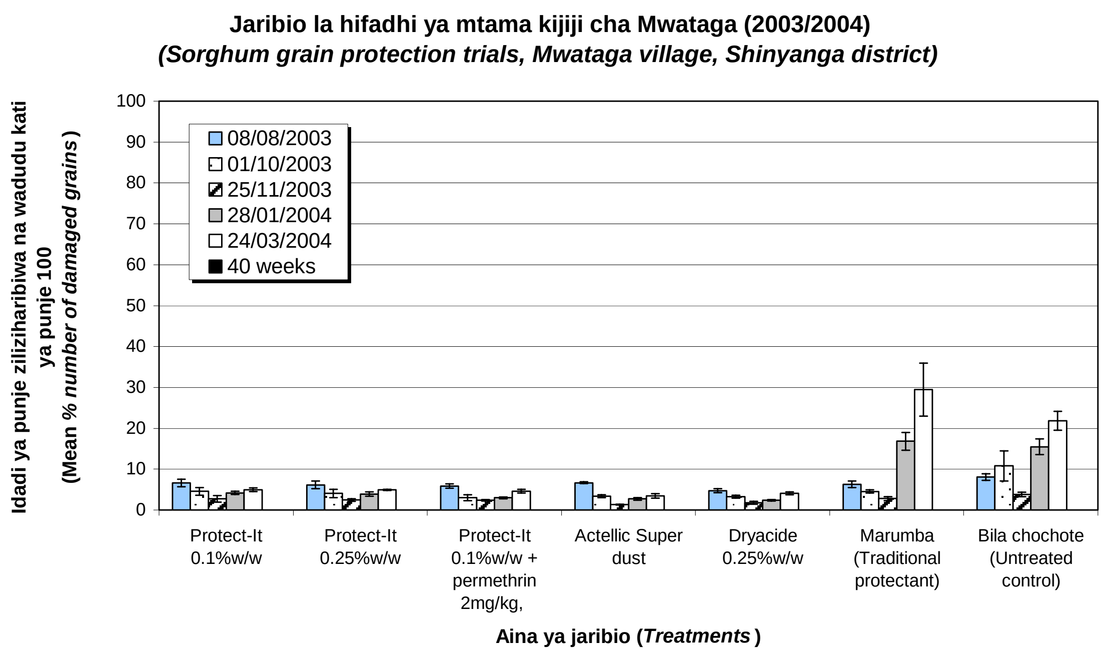


Figure 3e.

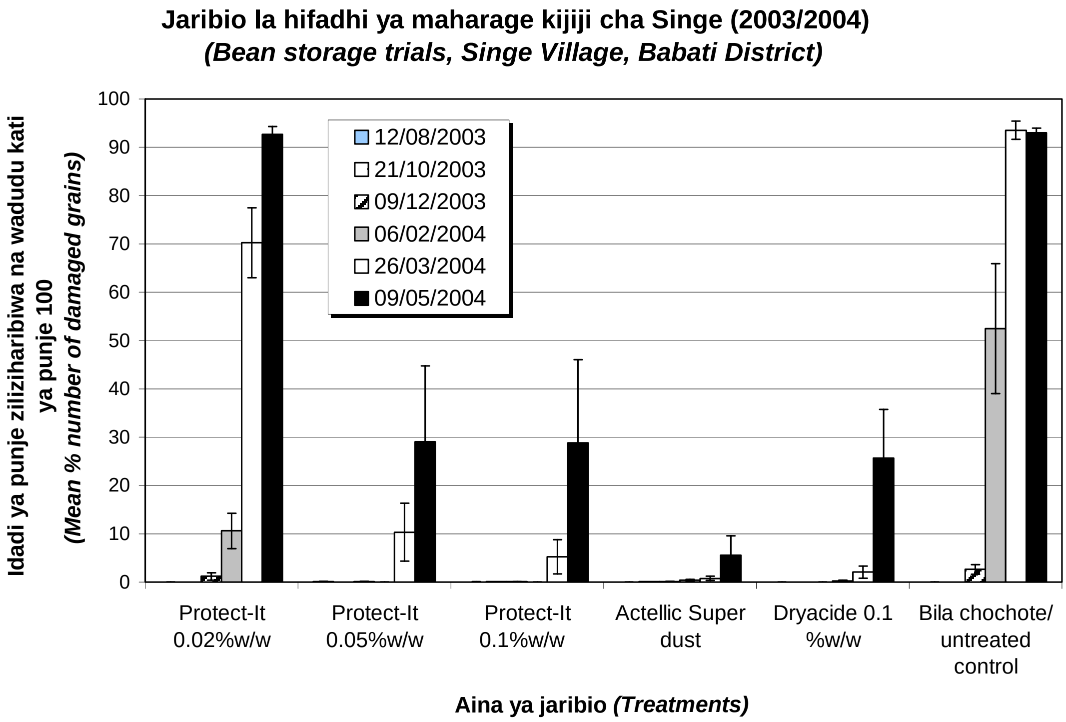


Figure 4a. Comparison of mean total number of adult insects/ kg per species on maize grain treated with different protectants during 2003/04 storage season at Mlali village, Kongwa district, Dodoma region, Tanzania.

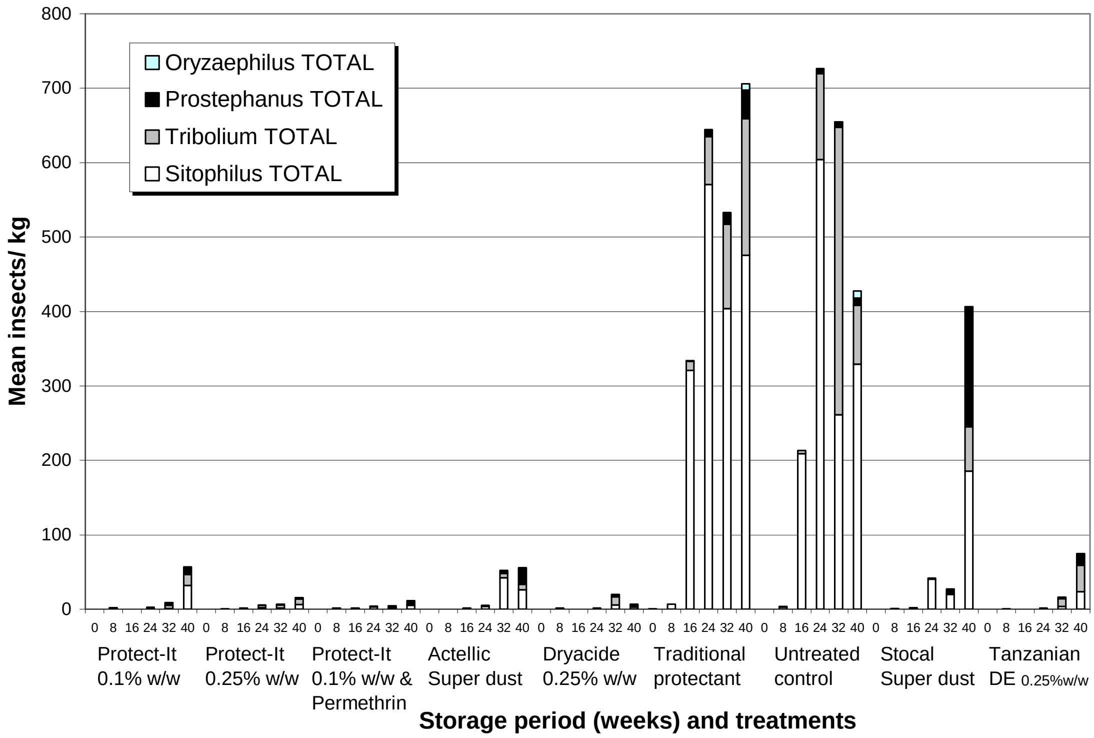


Figure 4b. Comparison of mean number of live adult insects/ kg per species on maize grain treated with different protectants during 2003/04 storage season at Mlali village.

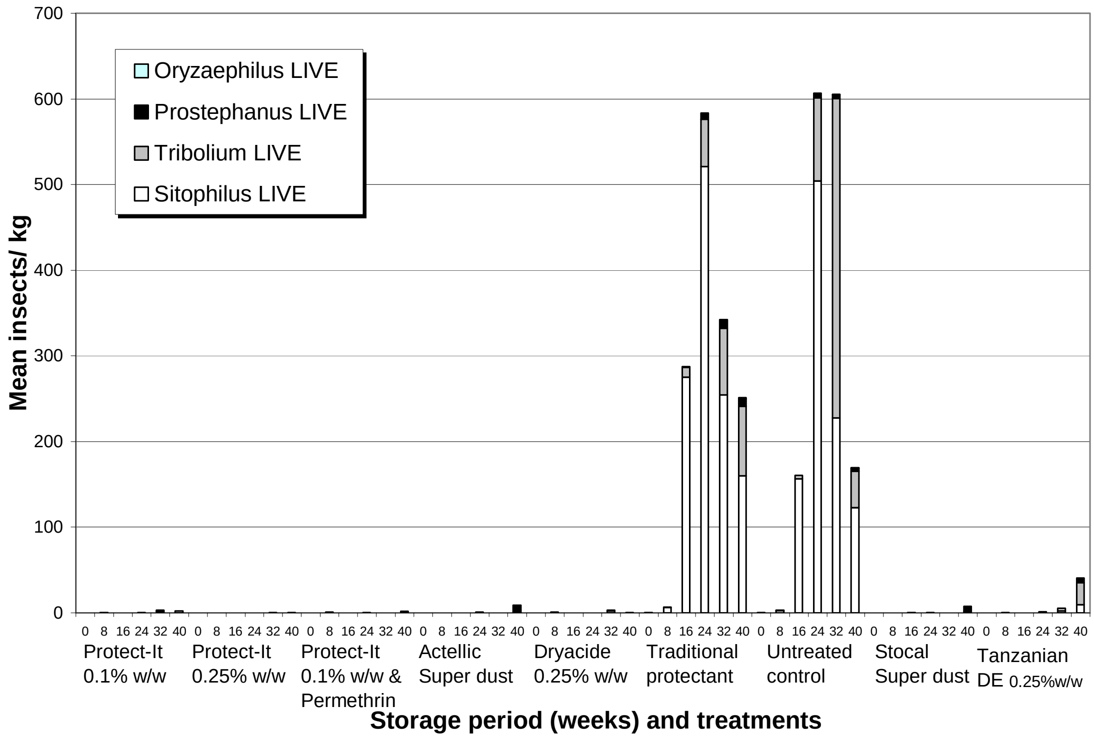
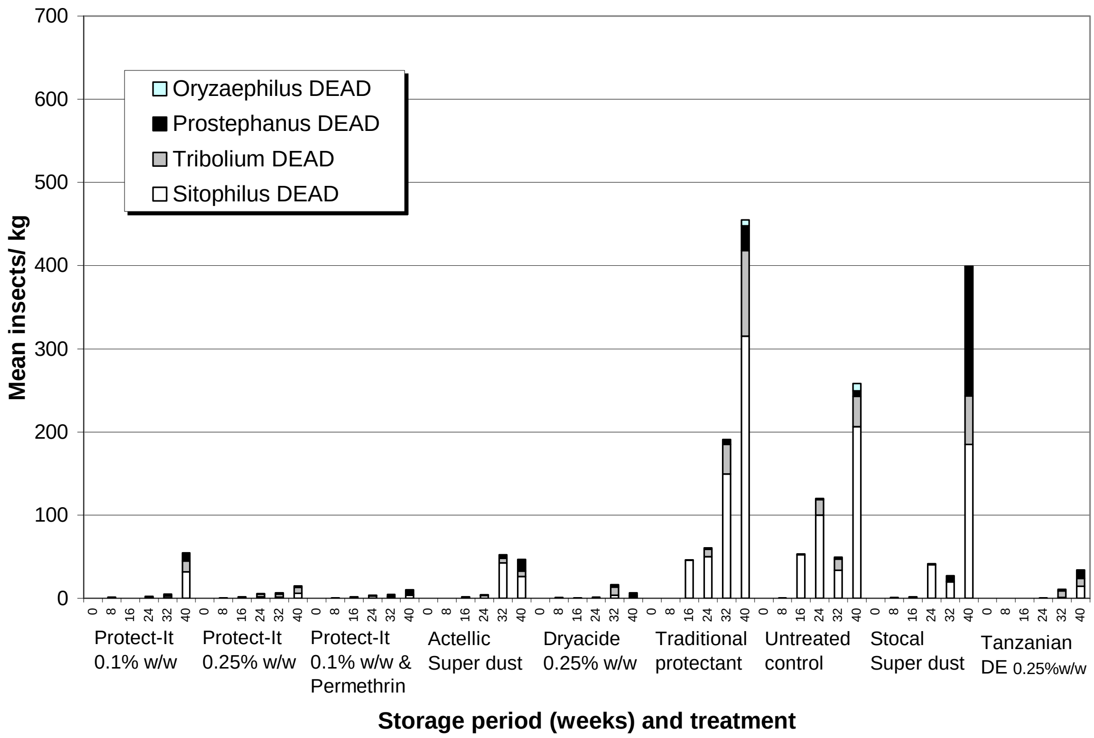


Figure 4c. Comparison of mean number of dead adult insects/ kg per species on maize grain treated with different protectants during 2003/04 storage season at Mlali village.



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