Combinations to enhance the efficacy of diatomaceous earths against the larger grain borer, *Prostephanus truncatus* (Horn)

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Abstract

Farmers in sub-Saharan Africa have repeatedly prioritised the need for improved methods of storage pest control. Reduction of storage losses will help to reduce the vulnerability of small-scale producers by improving household food security and improving income-generating opportunities and livelihood outcomes. Field trials in Zimbabwe have demonstrated that diatomaceous earths (DE) are highly effective and persistent grain protectants against the major storage insect pests attacking maize, sorghum and cowpeas. However, high application rates of DEs were required to prevent bostrichid beetle damage. As the damage caused by the bostrichid, *Prostephanus truncatus*, at the farm level in affected areas of sub-Saharan Africa is often much more severe than that of other storage insect pests, it is critical that any protectants used on grain are effective against it. The studies reported here evaluated combinations of Protect-It® DE with low levels of pyrethroids, plant extracts or soil bacteria metabolites against *P. truncatus*. Deltamethrin and permethrin, which are synthetic pyrethroids, caused a high knock-down effect and prevented progeny emergence of *P. truncatus* at application rates of 0.025 mg/kg and 2 mg/kg, respectively, and no further effects from the addition of Protect-It® were observed. The combinations of DE and plant extracts or soil bacteria metabolites, formulated as "All Natural" and "Spindeba", also prevented progeny emergence of *P. truncatus* at application rates of 50–100 ppm. The results are discussed in the context of improving the efficacy of DE against *P. truncatus* for use by small-scale producers in developing countries.

Keywords: Diatomaceous earth; Inert dust; Combinations; Stored-product pest management; *Prostephanus truncatus*; Larger grain borer; LGB; Pyrethroids; Protect-It®; All Natural; Spindeba

Introduction

Farmers in sub-Saharan Africa (SSA) are frequently forced to sell stored produce prematurely because of the deterioration due to insect damage that occurs if storage periods are extended (Golob et al., 1996; Brice et al., 1996; Marsland and Golob, 1996; Donaldson et al., 1996). Insect damage threatens not only the household's control over its grain sales, but also the family's food security. This damage affects the nutritional quality, taste, smell and quantity of food available until the next harvest. Farmers have expressed a desire to be able to maintain grain quality by reducing insect damage; they want a choice of methods that are not only relatively cheap, but also are safe.

Many small-scale farmers in the developing world still use traditional methods of mixing sand, kaolin, paddy-husk ash, wood ash and clays with grain to protect their laboriously grown food from insect attack. However, despite these materials being locally available, the large quantities (>20% by weight) which are usually required to exert an effect (Golob and Webley, 1980) often make their use impractical. In addition, farmers are not keen on this level of adulteration of their grain (although treatment of small quantities of grain kept for seed is acceptable) and the cleaning of these huge quantities of ash and sand from the grain is tedious and time consuming.

Other small-scale farmers apply synthetic organophosphate-based insecticides, Actellic dust or Actellic Super dust, the active ingredients of which have to be imported using valuable foreign exchange. Nevertheless, these insecticides are frequently unavailable when needed, or are adulterated or too expensive for farmers, and their misuse can be a health hazard. 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). 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 (DE) which can be applied at a much lower application rate than sand and ashes, offer a safer alternative to synthetic organophosphate insecticides for grain protection but, until recently, no information on their efficacy under tropical, small-scale-farming conditions existed (Golob, 1997).

During on-farm trials in three agro-ecological regions of Zimbabwe, two commercially available DEs (Protect-It® and Dryacide®) were shown to be effective in controlling

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postharvest insect-pest damage in maize, sorghum and cowpeas stored for periods longer than 8 months (Stathers et al., 2000; in press). The DEs were as effective as the locally recommended insecticide, Actellic Super dust, and also outscored other local grain protection practices during farmers' evaluations (Stathers et al., 2000; in press). Natural deposits of DEs exist in SSA and the potential for exploiting these deposits is currently being examined.

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). However, insect species differ in their sensitivity to the various DEs (Fields and Korunic, 2000). The most susceptible species tend to be those with:

- large surface-to-volume ratios;
- body hair (DE particles collect on the hair) (Carlson and Ball, 1962);
- thin cuticles (Bartlett, 1951);
- 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).

Recent work has shown that different strains of a single insect species can vary widely in their susceptibility to DEs (Rigaux et al., 2001). DEs have extremely low toxicity to mammals (e.g. DE rat oral LD_{50}, >5000 mg/kg (Subramanyam et al., 1994)) and are "generally regarded as safe" by the USA Environmental Protection Authority (Anonymous, 1991).

DEs were recently field tested in Zimbabwe, where the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera; Bostrichidae) is not yet endemic. *Prostephanus truncatus* is the most serious pest of stored maize in Africa, causing weight losses of up to 40% (Pantenius, 1988). *Prostephanus truncatus* appears to be less susceptible to DEs than are other storage pests, and high concentrations (≥0.25% w/w) of the DEs Protect-It® or Dryacide® were required to reduce damage by it in laboratory trials (Stathers et al., 2002). *Rhyzopertha dominica* (F.) (a closely related bostrichid) was found to cause high levels of damage on sorghum treated with Dryacide® at 0.1% w/w during on-farm storage trials in Zimbabwe (Stathers et al., in press).

Following the arrival of *P. truncatus* in Tanzania in the 1980s and reports of high losses, pyrethroids were found to cause high adult mortality (Golob et al., 1985). However, permethrin, the pyrethroid most easily available in East Africa at that time, was not able to control the other common storage pests such as *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae), *S. oryzae* (L.) and *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Therefore, a mixture of 0.3% permethrin and 1.6% pirimiphos-methyl applied as a dust to provide 2.5 and 10 mg/kg active ingredient, respectively, was used to control both *P. truncatus* and *S. zeamais* (Golob, 1988). This mixture was subsequently introduced to farmers as Actellic Super dust.

Due to the high efficacy of DEs against most of the common storage pests in SSA, with the exception of *P. truncatus* and *R. dominica*, it was decided to evaluate combinations of DEs with pyrethroids, plant extracts or soil bacteria metabolites (similar to those used against field crop pests) to enhance efficacy against *P. truncatus*. This paper reports on those studies.

Materials and methods

Preparation of insects

Prostephanus truncatus was reared on clean maize (*Zea mays*) under controlled conditions (constant temperature and humidity (CTH) room at 27±5°C, 60±5% r.h., 12:12 light:dark). Unsexed 7–21-day-old insects were used in all trials.

Grain protectants

Protect-It®, an enhanced DE of US origin, was obtained from Hedley Technologies, Inc. The pyrethroids, deltamethrin (2% a.i.) and permethrin (2% a.i.) dusts were obtained from Agropharm Ltd. The formulations of "All Natural" and "Spindeba" were developed by Korunic on behalf of Hedley Technologies, Inc. and Diatom Research and Consulting, Inc., respectively. All Natural is composed of a high-grade food DE, a Chinese plant extract and a food grade oil. Spindeba contains DE, a soil bacteria metabolite and a solvent for a metabolite.

Treatments

Pre-equilibrated maize grain (100 g, 27±5°C, 60±5% r.h.) was placed into 250 mL glass jars. The required quantity of grain protectant was added to the weighed commodity in each jar, and shaken by hand for one minute. The jars were then sealed with filter paper and molten wax and placed in CTH rooms at 27±5°C, 60±5% r.h.

The grain protectant treatments used in the trials included:

- deltamethrin doses of 0, 0.025, 0.05, 0.125 and 0.5 ppm, alone and in combination with Protect-It® at 500, 1000 and 2500 ppm;
- permethrin at 2 ppm alone and in combination with Protect-It® at 1000 ppm;
- All Natural at 50, 100, 200, 500 and 1000 ppm; and
- Spindeba at 100 ppm.

These application rates were chosen on the basis of the results of previous studies with P. truncatus or related species by various researchers. Five replicates of each treatment were used in all trials.

Adult mortality and knockdown assessments were made after 7, 14 and 28 days. In this study, the term knockdown is used to include those insects killed by the treatment or immobilised to a state where only the antennae or legs could twitch. Progeny emergence was recorded after specified times for each study.

Results

The initial doses of deltamethrin used (0.5 and 0.25 ppm) caused a very high a percentage knockdown of *P. truncatus* within the first seven days and prevented progeny emergence during an eight-week period, so that no further effects from the addition of the DE Protect-It® were observed (Fig. 1). Further studies using lower doses of deltamethrin (0.125, 0.05 and 0.025 ppm) also prevented progeny emergence in *P. truncatus*.

The combinations of DEs and plant extracts or soil bacteria metabolites, formulated as All Natural and Spindeba, and permethrin at 2 ppm also caused a high percentage of knockdown within the first seven days and prevented progeny emergence of *P. truncatus* during a seven-week period, at application rates as low as 50–100 ppm (Fig. 2). The high efficacy of permethrin at 2 ppm precluded any further advantage when this treatment was combined with Protect-It® at 1000 ppm.

Discussion

The synthetic pyrethroids deltamethrin and permethrin caused a high knockdown effect and prevented progeny emergence of *P. truncatus* at all application rates used. Thus, there was no advantage gained by the addition of Protect-It®. All Natural and Spindeba also prevented progeny emergence of *P. truncatus*, at application rates of 50–100 ppm. Further work should evaluate DEs in combination with even lower application rates of pyrethroids. The combinations must also be tested with multi-species pest complexes similar to those that occur naturally in stores in SSA. The persistence of these combinations also needs to be investigated, as farmers usually treat grain only at the beginning of the storage season which may typically last 4–10 months.

Although combining DEs with insecticides which knock down insects may result in reduced pick-up of DE particles

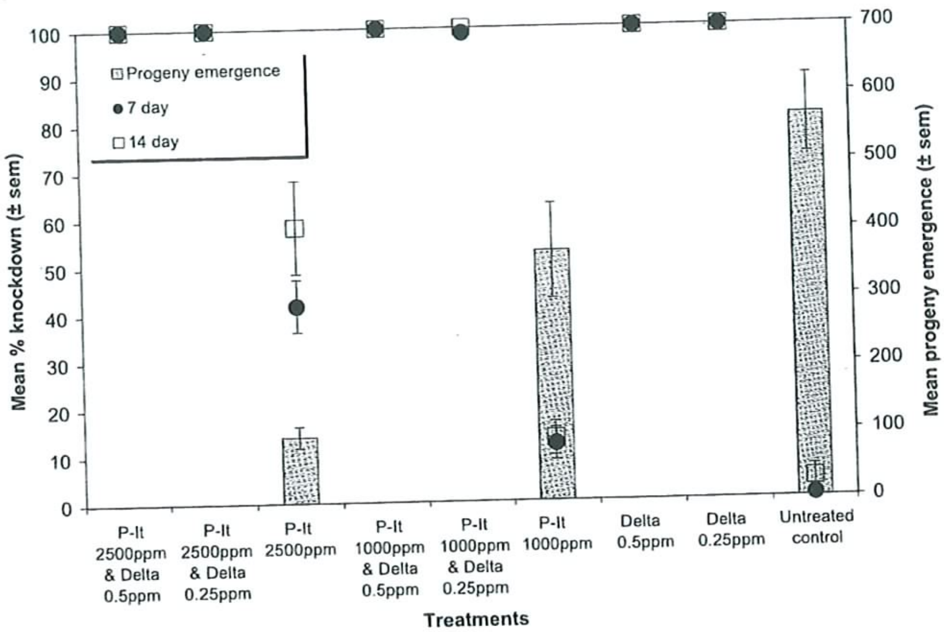

Fig. 1. Effect of combinations of Protect-It® and deltamethrin on the knock down and progeny emergence of 35 7–21-day-old *P. truncatus* adults during an 8-week period at 27°C and 60% r.h. ($n = 5$).

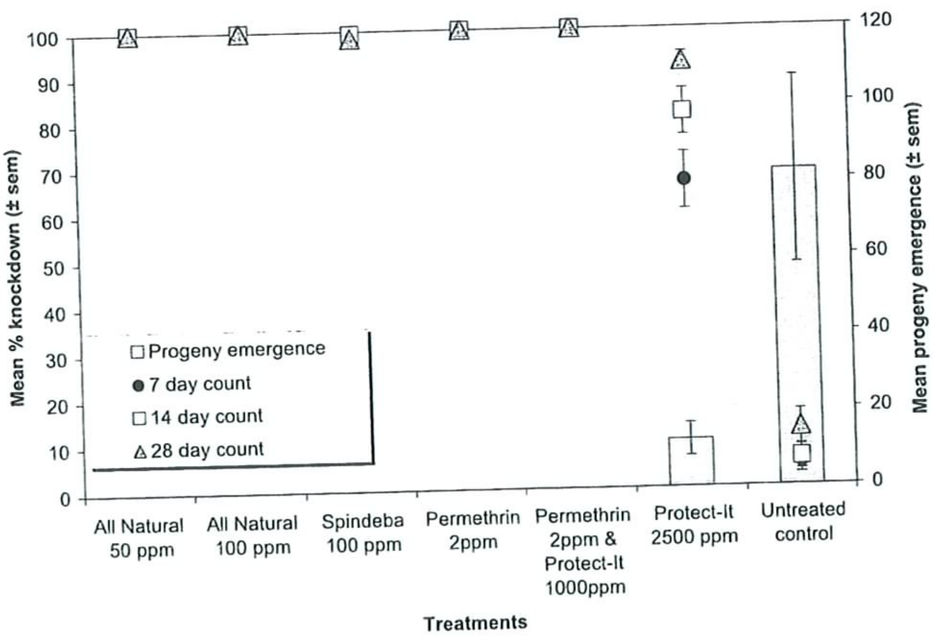

Fig. 2. Effect of All Natural, Spindeba and combinations of Protect-It® and permethrin on the knock down and progeny emergence of 40 7–21-day-old *P. truncatus* adults during a 7-week period at 27°C and 60% r.h. ($n = 5$).

by insects (Ebeling, 1971; Le Patourel and Singh, 1984), the DE and the pyrethroids are in this case being used against different target pests. The pyrethroids have been added to target specifically the bostrichids, because the DEs, although effective against *S. zeamais*, *S. oryzae* and *T. castaneum*, were found to be ineffective against the bostrichid *P. truncatus* unless applied at high concentrations. While the pyrethroids are effective against the bostrichids, they are not effective against *S. zeamais*, *S. oryzae* and *T. castaneum*. Given these facts, it is unlikely that this combination of DEs and pyrethroids will result in a reduced pick up of DE particles by the DE-targeted pests.

The reasons for the low susceptibility of *P. truncatus* to DEs, unless applied at high concentrations, are not well understood. However, it is likely that factors such as its internal feeding, oviposition and larval developmental behaviour result in reduced exposure to DE deposits on the surface of grains. Recent work using 14 different strains of *T. castaneum* found that factors such as the speed of water loss, speed of movement through grain and behavioural avoidance of DE-treated grain all differed between tolerant and susceptible strains (Rigaux et al., 2001). These factors may also be relevant for slow-moving bostrichids adapted to feeding on dead wood (Nang'ayo et al, 1993).

The significant amount of feeding dust produced by *P. truncatus* may dilute the efficacy of the admixed DEs. A study of the effect of DEs on the survival of the natural enemy *Teretrius nigrescens* (Lewis) (Coleoptera: Histeridae) found *T. nigrescens* mortality was much higher in all the DE application rates in the absence of *P. truncatus* (Stathers et al., 2002). Observations suggested that dust produced by *P. truncatus* during feeding diluted the DE, reducing the likelihood of *T. nigrescens* coming into physical contact with enough DE to cause death.

Other control options that could potentially be combined with DEs to complement their effects in small-scale storage systems in SSA include antifeedants, chitin-synthesis inhibitors, natural enemies, entomopathogenic fungi and heat.

Antifeedants reduce the uptake of water in insects, therefore increasing the efficacy of DEs (Mewis and Ulrichs, 1999). Slightly higher *T. castaneum* and *S. oryzae* mortality in rice was reported when the DE Fossil Shield® was combined with a neem product in comparison to either treatment alone (Ulrich and Mewis, 2000).

Insect parasitoids and predators are frequently found in farm-level storage systems in SSA and it would be advantageous if DEs could be integrated into these systems without detrimentally affecting the natural enemy populations. However, the limited work to date has found that parasitoids and predators are very sensitive to direct contact with DE (Perez-Mendoza et al., 1999; Stathers et al., 2002). Natural enemies differ in their host-locating activities, with some species penetrating grain masses while others remain mainly on the grain surface. Searching behaviour among these species could affect the degree of their exposure to DEs. Targeting of DEs within the grain mass may enhance the combined use of DEs and natural enemies.

Preliminary laboratory work on the use of DE in combination with the entomopathogenic fungus *Beauveria bassiana* against *R. dominica* showed that they acted synergistically (Lord, 1999). Lord (1999) suggested that DEs might induce changes in cuticular lipids that may affect attachment, germination, and penetration of entomopathogenic fungi. However, to date there are no reports of entomopathogenic fungi successfully reducing insect damage to grain during storage trials in the field (Oduor, 2001; Meikle et al., 1998; 2001; Stathers, 2002) despite numerous laboratory studies on this subject. Chitin-synthesis inhibitors also affect the cuticle, and combining their application with DEs may result in synergy.

In large-scale storage and processing systems, the use of DEs in combination with heat sterilisation was more effective than the use of heat sterilisation alone (Fields et al., 1997; Dowdy, 1999; Dowdy and Fields, 2002). The authors suggest that heating may increase the rate of desiccation due to the control of water regulation being compromised by the DE. The temperatures and times needed for insect control might be reduced when heat sterilisation is used in combination with DEs. Many small-scale farmers use regular sun drying to reduce pest damage to their stored products. Combining this practice with DE use might have benefits, particularly in areas where environmental conditions often make it difficult to raise the grain temperature high enough for sufficiently long periods to kill developing insects, or where labour shortages for guarding the crop during sun drying are a constraint. The economics and cultural acceptability of any of these combinations would also need careful study.

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