Challenges of grain protection in sub-Saharan Africa: the case of diatomaceous earths

Brighton M. Mvumi[1] and Tanya. E. Stathers[2]

[1]Department of Soil Science and University of Zimbabwe, PO Box MP 167, Mount Pleasant, Harare, Zimbabwe. (Contact: mvumibm@agric.uz.ac.zw)
[2]Natural Resources Institute, University of Greenwich, Central Avenue, Chatham Maritime, Kent ME4 4TB,UK

Abstract
Environmental and safety concerns have created a global drive towards reduction in pesticide use and subsequent withdrawal of some that are considered hazardous, hence increasing the pressure to seek alternatives; and grain protectants have not been spared. Farmers in sub-Saharan Africa (SSA) have repeatedly indicated their concerns about the safety of synthetic insecticides for grain protection. The use of diatomaceous earths (DEs) is one option that has been identified by research as a possible alternative. However, the operationalisation of the DE technology is still constrained by a number of factors including: product availability; product stewardship; applicability on cob maize; high humidity in some parts of SSA which renders the DEs less effective; occurrence of the Larger Grain Borer, *Prostephanus truncatus* in some countries which requires higher concentrations of DEs for effective control; and grain marketing standards in central storage systems which need to be revised. This paper discusses these challenges in a scenario where on-farm grain storage for household food security will continue to characterise small-scale farming in SSA; more so with the marketing liberalisation era and frequent droughts in some parts of Africa. At commercial level, the withdrawal of methyl bromide means that central storage systems need to consider other grain protection methods in addition to phosphine; such as use of DEs.

Key words: grain protection, sub-Saharan Africa, diatomaceous earths (DEs), food safety

Introduction
In sub-Saharan Africa (SSA), where grain is stored on-farm for household food security, storage insect pests cause substantial damage to the stored grain. In some parts of SSA such as Zimbabwe, the majority of farmers (≥75%) rely on imported synthetic insecticides to control these pests. There is a global drive towards reduction in pesticide use and eventual phasing out of organophosphate-based grain protectants, articulated mainly by consumers and environmentalists who are concerned with health risks and environmental damage. Various post-harvest stakeholders, including farmers and researchers, are concerned about the development of insect resistance to the narrowing range of acceptable grain protectants. Faced with these challenges, researchers have the task of developing safe, cost-effective, ecologically sound and sustainable alternatives or at least reducing the use of synthetic insecticides. The pressure to search for alternatives to these chemicals has been demonstrated recently by the following examples:

1. a conference on "Ecologically safe alternatives for the control of stored-product insects" in Netherlands (Bell and Shaaya, 1997);
2. a book on "Alternatives to pesticides in stored-product IPM" (Subramanyam and Hagstrum, 2000);
3. third workshop on "Stored Product Pest Management and Heat Treatment" in USA (Subramanyam, B., personal communication) held in August 2001; and
4. a Royal Entomological Society Special Interest Group meeting on "Strategies to limit the use of synthetic pesticides in storage pest management" at the Natural Resources Institute in the UK held in September 2001 (Hodges, R. J., personal communication).

One option identified by research, which is considered safe to humans and environmentally friendly in protecting grain against storage insect pests, is the use of inert dusts called diatomaceous earths (DEs). DEs consist of fossilised phytoplanktons or diatoms mainly composed of amorphous hydrated silicates (Quarles and Winn, 1996). DE dust works by adsorbing the waxy layer from insect cuticles which results in water loss and, dehydration and death (Ebeling, 1971). DEs have extremely low mammalian toxicity (Subramanyam *et al.*, 1994). If DEs could be locally or regionally sourced in SSA, as opposed to the organophosphorous insecticides which have to be imported using valuable foreign currency, it would help stabilise prices of grain protectants. This paper examines recent and on-going research and identifies and discusses key issues faced by developing countries in SSA regarding the use of DEs as grain protectants.

Efficacy of diatomaceous earths against storage insect pests

Laboratory experiments showed that while DEs are effective against most storage insect pests at ≤ 1g/kg of grain, bostrichids (*Rhyzopertha dominica* F. and *Prostephanus truncatus* (Horn)) are less susceptible (Subramanyam *et al*., 1994; Korunic *et al*., 1997; Stathers *et al*., 2000). Effective control of *P. truncatus* was only achieved with DE concentrations of 2.5g/kg (Stathers *et al*., 2000).

There is limited published work on the efficacy of DEs under tropical conditions. On-farm experiments conducted in Zimbabwe demonstrated that DEs are effective at 1g/kg in semi-arid or sub-humid conditions for storage periods of 40 weeks (Fig. 1.) (Stathers *et al*., 2002a). However, *R. dominica* on threshed sorghum could only be effectively controlled at higher concentrations of 2g/kg. DE efficacy mainly relies on contact with the insect body and to enhance this, grain must be stored threshed and undamaged to allow effective admixing and to prevent insects from hiding within grain cavities. DE treatment of unthreshed grain or maize cobs would probably require at least double the dose for effective control of bostrichids and this has cost implications for the farmer.

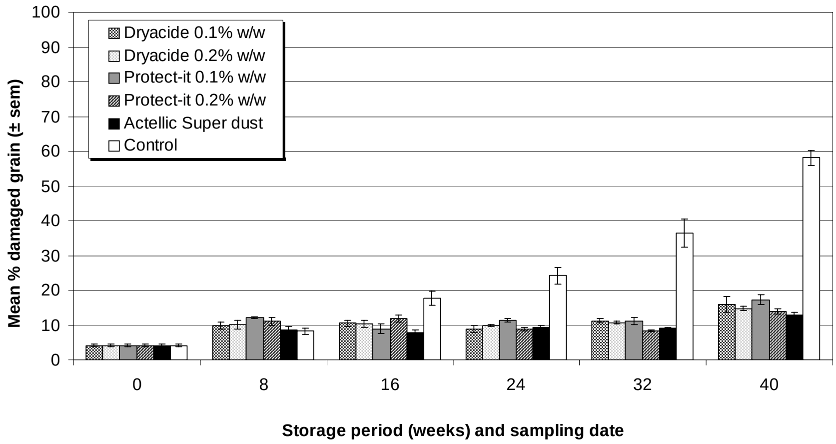

Figure 1. Insect damage to maize grain treated with diatomaceous earth or Actellic Super dust during the 1998/99 storage season in Buhera district, Zimbabwe (n=4) (Source: Stathers et al., 2002a).

To counter the failure of low rates of DEs in controlling bostrichids at concentrations of ≤1g/kg, one could explore several options including:

1. Combining DEs with synthetic pyrethroids to provide a knockdown effect. However, since DEs are more effective on active insects (le Patourel *et al*., 1989), the rate of accumulation of the DE on the insect body is reduced when the insect has been immobilised by the knockdown effect. Deltamethrin at 0.25mg/kg was found to cause 100% mortality of *P. truncatus* after 14 days of exposure to maize and no additional effect was derived from combining with DEs (Stathers *et al*., 2002b). Doses as low as 0.025ppm of deltamethrin were highly effective.
2. Targeted treatment of bulk grain, in which only the top 10% and bottom 20% of bulks were treated using Protect-It 0.1% (w/w), have successfully protected uninfested grain against infestations of *Sitophilus* spp. and *Tribolium* spp. in small-farm stores in Zimbabwe (Hodges, R. J., personal communication). If bostrichids were part of the pest complex, higher concentrations of DE would be required in the targeted zones. In laboratory experiments, Korunic and Mackay (2000) found that by admixing the top 100cm of a bulk wheat column with Protect-It 0.5g/kg, *R. dominica, S. oryaze* and *T. castaneum* populations introduced at the top surface were reduced by 98-100%. However, DEs adhere to wheat better than maize (Korunic *et al*., 1997) and therefore, maize would require higher concentrations of DE.
3. Large numbers of parasitoids and predators were found in untreated grain in field insect ecology experiments in Zimbabwe while relatively few were found in DE experiments conducted in the same agro-ecological zone on the same type of grain (Mvumi, 2001). It could be that the DE dust repelled the natural

enemies (Ebeling, 1971; Quarles, 1992) or hymenopteran wasps are more susceptible than coleopteran pests (Perez-Mendoza *et al*. 1999). There is, therefore, a need to identify means of integrating DE treatments with natural enemies. For example, bottom layers could be treated and the top layer left untreated to allow the natural enemies to survive and attack the pests. In the absence of *P. truncatus*, Protect-it 0.25g/kg admixed with maize caused 100% mortality of the predatory *Teretrius nigrescens* Lewis compared to less than 15% mortality when the bostrichid was present (Stathers *et al*., 2002b). This could be attributed to the fact that the dust generated by the feeding activity of *P. truncatus* dilutes the DE reducing the effect of the predator.

Occurrence of DE deposits in Africa

Local deposits of DEs are present in several countries in Africa including: Algeria, Egypt, Kenya, South Africa (Ross, 1981), Zimbabwe (Mugumbate *et al*., 2001)) and Tanzania (W. Riwa; pers. comm.). A rapid assessment of DE samples collected from South Africa, Tanzania and Zimbabwe showed low insecticidal potential (Korunic, 2003). However, some of the samples had significant foreign material and it was recommended that purer samples be collected from deeper layers of the DE deposits. Part of the assessment included the preliminary bioassays using DE concentrations of 0-1g/kg. Further bioassay tests using higher concentrations of up to 2.5g/kg need to be conducted. The costs of such concentrations may not be as prohibitive as importing the DEs or using synthetic insecticides. However, data on their safety to humans has not yet been collected.

Commercialisation of DEs and legislative issues

Currently there are no DE products registered against storage insect pests in SSA, although temporary registration of Protect-It by a private company is at an advanced stage in Zimbabwe. In Zimbabwe, consumption of DE-treated grain is prohibited by regulation until the product has been registered. This is a crucial constraint limiting future research work on the acceptability and uptake of this promising alternative grain protection method.

The development and registration of DE products should be the responsibility of the private sector. This will ensure the viability and sustainability of the technology because product prices will be market-driven. Although researchers cannot influence the eventual pricing of DEs, it is hoped that by tapping local deposits, the unstable prices caused by fluctuating foreign exchange rates can be avoided. Locally produced DE products may be more affordable than imported DEs or synthetic pesticides, although this will be dependent on the economics of the extraction, production and marketing processes.

When DEs are registered as grain protectants and become easily available to small-scale producers as a successful alternative to organophosphate-based pesticides, other issues such as product adulteration by unscrupulous dealers could arise. This is already a widespread problem in Tanzania and Kenya where adulteration of registered agrochemical products has reached serious levels. The Tanzanian Ministry of Agriculture and Food Security is addressing this problem through the publication of lists of approved pesticide distributors, the registration of alternative products to provide users with more choice, the introduction of new packaging material with batch details for the affected products, awareness raising amongst stakeholders, and legislation to enable prosecution of those found guilty of adulterating or distributing adulterated products. Some manufacturers are importing pre-formulated products into Tanzania to try and avoid adulteration problems (Frumerman, E., personal communication).

One potential source of controversy is the fact that a community may have free access to DEs in an area, yet if a private company invests in mining those DEs, they would want to patent the product(s). Thus the product(s) would not be freely available to the community and ‘illegal’ tapping of the DEs might occur as has been the case with gold panning in Zimbabwe resulting in serious environmental problems. However, to date no traditional use of DEs by indigenous communities in SSA has been documented. If commercialisation of DEs is done through a private company, the company will be expected to meet certain statutory requirements including an environmental impact assessment. Although natural DEs and synthetic silicas are amorphous, some contain up to 4% crystalline silica in the form of cristobalite which has been linked with lung cancer (Quarles and Winn, 1996; Subramanyam and Roesli, 2000). To reduce safety risks DE dusts should contain less than 1% crystalline silica (Subramanyam and Roesli, 2000). Thus it will also be mandatory for the company to observe safety precautions for workers and consumers.

However, for the DE technology to become operational in SSA, there are a number of issues that will need to be considered including efficient distribution systems, appropriate packaging and comparative cost-effectiveness with synthetic insecticides.

Issues pertinent to small-scale use of DEs

The primary target users of the technology must participate and contribute to the testing and development of the DE technology. In participatory evaluations of Protect-It compared to their normal grain protection practices, farmers gave superior ranking to the DE for all the visual quality parameters the farmers considered important (e.g. insect damage, expected flour yield, quality and sale price) (Stathers *et al*., 2002c). However, there is still need for more research to determine other aspects such as palatability, effect on cooking and brewing properties, and on processing quality of the grain. Socio-economic studies of this nature are important because they determine the final acceptability of the DE products by the end users.

In places where bulk grain is stored in solid-walled structures, and assuming that most of the insect infestation is attributed to immigration through the top, it is logical to target treatment to the top 30cm-layer of grain to create a barrier against the insects. Households regularly withdraw grain for consumption, this practice can disrupt the barrier effect of the treatment; hence modifications to the store might be necessary to allow grain withdrawal, probably through a chute near the bottom. Another option is to treat the bottom layer only and assume that regular withdrawal from the top is sufficient to prevent insect build-up from the resident population or from re-infestation. There is a high risk in this approach in that reduction in insect population due to grain withdrawal will depend on the amount, frequency and method of grain withdrawal, the surface area of the grain layer and the pest spectrum. The whole concept of which layer to treat may depend on how long a farmer anticipates storing the grain for before consumption starts. The longer (>6months) the storage period, the more appropriate top layer treatment becomes. Different ethnic groups typically use different storage structures and systems, and those who have compartmentalised granaries may wish to treat only that grain to be stored for ≥4 months. Polygamous households who consume grain from the wives granaries first may choose to treat only the grain stored in the husband's granary.

P. truncatus is a major pest of stored maize and dried cassava in SSA. The pest is indigenous to Central America and was introduced to Africa in the early eighties and has to-date spread to 16 countries in East, West, Central and Southern Africa. The pest causes grain losses of more than five times the normal spectrum of storage pests and is therefore a serious threat to the food security of farmers. In countries where the pest already occurs, the management strategy has been use of synthetic insecticides; mainly organophosphate-pyrethroid combinations. DEs are currently being tested as a possible replacement of the organophosphate component against *P. truncatus* under field conditions in Tanzania using Protect-It at 1g/kg in combination with permethrin 2mg/kg.

Under humid conditions, the efficacy of DEs is greatly reduced. This coupled with the prevalent practice of cob storage makes control of *P. truncatus* particularly difficult in the absence of the organophosphate-pyrethroid emulsifiable concentrates, which are normally used instead of dilute dust insecticidal formulations. Further research is required to adapt the DE technology to such scenarios.

Although, DEs might have tremendous potential for grain protection, the ultimate factors which will determine uptake of the DE technology by small-scale farmers in developing countries are the socio-cultural acceptability, cost-effectiveness and availability of the products relative to synthetic insecticides. The DEs will need to fit into, and be promoted as part of an integrated pest management (IPM) framework appropriate for small-scale farmers involving use of resistant cultivars, timely harvesting when field infestation is still low, solarisation, hygiene, exclusion and regular monitoring.

Issues pertinent to commercial use of DEs

With grain market liberalisation now common in most parts of SSA, some small-scale farmers may want to retain their DE-treated grain in anticipation of attractive mid-season prices. For farmer-to-farmer trade, DE-treated grain is not a problem. However, for central marketing systems and commercial millers, existing grading standards will have to be amended for them to purchase DE-treated grain from farmers. Staff in the central marketing systems will need to be trained in the recognition of DE-treated grain to avoid acceptance of grain adulterated with other substances. Rapid and reliable determination of DE concentration on grain is difficult. Jackson and Webley (1994) measured flow-rate, bulk density and angle of repose for different types of grains treated with different concentrations of Dryacide. Similar parameters could be determined for different DEs and the data used to guide grain graders. Bulk density is already one of the grading parameters used by the central marketing systems in Zimbabwe for example. The use of scanning electron microscopy to ascertain DE treatment as suggested by Subramanyam and Roesli (2000), is likely to be too costly in developing countries.

When grain kernel surfaces are coated with DE by admixing, friction between the grains is increased and this affects flowability especially in mechanised handling systems. Jackson and Webley (1994) found that when Dryacide was applied at 0.5g/kg on maize, the flow rate was reduced by about 39%. The concept of target treatment may also apply here such that total amount of DE applied per unit grain mass is greatly reduced. However, such a system will work best when combined with temperature control or use of a fumigant. In Australia, Dryacide is being used as a structural treatment on surfaces or machinery as dust or slurries to dis-infest them. Wet application can be much safer to workers as it minimises inhalation of the DE dust but is less efficacious than the dust formulation (Maceljski and Korunic, 1971). It is likely that a combination of DE as a top-dressing and a fumigant such as phosphine will be more appropriate for central storage systems in SSA from an economic point of view.

Conclusion

Withdrawal of organophosphorous insecticides from the SSA market is imminent. DEs have been technically demonstrated to be an effective alternative option appropriate for small-scale farmers under semi-arid and sub-humid conditions in Zimbabwe (Stathers et al., 2002a & c). There are, however, several issues that still need to be addressed. All future work focussed on producer utilisation and consumer acceptance of the product will remain contingent on successful registration of the DE products. The transformation of pest management strategies from an organophosphate-based to a DE-based approach would require the participation of all relevant stakeholders as it will have numerous downstream effects. The stakeholders will need to be made aware of the changes for them to conform. This will require investment in awareness campaigns using various media and training of extensionists and intermediary agencies.

Acknowledgements

This paper is an output from research projects funded by United Kingdom Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. R7034 and R8179: Crop Post-Harvest Research Programme.

References

Bell, C. and Shaaya, E., eds, (1997) Ecologically safe alternatives for the control of stored-product insects. Papers presented at the XIII International Plant Protection Congress, July 1995, The Hague, Netherlands. Reported in a special issue of Journal of Stored Products Research 33, 1, 1997.

Ebeling, W. (1971) Sorptive dusts for pest control. Annual Review of Entomology 16, 123-158.

Jackson , K. and Webley, D. (1994) Effects of Dryacide® on the physical properties of grains, pulses and oilseeds, pp635 – 637. In: Highley, E., Wright, E. J., Banks, H. J. and Champ, B. R, eds, Proceedings of the 6th International Working Conference on Stored-product Protection 2. Canberra, Australia. CAB International.

Korunic, Z. (2003) Potential insecticide efficiency of Africa's diatomaceous earths. Report for the project "Small-scale utilisation of diatomaceous earths during storage". Natural Resources Institute, Chatham. 12pp.

Korunic, Z. and Mackay, A. (2000) Grain surface-layer treatment of diatomaceous earth for insect control. Archives of Industrial Hygiene and Toxicology 51, 1, 1 – 11.

Korunic, Z., Fields, P. G., Timlick, B., Ormesher, P. and van Natto, C. (1997) Enhanced diatomaceous earth insecticide, safe, effective and long-lasting grain protectant. Paper presented at FAO VIII Round Table on Prevention of Post-harvest Food losses. Cartagena, Columbia. 13 - 15 August 1997.

le Patourel, G. N. J., Shawir, M. and Moustafa, F. I. (1989) Accumulation of mineral dust from wheat by *Sitophillus oryzae* (L.) (Coleoptera: Curculionidae). Journal of Stored Products Research 25, 65-72.

Maceljski, M. and Korunic, Z. (1971) Trials of inert dusts in water suspension for controlling stored-product pests. Zastita Bilja 22, 115/116, 377 – 387.

Mugumbate, F., Oesterlen, P. M., Masiyambiri, S. and Dube, W. (2001) Industrial and rock deposits of Zimbabwe. Zimbabwe Geological Survey Mineral Resources Series No. 27, Harare. v+159pp.

Mvumi, B. M. (2001) The ecology of stored grain insects in Zimbabwe and their control using diatomaceous earths with particular reference to the grain moth *Sitotroga cerelealla* (Olivier) (Lepidoptera: Gelechiidae). PhD Thesis, Natural Resources Institute, University of Greenwich, Chatham.

Perez-Mendoza, J., Baker, J. E., Arthur, F. H. and Flinn, P. W. (1999) Effects of Protect-It on efficacy of *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae) parasitising rice weevils (Coleptera: Curculionidae) in wheat. Environmental Entomology, 28, 3, 529 – 534.

Quarles, W. (1992) Diatomaceous earth for pest control. IPM Practitioner, 14, (5/6), 1-14.

Quarles, W. and Winn, P. S. (1996) Diatomaceous earth and stored product pests. IPM Practitioner 18, (5/6), 1-10.

Ross, T. E. (1981) Diatomaceous earths as a possible alternative to chemical insecticides. Agriculture and Environment, 6, 43-51.

Stathers, T., Mvumi, B., Chigariro, J., Mudiwa, M. and Golob, P. (2000) Grain storage and pest management using inert dusts. Crop Post-harvest Programme, Final Technical Report. Natural Resources Institute, UK. ii + 66pp.

Stathers, T. E., Mvumi, B. M. and Golob, P. (2002a) Field assessment of the efficacy and persistence of diatomaceous earths in protecting stored grain on small-scale farms in Zimbabwe. Crop protection 21, 1033-1048.

Stathers, T., Mvumi, B. and Golob, P. (2002b) Can diatomaceous earths have an integrated role in small-scale tropical grain storage? International Organisation for Biological Control Bulletin 25, 3, 231-237.

Stathers, T. E., Chigariro, J., Mudiwa, M., Mvumi, B. M. and Golob, P. (2002c) Small-scale farmer perceptions of diatomaceous earth products as potential stored grain protectants in Zimbabwe. Crop protection 21, 1049-1060.

Subramanyam, Bh. and Hagstrum, D. W. (2000) Alternatives to pesticides in stored-products IPM. Kluwer Academic Publishers, Norwell, Massachusetts. xv + 437pp.

Subramanyam, Bh. and Roesli, R. (2000) Inert dusts, pp321-380. In: Subramanyam, Bh. and Hagstrum D. W., eds, Alternatives to pesticides in stored-product IPM. Kluwer Academic Publishers, Norwell, Massachusetts.

Subramanyam, Bh., Swanson, C. L., Madamanchi, N. and Norwood, S. (1994) Effectiveness of Insecto, a new generation diatomaceous earth formulation, in suppressing several stored-grain insect species, pp650-659. In: Highley, E., Wright, E. J., Banks, H. J. and Champ, B. R., eds, Proceedings of the 6th International Working Conference on Stored-product Protection, 2. Canberra, Australia. CAB International.