Section: Residual Insecticides – Synthetic and Botanical

Residual insecticides, inert dusts and botanicals for the protection of durable stored products against pest infestation in developing countries

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Abstract

Insect pests associated with durable grains and processed food cause considerable quantitative and qualitative losses throughout the world. Insect infestation can occur just prior to harvest, during storage in traditional storage structures, cribs, metal or concrete bins, and in warehouses, food handling facilities, retail grocery stores as well as in-transit. Many tools are available for managing insects associated with grains and processed food. Although pest management strategies are changing to meet consumer's demand for food free of insecticide residues, address concerns about safety of insecticides to humans, delay insecticide resistance development in insects and comply with stricter insecticide regulations, the use of synthetic residual insecticides will continue to be a major component of stored-product pest management programmes. Selective use of residual insecticides requires a through understanding and evaluation of risks, costs and benefits. The use of plant and inert materials may be a safe, cost-effective and environmentally friendly method of grain preservation against pest infestation among low-resource poor farmers who store small amounts of grains. There is a dearth of information on the use of plant materials by rural farmers in Africa for stored-product protection. The most promising candidate plant materials for future utilization as grain protectants are *Azadirachta*, *Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum, Piper* and *Tetradenia* together with vegetable oils from various sources. Neem is the only plant from which several commercial products have been developed worldwide. However, unlike synthetic insecticides these alternatives often do not provide effective or rapid suppression of pest populations and may not be effective against all species of pests. These alternatives are also more expensive than synthetic insecticides, and have not been tested extensively under field conditions in the tropics. This paper focuses on the current state of the utilization of residual insecticides, inert dusts and botanicals by resource-poor farmers for protection of durable stored produce against pest infestation in Africa. A major research priority is a well designed on-farm trials to validate the efficacy of botanicals and inert dusts for stored-product protection using standard procedures and formulations that can be transferred to other communities.

Key words: Botanicals, Residual insecticides, Inert dusts, Grain storage, Storage pests, Stored products

1. Introduction

Presently the world's population stands at about 6.5 billion and it is projected to increase at 2.2% per year to around 11.5 billion by 2100, with 87% living in the developing countries of Africa, Asia and Latin America and only 13% in the developed countries of North America, Europe and Far East (Penning de Vries, 2001). The high population growth rate, particularly in the developing countries, and the changing diets will lead to a much higher food demand by 2020 (Penning de Vries, 2001). The attainment of food security in sub-Saharan Africa and Asia can only be realized from increase in productivity through the use of sustainable good agricultural practices (GLOBALGAP) and prevention of losses caused by pests in the field and along the value chain.

It is estimated that between 60-80% of all grain produced in the tropics is stored at the farm level (Golob et al., 1999). Grains (cereals, legumes, oilseeds) contribute the bulk of the world's calories and protein. The reduction of postharvest grain losses, especially those caused by insects, microorganisms, rodents, and birds, can increase available food supplies, particularly in less developed countries where the losses may be largest and the need is greatest. Postharvest losses are recognized as a major constraint in Africa with reports of losses averaging 30% of durable stored grains (Golob and Webley, 1980). In the developing countries, the greatest losses during storage to cereals and grain legumes are caused by insect pests. Insect pest control in durable stored agricultural produce at farm level is increasingly relying on the use of synthetic insecticides by farmers who lack technical knowledge in the safe handling and use of such products. The misuse of synthetic pesticides has led to accidental poisoning, the development of insect resistance and other adverse environmental and health hazards. Furthermore, the development of synthetic insecticide-based techniques for grain protection in traditional stores in Asia and Africa has been partially caused by the high cost, unavailability or erratic supply of safe insecticides (Obeng-Ofori, 2007). In many developing countries availability of suitable and safe pesticides is poor, and often dangerous, highly toxic or persistent chemicals, such as fenthion, lindane and DDT, may be used to the detriment of the health of applicators and consumers and the environment as a whole (Golob et al., 1999).

However, the protection of the consumers of treated produce and education of the users of the chemicals is imperative. The phase-out of the fumigant methyl bromide has begun. In addition, many stored-product pests have developed resistance to the phosphine, due to its wide application for insect control in stored grains. It is most likely that residual insecticides will continue to constitute the dominant and valuable tool in stored-product pest management programs (White and Leesch, 1995).

Moreover, residual insecticides can be applied easily without specialized equipment, are compatible with international grain trade and global restrictions for zero insect tolerance, are generally less expensive than fumigants or biopesticides and are effective against a wide range of storage pests. Chemical pest control methods, if carried out intelligently and knowledgeably, can be both effective and safe. It is therefore important for users to have good knowledge of the classification, mode of action, properties, metabolism and residues of the pesticides, to enable them make proper appraisal of the benefits and potential hazards of the pesticides. Thus, they should be able to choose insecticides judiciously and formulate efficient control measures in any particular set of circumstances. There is also, the need for continuous education and training on selective and appropriate use of safe residual insecticides to ensure human safety and environmental protection.

In Africa, most of our agricultural produce is produced by poor resource farmers who cannot easily afford the cost of safer synthetic pesticides. It has therefore become necessary to search for other alternatives such as inert dusts and botanical insecticides, which are environmentally friendly and cost effective at the small-scale farmer level (Niber, 1994; Bekele et al., 1997). In many systems utilizing chemical pesticides, resistance is the rule rather than the exception; operator hazards are very real; environmental and consumer concerns cannot be ignored; and the proponents of IPM have to be taken seriously in order to develop sustainable systems for protecting stored products against pest infestation (Haines, 2000).

Inert dusts are non-toxic materials that can be mixed with the produce to control stored-product insect pests. Inert dusts can also be used to disinfect storage facilities before new produce is brought for storage. These dusts do not deteriorate or break-down and, therefore, provide long-term control of insect pests and are non-toxic, and therefore completely harmless to humans and mammals. In India during the 1960, about 70% of the grain was treated with activated Kaolin clay. Egypt also used rock phosphate as a grain protectant. Some local farmers in West Africa use ashes, lime and sand dust as grain to protect grains against pest infestation (Obeng-Ofori and Boating, 2007).

Botanicals are traditional and non-synthetic protectants derived from plants. Traditionally, many different types of plant parts are used for the protection of agricultural produce. These plants are available in many developing countries and contain several active ingredients and act in different ways under different circumstances (Schmutterer, 1990; Isman, 2006). Botanicals break down rapidly to harmless metabolites and appear less likely to build up genetic resistance in targeted species. They can also less harmful to mammals and other beneficial organisms. Botanicals can be used reliably and safely to treat cereals and grain legumes when stored in small quantities at the farm level.

The wide-scale commercial use of plant extracts as insecticides began in the 1850s with the introduction of nicotine from *Nicotiana tabacum,* rotenone from *Lonchocarpus* sp, derris dust from *Derris elliptica* and pyrethrum from the flower heads of *Chrysanthemum cinerariaefolium* (Golob et al., 1999). Several other traditionally used plant preparations and constituents of many aromatic plants used for flavouring or medicinal purposes have been found to possess insecticidal properties (Tanzubil, 1986; Bell et al., 1990; Obeng-Ofori et al., 1997). The use of locally available plants avoids the need to establish complex mechanisms and structures for pesticide distribution and other related issues (Golob et al., 1999). The community can collect or grow the plants itself; the technique is therefore sustainable for rural farmers in Asia and sub-Saharan Africa.

2. Current status of the use of residual insecticides

The most important curative measure in stored-product pest control is the application of synthetic residual or contact insecticides. There are general principles that underlie selective use of residual insecticides to control storage pests. While there is great number of products against field pests there are only few products available which meet the special requirements of pest control during storage. None of the existing products, however, will entirely fulfill all of them. However, it is user's responsibility to select the correct insecticide that meet most of these specific requirements:

- Effective against most storage pests (broad-spectrum effect)
- Long persistence and stable under various climatic conditions
- Low toxicity to warm-blooded animals and low tendency to create insect resistance
- No harmful residue left in stored produce
- No influence on the smell or taste of the stored produce
- No chemical reaction with the ingredients of the stored produce (proteins, fats, etc.)
- Simple to use and low price

2.1. Groups of active ingredients in storage pest control

There are two main groups of active ingredients commonly used in stored-product protection. These are organophosphorous compounds and pyrethroids (Tables 1 & 2). Organophosphorous compounds are effective against most storage pests, although less against the Bostrichidae *(Rhyzopertha dominica* (F.), *Prostephanus truncatus* (Horn), *Dinoderus* spp.). Pyrethroids are very effective against Bostrichidae, though less against other species of beetles. Combined products, also known as "cocktails", containing an organophosphorous compound and a pyrethroid have been used as broad spectrum contact insecticides against mixed insect infestation (Table 3). The selection of insecticides for treatment of edible commodities is based mainly on the toxicological data (low mammalian toxicity), the effectiveness and persistence under certain storage conditions and absence of side effects such as discolouration, flavour alternation and odour. The Food and Agriculture Organization (FAO) and the World Health Organization (WHO) collect toxicological information and give advice on overall acceptable tolerance levels (Table 4).

2.2. Insecticide resistance and its management

The frequent and indiscriminate use of insecticides as a substitute rather than as a supplement to non-chemical management techniques has resulted in the failure of these chemicals to effectively control storage insect pests (Subramanyam and Hagstrum, 1996). Almost all the economically important stored-product insect pests throughout the world are resistant to most of the insecticides commonly used to protect commodities against inset infestation and damage (Subramanyam and Hagstrum, 1996). Resistance is the ability in individuals of a species to withstand doses of toxic substances that would be lethal to the majority of individuals in a normal population. This means that the target pests are no longer controlled by the originally recommended application rate of an insecticide. Resistance may be suspected under the following circumstances:

- If higher doses are required to achieve a constant mortality of insects
- If there is a significant decrease in insect susceptibility to a fixed amount of the insecticide
- If it takes longer to obtain a fixed mortality of insects
- If the mortality of field populations of a species frequently exposed to insecticides is significantly less than mortality of the same species that has little or no insecticide exposure

Table 1 Common organophosphorous contact insecticides used for stored product pest control.

Active Ingredient	Brand names
Chlorpyrifos-methyl	Reldan
Dichlorvos (DDVP)	Nuvan, Vapona
Fenitrothion	Folithion, Sumithion
Iodofenphos	Nuvanol
Malathion	Malathion, Malagrain etc
Methacrifos	Damfin
Phoxim	Baythion
Pirimiphos-methyl	Actellic
Tetrachlorvinphos	Gardona

Table 2 Common pyrethroid contact insecticides used for stored product pest control.

Active Ingredient	Brand names
Cyfluthrin	Baythroid
Deltamethrin	K-Othrin
Fenvalerate	Sumicidin
Permethrin	Permethrin

Table 3 Combined contact insecticides commonly used against mixed insect infestation in storage.

Active ingredients	Brand names
Fenitrothion + Cyfluthrin	Baythroid Combi
Fenitrothion + Fenvalerate	Sumicombi
Pirimiphos-methyl + Deltamethrin	K-Othrine Combi
Pirimiphos-methyl + Permethrin	Actellic Super

Table 4 Acute oral LD (mg/kg body wt. rate) of insecticides used for storage pest control.

Insecticide	Rat Oral LD50 (mg/kg)	Rat Dermal LD50 (mg/kg)
Malathion	1375-2800	4000-4800
Pirimiphos methyl	2050	2000
Chlorpyrifos methyl	1650-2100	3000
Tetrachlorvinphos	4000-5000	5000
Bromophos	4000-8000	2188
Dichlorvos	80	107
Fenitrothion	250-500	3000
Diazinon	300-850	2150
Iodofenphos	2100	-
Phoxim	1845	7100
Etrimfos	1800-2040	-
Methoxychlor	5000-7000	2820-6000
Pyrethrum	1500	1800
Bioresmethrin	9000	10.000
Deltamethrin	1290	2940
Fenvalerate	450	3700-5000
d-Phenothrin	5000	5000
Resmethrin	1500	3040
Permethrin	4000	4000
Methoprene	5000	Relatively nontoxic
Piperonyl butoxide	Relatively nontoxic	Relatively nontoxic

The rate of evolution of resistance depends on several factors. In general, the rate of selection for resistance increases with increase in the dose, coverage, frequency of application, and persistence of an insecticide. The most effective way to delay the development of resistance is to use integrated pest management (IPM) approach which emphasizes on the use of non-chemical methods and selective insecticide treatments. Resistance management strategy for stored-product insects should therefore rely heavily on non-chemical methods because of the limited number of safe insecticides available to practitioners. Monitoring of resistance is important for making resistance management decisions and diagnostic tests that distinguish between resistant and susceptible individuals must be used instead of dose-response tests. The following measures can prevent or delay the development of resistance:

- Change the active ingredient regularly (if possible once a year). The use of different insecticides to which the insects are not cross resistant can contribute substantially to slowing the development of resistance.
- Two insecticides can be used sequentially, as mixtures, in rotation or as mosaics (some areas treated with the first insecticide and other areas with the second insecticide. Applying insecticides in rotation is generally the preferred method because susceptible genotypes generally have a reproductive advantage over resistant genotypes in the absence of an insecticide. The frequency of susceptible genotypes may increase during the periods when an insecticide is not used.
- Use insecticides only under good hygiene conditions
- Ensure that dosage and application method are correct
- Do not use insecticides on calendar basis but only when it is necessary
- Apply insecticides efficiently using the correct application equipment to minimize wastage
- Increasing the amount of insecticide is no solution as it promotes further resistance. This approach is also uneconomical and not permitted because of lethal stipulations of maximum residue limits. It has been suggested that the risk of resistance be incorporated into pesticide registration requirements and that resistance management be used as justification for the registration of insecticide mixtures.

3. Current status of the use of inert dusts for stored-product pest control

The use of inert dusts is one of several innovative, reduced-risk or biorational and physical methods for stored-product insect pest management (Subramanyam and Roesli, 2000). Inert dusts are non-toxic dry powders of different origins that are chemically un-reactive in nature and, which can be mixed with the produce to control stored-product insect pests. Inert dusts can also be used to disinfect storage facilities before new produce is brought for storage. Inert dusts do not deteriorate or break-down and, therefore, provide long-term control of insect pests and are completely harmless to humans and mammals. Clays were used as grain protectant in North America and Africa over thousands of years ago (Ebeling, 1971; Golob and Webley, 1980). The research on inert dusts against storage pests started in the 1920s (Headlee, 1924) and there have been several reviews and research papers on the subject since then (Ebeling, 1971; Fields and Muir, 1995; Golob, 1997; Korunic, 1998; Subramanyam and Roesli, 2000). The main advantages of inert dusts are that they are non-toxic and provide continued protection of produce. They do not affect baking quality when applied to grains and are compatible with other control techniques such as heat treatment, fumigants and aeration (Bridgeman, 2000) and host-plant resistance (Chanbang et al., 2008) (Table 5). Inert dusts are suitable for disinfesting empty storage facilities and for grain treatment.

3.1. Types of inert dusts

There are four main types of inert dusts available for use against stored products. These are (earth, diatomaceous earth, silica aerogels, and non silica dusts.

3.1.1. Earth

Earth includes clays, sand, paddy husk ash, wood ash and volcanic ash (Subramanyam and Roesli, 2000). These materials have been applied traditionally in some developing countries as stored-product protectants and are usually used as a layer on top of stored seeds (Golob and Webley, 1980). These materials are effective at high rates (≥10 g per kilogram of gram (Subramanyam and Roesli, 2000). Local farmers in West Africa including Ghana, Benin, Senegal, Niger and Mauritania still use varying levels of fine sand and ashes from different plants to protect stored grain against insect pest infestation (Obeng-

Ofori, 2007). Research is being carried out in many parts of Africa to replace these traditional dusts with more effective synthetic silica dusts that work at lower rates (Golob, 1997; Obeng-Ofori, 2007).

Table 5 Percentage insect-damaged kernels caused by *Rhyzopertha dominica* exposed on the different rough-rice varieties treated with 0 to 1000 mg/kg diatomaceous earth (DE) and held at 32°C and 75% r.h. for 56 days.

Rice variety	**Insect-damaged kernels (%)**				
	DE (mg/kg)				
	0	**250**	**500**	**750**	**1000**
Resistant variety					
Bengal	10.0 ± 2.0 c	1.3 ± 0.5 bc	0.5 ± 0.3 c	0.2 ± 0.2 c	0.1 ± 0.1 e
Jupiter	1.9 ± 0.8 ab	0.1 ± 0.1 d	0.0 ± 0.0 c	0.0 ± 0.0 c	0.0 ± 0.0 e
Pirogue	13.4 ± 1.6 ab	16.2 ± 2.4 ab	9.7 ± 1.3 b	7.7 ± 1.3 ab	8.7 ± 1.1 bc
Wells	8.8 ± 1.2 b	2.4 ± 1.1bc	0.4 ± 0.4 c	0.5 ± 0.3 c	0.5 ± 0.4 e
Susceptible variety	22.9 ± 4.4 a	22.4 ± 3.8 a	25.3 ± 1.1 a	20.4 ± 1.9 a	18.6 ± 2.3 a
Akita	19.1 ±2.6 ab	17.1 ± 3.4 ab	14.7 ± 1.0 ab	12.8 ± 4.8ab	11.3 ± 0.5 ab
Cocodrie	19.1 ± 2.2 ab	13.9 ± 3.6 ab	11.2 ± 3.3 b	8.7 ± 1.0 ab	3.3 ± 0.5 d
M-205 Rico	9.7 ± 1.0 ab	8.1 ± 1.3 bc	6.8 ± 0.8 b	7.6 ± 2.9 b	5.1 ± 1.4 cd

Means ± within the same DE concentration followed by different letters are significant at P<0.05 (Bonferroni (Dunn) *t-test,* (Chanbang et al*.,* 2008).

3.1.2. Diatomaceous earth

Diatomaceous earth is used in a number of countries for stored-product protection. The admixture of finely ground silica-based dusts with quartz as the active ingredient for the control of stored-product insect pests is an ancient practice because during the 1930s and 40s, commercial products such as 'Naaki' and 'Neosyl' were marketed in Germany and England, respectively as grain protectants (Jenkins, 1940; Parkin 1944). The commercial DE formulations currently available are predominantly made up of amorphous silica and contain little or no crystalline silica (Subramanyam and Roesli, 2000). Diatomaceous earth is the fossilised siliceous remains of diatoms that were deposited during the Cenozoic era. Diatoms are microscopic unicellular aquatic plants closely related to brown algae that have a fine shell made of silica ($SO_2 + H_2O$). The main constituent of these deposits is therefore silica (SO_2), although there are small amount of oxides of other minerals such as aluminum, iron, lime, magnesium and sodium. As particle aggregates, DE is used as an industrial absorbent and as non-toxic insecticide to control stored-product and household pests.

3.1.3. Mineral (non-silica) dusts

Mineral (non-silica) dusts have been tested for their efficacy as grain protectants. Several workers have reported the use of different types of mineral dusts for the control stored-product insect beetle and moth pests (Davis et al*.,* 1984; Davis and Boczek, 1987). Typical mineral dusts include calcium carbonate (lime), rock phosphate, zinc oxide, magnesium oxide and dolomite.

3.1.4. Silica gels

Silica gels are made up of 99.5% silicon dioxide. Silica gels are dusts that contain extremely small particles of less than 3 micrometers with a bulk density in the range of 72-450 g/L and specific surface in the range of 200-850 m^2/g (Quarles, 1992). Silica gels are capable of absorbing about 1.9-3 g of linseed oil per gram gel and this makes them more effective than DE dusts (Subramanyam and Roesli, 2000). There are three main types of silica gels namely, precipitated silica gel, silica aerogel and fumed silica. In general silica gels could become suitable alternatives for grain protection in most developing countries where access to quality insecticides is limited or where local expertise on the use of synthetic insecticides is lacking. Currently, some commercial DE products such as Dryacide and Protect-It contain silica gels to improve their effectiveness (Fields and Korunic, 2000).

3.2. Mode of action of inert dusts

Inert dusts cause desiccation in insects by destroying the wax layer in the cuticle. Insects die of desiccation when they lose 60% of their water i.e. 30% total body weight (Ebeling, 1971). Inert dusts such as silica aerogels can absorb as much as three times their own weight in oils. As insects move through the grains the inert dusts absorb waxes from the insect cuticle. Because storage insects live in very dry environments with limited access to free water, water retention is crucial to their survival. Also by their small size insects have a large surface area in relation to their body weight and therefore have greater problems retaining water than large animals. The wax layer in the insect cuticle consists of an ordered monolayer of lipid, and determines the permeability characteristics of the cuticle. Indeed, the wax layer that inert dusts destroy is one of the main mechanisms insects use to maintain water balance.

The presence of powdered dusts between grains also interferes with the movement and respiration of insects. Dusts may also affect the oviposition behavior and sensory perception in insects. In summary, the modes of action of inert dusts include the following: (inert dusts block insect spiracles and insects die from asphyxiation, inert dusts lodging between cuticular segments increase water loss through abrasion of the cuticle, inert dusts absorb water from the insect's cuticle (d) insects may die from ingesting the dust particles, and inert dusts absorb the epicuticular lipids of insects leading to excessive loss from the cuticle (Subramanyam and Roesli, 2000).

3.3. Susceptibility of storage pests to inert dusts

Insects differ in their susceptibility to inert dusts. In general, *Tribolium* species are the most resistant and *Cryptolestes* species are the least resistant. The capacity of insects to survive dry conditions is correlated with resistance to inert dusts. The effectiveness of inert dusts may be determined by such factors as greater capacity of insects to gain water from their food, greater water re-absorption during excretion, less water loss through the cuticle, type of cuticular wax or amount of movement through grain. The effectiveness of inert dusts may also depend on the size of the particles, the finer the particle size, the more active they are. Generally, DEs are more effective against insects at higher temperatures and lower grain moisture contents (Fields and Korunic, 2000). The condition of the grain may affect efficacy of inert dusts. Most DE dusts are more effective on clean grain than in cracked grain (McGaughey, 1972).

3.4. Commercially available inert dusts

Commercially, a number of inert dusts especially diatomaceous earth products are registered as residual grain protectants and for use in crack and crevice treatment and disinfestation of storage structures before new grain is stored in a few countries, especially in the USA. Several products have been registered by the US Environmental Protection Agency. Australia has made considerable progress in integrating DE with aeration and fumigation (Bridgeman, 2000). In Germany, SilicoSec has been a registered diatomaceous earth since 1997. It is a natural silica powder based on fossilized diatom algae and contains 96% inert amorphous SO_2 with particle size between 13-15 microns. SilicoSec controls all stored grain insect pests including weevils, beetles, borers and moths. Even species resistant to chemical insecticides are controlled. The sharp-edged silica particles destroy the wax layers of the insect cuticle and quickly absorb lipids and body fluids leading to desiccation and death.

In the UK, two products of diatomaceous earth are commercially available for use in stored-product protection. These are Protect-It and Dryacide. These products have been found to be effective in protecting grain against insect pest damage for small-scale on-farm storage systems in Zimbabwe. The two products have been evaluated in a community-wide basis in Tanzania and the treated products include maize, sorghum and beans. However, field tests in Malawi using different rates of Dryacide, Protect-It and a precipitated silica gel (Gasil 23D) failed to provide long term protection of shelled or cob maize against infestation by *Tribolium castaneum* (Herbst) and *Sitotroga cerealella* (Olivier) (Gudrups et al., 2000). Other examples of commercial inert dust products include Perma-guard (DE), Dri-Die (DE and silica aerogel), Sipernat (silica aerogel) and SG-67 (silica aerogel).

In India during the 1960, about 70% of grain was treated with activated Kaolin clay. Egypt also used rock phosphate as grain protectant. Some local farmers in West Africa use ashes, lime and fine sand dusts as grain protectants.

3.5. Shortcomings of inert dusts

Inert dusts decrease the bulk density and flowability of grain. They adhere to the surface of grain kernels and increase the friction between the grains so that grains do not flow as easily thereby increasing angles of repose and decreasing bulk density. They also affect the appearance of the treated product and are dusty to apply. There have also been some concerns that inert dusts will increase wear on machinery.

3.6. Research needs

Compatibility of inert dusts with other control techniques will increase their practical utilization for stored-product protection. To enable more countries to explore ways of making inert dusts especially DE a part of the pest management strategy, research is needed to develop appropriate technologies for integrating inert dusts with other techniques such as conventional insecticides, botanicals, aeration and heat treatment. More research is also needed to evaluate the effectiveness of inert dusts under different range of field conditions and treatment techniques to empty storage facilities and on grain. Information on the effect of sanitation on the performance of inert dusts such as DE and silica gels in food-handling facilities will facilitate their utilization in such establishments. At the 7th International Working Conference on Stored-Product Protection (IWCSPP) held in China in 1998, a working group was formed comprising scientists from Australia, Brazil, Canada, Germany, UK and the USA to develop standardized techniques for evaluating DE dusts. This group published a standard protocol at the subsequent IWCSPP (Fields et al., 2002). The development of such standardized procedures will ensure that consistency is achieved from results obtained from different laboratories for comparison.

4. Current status of the use of botanicals by small-scale farmers

Botanicals are plant-derived compounds with different modes of action (Weaver and Subramanyam, 2000). The use of locally available plant materials for stored-product protection is a common practice, and has more potential in subsistence and traditional farm storage conditions, in developing and underdeveloped countries (Golob and Webley, 1980; Obeng-Ofori, 2007). Resource-poor farmers in different countries in Asia and Africa have utilized plant materials to protect durable stored products against insect infestation for a long period of time (Golob et al., 1999; Obeng-Ofori, 2007). Many of these plants are widely used in traditional medicine by local communities for the treatment of several ailments. The local farmers also admix leaves and powders with various cereals and pulses as protectants in different parts of the world, particularly India, China and most sub-Saharan African countries for the control of mostly insect pests. The practical advantage of using locally available material to protect stored products destined for household and small-scale use remains compelling (Weaver and Subramanyam, 2000). A number of excellent publications provide useful information regarding the types of plants used in different parts of the world for stored-product protection (Golob and Webley, 1980; Golob et al., 1999; Weaver and Subramanyam, 2000; Obeng-Ofori, 2007). It is, however, the transfer of such technology to other environments or the extension of the use of these methods to other communities within the same areas that have not been feasible to date.

There is therefore the need for more systematic studies to determine how farmers utilize plant protectants, the methods employed and their effectiveness in the field. For this to be achieved, a good understanding of the farming and sociological systems operating in the target communities is required. The introduction of rapid rural appraisal (RRA) and participatory rural appraisal (PRA) techniques in recent years has facilitated the collection of this type of information (Golob et al., 1999). In a survey in Benin, West Africa, out of the 33 plants collected and tested, the powders of *Nicotiana tabacum, Tephrosia vogelii* and *Securidaca longepedunculata* significantly reduced progeny production of *Callosobruchus maculatus* (F.) in stored cowpea while *Clausena anisata, Dracaena arborea, T. vogelii, Momordica charantia* and *Blumea aurita* were repellent to the beetle (Boeke et al., 2004). In a similar survey of plants used as traditional insecticides in 12 districts in forest areas of the Ashanti Region in Ghana involving about 500 farmers, 26 different plant species were found to be used as grain storage protectants (Cobbina et al., 1999). The most common were *Chromoleana odorata* (Siam weed), *Azadirachta indica* (neem) and *Capsicum annum* (chili pepper). Smoking maize stores was the most common method of control in most districts of the region.

In another PRA survey in the northern, semi-arid regions of Ghana only 16 plants were identified as being used as grain protectants. Apart from neem, none of the plants were used as stored-product protectant in the survey carried out in the Ashanti Region. Two of the plants, *Chamaecrista nigricans* and *C. kirkii* (both known locally as 'lodel'), and said to be the most effective, have not been recorded any where in the world and have not been studied to evaluate their potential as grain protectants. Another plant found to be commonly used by subsistence farmers as dry powder and admixed with grains in northern Ghana to protect stored cowpea, bambara groundnut, millet, sorghum and maize was *Cassia* species (Belmain et al., 1999; 2001). These plants, like many of the others used in Northern Ghana, are weeds and serve no other useful purpose. Based on the above studies, the Ghanaian Ministry of Food and Agriculture (MoFA) has identified 16 different plant species used by farmers for stored-product protection (Table 6).

Table 6 Plant species used by farmers to protect food stuffs against pest infestation in Ghana.

Azadiracta indica	*Ocimum americana*
Capsicum annuum	*Pleiocapa mutica*
Cassia sophera	*Pterocarpus erinaceus*
Chamaecrista nigricens	*Securidaca longepedunculata*
Citrus sinensis, Combretum sp.	*Synedrella nodiflora*
Cymbopogon schoenanthus	*Chromolaena odorata*
Khaya senegalensis	*Vitellaria paradoxa*
Lippia multiflora	*Mitragyna inermis*

Plant materials from several families including Annonaceae, Piperaceae and Rutaceae are used for the protection of stored products against insect pests in Nigeria (Okonkwo, 2004). Of the several families identified to have insecticidal properties only a few in the genera *Azadirachta, Citrus, Dennettia* and *Piper* have been sufficiently tested in the laboratory to provide an indication of their potential usefulness as stored-product protectants.

Botanical products are an essential part of post-harvest pest control in East Africa (Kokwaro, 1976; Weaver et al., 1994). The commonly used grain protectants in East Africa particularly Kenya and Tanzania include *Ocimum* spp., *Eugenia aromatica, Bascia* spp., *Tagetes* spp., *Tephrosia vogelis*, *Azadirachta indica*, *Eucalyptus* spp., and *Lantana camara.* Over 450 botanical derivatives are used in traditional agricultural systems in India with neem as one of the well-documented trees, in which almost all the parts of the tree have been found to have insecticidal value. The use of neem leaves and powdered kernels in managing pests of stored grains is an ancient practice in India. Turmeric, garlic, *Vitex negundo*, glyricidia, castor, Aristolochia, ginger, Agave Americana, custard apple, Datura, Calotropis, Ipomoea and coriander are some of the other widely used botanicals to control and repel crop pests (Saxena et al., 1992).

Clearly, there is adequate information on the use of plants by farmers in Asia and sub-Saharan Africa for stored-product protection. Undoubtedly, there are many plants used as grain protectants by rural communities, which are yet to be identified and characterised. To encourage local production of plant protectants it is essential that farm practices are recorded and more information acquired on the exact application procedures and formulations used by farmers. Currently, little or no information is available on how farmers apply plant protectants to protect their stored produce against pest infestation. This is because farmers are either unable to describe the procedures with sufficient accuracy or their accounts vary considerably from one farmer to another. Thus, research projects which pursue optimal methods of using plant protectants on grain must focus on the development of the most cost-effective procedures for application as well as identifying the biologically active components involved.

4.1. Application of plant materials at farm level

A number of surveys have been conducted in some countries in Africa to determine the methods and procedures by which small-scale farmers treat stored grains with plant materials (Hassanali et al., 1990; Belmain et al., 1999; Cobbina et al., 1999; Boeke et al., 2004). In most cases the dry whole leaves are placed as layers when undehusked maize cobs are stacked in cribs or other locally constructed storage structures. Milled dry leaves in the form of powder are also admixed with grains in storage. In addition, many rural farmers in Africa, particularly West Africa admix wood ashes of various plants with grains as a physical control treatment against infestation by storage pests. Rural farmers in some African countries also commonly use smoke from burning plant materials to protect on-farm stored cereal grains against pest infestation. Thus, farmers have different ways of preparing the botanicals as storage protectants. Some farmers prepare hot water extract of the plant, which they pour over their commodity or use as grain dip. Experiments in Northern Ghana have shown that, dipping durable produce into a hot water extract appeared to be more effective than admixing powdered plant materials (Belmain et al., 2001).

Currently, currently no standardized procedures are used by farmers with regards to methods and dosages of the plant materials that are applied. The precise strategy used by different communities varies from place to place and appears to depend partly on the type and perceived efficacy of suitable materials available in different localities. In some communities, the usage of plant materials is ethnically and culturally biased and this could be a constraint to the availability of indigenous knowledge systems. The efficacy or otherwise of the plant materials are also not determined by the farmers, nevertheless most rural farmers claim these materials are effective. Detailed information on the reliability and efficacy of botanicals with respect to where and when the plant materials are collected is also lacking. Plant secondary metabolites are well-known to vary according to climatic, seasonal, geographical location and genetic effects. For example, in Ghana materials derived from neem collected from Upper East Region were generally found to be more potent than those from Northern Region (Belmain et al., 1999).

4.2. Vegetable oils as storage protectants

The use of plant oils including, vegetable oils, essential oils and mineral oils by rural farmers in sub-Saharan Africa for the control of durable stored-product pests is an ancient practice (Obeng-Ofori, 1995). Examples of the commonly used plant oils by small-scale farmers include coconut, palm oil, groundnut oil, cotton seed oil and soybean oil. Others are sunflower oil, castor oil, sesame oil and mustard oil. Plant oils are usually mixed with grains such as maize, rice, wheat and cowpea. The mode of action of plant oils is not clearly understood. However, the protection of grains by oils could be due to both physical and chemical factors. The oils may kill the embryos of unhatched eggs or block the trachea of the insects and thus interfere with respiration. Plant oils could also act as antifeedant or modify the storage micro-environment, thereby discouraging insect penetration and feeding (Don-Pedro, 1989).

Plant oils are harmless to humans, are easily obtained and can be integrated with other control methods. Vegetable oils are the most commonly used cooking oils in Africa and are generally available in rural communities. The practical utilization of plant oils and botanicals as grain protectants is limited by the high rates of oil required to disinfect grain and the low persistence in grain. It had been demonstrated that pirimiphos-methyl and botanical insecticides can be used at reduced rates if combined with lower dosages of plant oils to control the infestation of stored-product beetle pests (Obeng-Ofori and Amiteye, 2000). Combination of lower doses of pirimiphos-methyl and neem oil provided adequate protection of maize stored in traditional cribs in Ghana against pest infestation (Table 7). Plant oils can also act as potentiation agents for botanicals by increasing their potency and persistence in grain (Obeng-Ofori and Reichmuth, 1999).

Table 7 Grain damage caused by *S. zeamais* and *P. truncatus* in maize treated with mixtures of neem oil and pirimiphos-methyl and stored in traditional cribs for 3 months in Ghana.

Pirimiphos-methyl (mg/kg)	Neem oil (mg/kg)	Weight loss (%)
2.0	0	0.1
0.5	1.0	0.6
0.5	2.0	0.5
1.0	1.0	0.2
1.0	2.0	0.1
0	5.0	2.1
0	0	7.5
LSD ($P<0.05$)	-	0.3

4.3. Challenges to the utilization of botanicals pesticides

Many plant species contain secondary metabolites that are potent against several pest species. Not only are some of the plants (e.g. the neem trees) of major interest as sources of phytochemicals for more environmentally sound crop protection, they can also play important role as instruments in the arena of global climatic changes. Some of the tropical trees are excellent carbon dioxide sinks. They are fast growing, tolerant to high temperatures and drought and can thrive well in degraded, eroded and acid soils. They can, therefore be useful in mitigating the process of desertification by serving as windbreaks, producing leaf-litter and fuel wood to poor rural communities where fuel is becoming a scarce resource (Obeng-Ofori, 2007). The tress can also help restore fertility to highly exhausted soils. Thus, these plants are valuable natural resource, which could be harnessed to advance sustainable economic development in the least developed countries of Asia and sub-Saharan Africa. Phytochemical products can provide environmentally sound pesticides, increase incomes of rural farmers and promote safety and quality of food and life in general.

There is no doubt that the successful utilization of botanicals can help to control many of the world's destructive pests and diseases, as well as reduce erosion, desertification, deforestation, and perhaps even control human population due to the anti-fertility action of some of them such as the neem (Obeng-Ofori, 2007). Although the possibilities of using botanical pesticides seem almost endless, so many details remain to be clarified. Many obstacles must be overcome and many uncertainties clarified before their potential can be fully realized. These limitations seem surmountable; however, they present exciting challenges to the scientific and economic development communities. Solving the following obstacles and uncertainties may well bring a major new resource which will benefit much of the world. These obstacles include:

- Lack of experience and appreciation of the efficacy of botanicals for pest control. There are still doubts as to the effectiveness of plant-derived products (both 'home-made' and commercial products) due to their slow action and lack of rapid knock-down effect
- Genetic variability of plant species in different localities
- Difficulty of registration and patenting of natural products and lack of standardization of botanical pesticide products
- Economic uncertainties occasioned by seasonal supply of seeds, perennial nature of most botanical trees and change in potency with location and time with respect to geographical limitations
- Handling difficulties as there is no method for mechanizing the process of collecting, storing or handling the seeds from some of the perennial trees
- Instability of the active ingredients when exposed to direct sunlight
- The usage of botanicals is still not held in high social esteem in many countries
- Competition with synthetic pesticides through aggressive advertising by commercial pesticides dealers and commercial formulated botanicals are more expensive than synthetic insecticides and are not as widely available
- Possible health hazards when seeds used in the preparation of the products are infected with the *Fungus aspergillus flavus* which produces aflatoxins, which is one of the most potent carcinogens known in the world.
- Rapid degradation, although desirable in some respects, creates the need for more precise timing or more frequent applications.
- Data on the effectiveness and long-term (chronic) mammalian toxicity are unavailable for some botanicals, and tolerances for some have not been established.

4.4. Field-based trials using botanicals

Active research is going on in several countries to determine the efficacy and practical utilization of locally available plants for controlling insect pests. These countries include India, Bangladesh, Pakistan, the Philippines, Japan, Rwanda, Nigeria, Ghana, Senegal, Benin, Kenya, Egypt, Israel, Germany, the Netherlands, UK and USA. However, the bulk of the trials are laboratory-based and usually of very short duration. They therefore do not reflect real farm conditions in the field. A few trials have been undertaken in the field in some developing countries which partially simulate on-farm conditions. The use of jute bags impregnated with 10% concentration of aqueous extracts from *Chenopodium ambrosiodes* and *Lantana camara,* to reduce infestation to cowpea and broad bean seeds by *C. maculatus* and *Acanthoscelides obtectus* (Say) was compared with direct seed treatment using plant powders at 4% (w/w) (Koona et al*.,* 2007). After 6 months storage, the jute bags impregnated with plant extracts were found to be more effective than seed treatment with plant powders in terms of reduction in seed damage. Application of *A. indica* (neem) seed extract at 8% by weight to wheat in jute bags in the Sind, Pakistan was considered to be as effective as 5 mg kg^{-1} pirimiphos-methyl, reducing insect populations after six months storage by 80% (Golob et al., 1999). Field trials conducted to control the larger grain borer, *P. truncatus* using extracts of neem leaves were found to be relatively unsuccessful in simulated storage experiments in both Tanzania and Ghana (Golob and Hanks, 1990). Treatment of maize with a commercial neem product (Calneem oil) and stored in on-farm cribs in Ghana protected the grain against insect pest infestation for two to five months (Tables 8 & 9)

Table 8 Protectant effect of Calneem oil and Actellic on damage caused by *E. cautella* to maize stored in the crib for 5 to 20 weeks in Ghana.

Treatment (mL/L)	**Weight loss ± SE (%)**			
	Time (weeks)			
Calneem oil	**5**	**10**	**15**	**20**
0.0	3.03±0.40	3.39±0.32	3.61±0.47	4.55±0.18
5.0	0.24±0.02	1.15±0.20	1.65±0.11	1.69±0.26
Actellic 2.0	0.18±0.01	1.20±0.15	1.15±0.03	1.23±0.15
LSD (P<0.05)	0.85	0.82	0.65	0.75

Table 9 Percent dry weight loss of maize caused by *E. cautella* after 60 days of storage using the count and weigh method.

Dosage (ml/L)	**Dry weight loss ± SE (%)**
Control	2.5±0.0
Hocklicombi	0.4±0.0
Novaluron	0.6±0.0
Neem oil	0.6±0.0
LSD (P<0.05)	0.9

4.5. Commercial development and use of botanicals for grain protection

Little information is available on the evaluation of a large number of plant species from a wide range of families for their potential as grain protectants. It had been suggested that the most promising botanicals were to be found in the families Meliaceae, Rutaceae, Asteraceae, Annonaceae, Labiatae and Canellaceae. In a comprehensive review references to trials using plant species from over 50 families were cited (Golob et al., 1999). The most numerous were in the families Compositae, Fabaceae, Labiatae, Leguminoceae, Solanaceae and Umbelliferae. From the evidence available to date the most promising candidate plant materials for consideration as future grain protectants are *Azadirachta*, *Acorus, Chenopodium, Eucalyptus, Mentha, Ocimum, Piper* and *Tetradenia* together with plant oils from various sources.

However, so far only products from four plant species have found widespread use as insecticides. Rotenone is obtained from *Derris* and *Lonchocarpus* species and was widely used during the early part of the century in England as an insecticide. *Derris elliptica* and *D. malaccensis* occur quite commonly in East Africa and China where the roots have been used as fish poison. Pyrethrum has been produced commercially for more than 150 years, with over 90% of the world's production coming from Kenya, Tanzania, Equador, Rwanda and Japan mainly for export. Neem is the only other plant from which several commercial products have been developed in different countries. Neem products are broad spectrum in activity and potent against over 300 species of insects, mites and some micro-organisms. They also have insecticidal, repellent, antifeedant, sterilizing and growth inhibition effects. Neem extracts have been found to contain several active ingredients including azadirachtin, memaliantriol, selamin, nimibin and nimbidin, which act in different ways under different circumstances (Schmutterer, 1990).

Over 100 neem-based products are marketed in India alone. Commercial neem-based products are marketed in a few African countries including Kenya, Benin, Nigeria, Senegal and Ghana. Currently a number of commercial neem products are also registered and marketed in some developed countries such as the USA, Germany, Australia, Italy, Switzerland, Sweden, Denmark, Austria, Spain and Israel (Foster and Moser, 2000). The only other plant to be exploited commercially is *Acorus calamus*. A preparation containing 70 percent β -asarone, is marketed by Alrich of Germany. It must be emphasized that before any of the botanicals can be commercialised even for local production and consumption, it must be shown to be safe.

4.6. Research needs

Clearly, there is enough information on the use of plants by farmers in Asia and Africa for stored-product protection. There are also undoubtedly, many plants used as grain protectants by rural farmers, which are yet to be identified and characterized. To encourage local production of plant protectants it is essential that farm practices are recorded and more information acquired on the exact application procedures and formulations used by farmers. There is often an erroneous assumption that plant compounds because of their natural source are innately safer. Some botanicals such as nicotine are as toxic to mammals as some synthetic pesticides (Weaver and Subramanyam, 2000). A largely neglected area has been the safety of botanicals from the point of environmental contamination. It must be emphasized, however, that for practical utilization of plant materials for stored-product protection further information is required on the residual effects of plant materials over a longer duration period of 6-12 months or more against key insect species, toxicity of the materials to non-target organisms, and local availability of appropriate extraction and application techniques. Of important research priority is well designed on-farm trials to validate the efficacy of plant materials under real farm conditions. Agricultural extension officers must also be trained in the practical utilization of plant materials to enable them transfer the technology to farmers. The development of appropriate infrastructure at the community level for the introduction of plant materials to be used as protectants is also necessary.

Botanical pesticide research is undertaken to find solutions to economic problems. Research efforts should therefore not focus only on their efficacy but also cost implications relating to processing, storage, extraction, formulation, product stability and application. Donor agencies must give priority attention to botanicals and support research projects which pursue optimal methods of using plant protectants on durable products at the farm level with the focus on the development of the most cost-effective procedures for application as well as identifying the biologically active components and establishing appropriate safety standards.

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