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CURRENT STATUS AND FUTURE PERSPECTIVES FOR INERT DUSTS FOR CONTROL OF STORED PRODUCT INSECTS

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Abstract

Inert dusts, particularly those based upon activated silicas, are finding increasing use as storage protectants in the grain industry. These materials can be classified into different groups depending on their composition and particle size. Non-silica dusts and those composed of coarse grain silicates, such as kaolin and sand, have been used traditionally as grain protectants by small-scale farmers in the developing world. More recently, materials including diatomaceous earths and silica aerogels, have been increasingly finding use in commercial storage in the developed world, replacing conventional chemicals.

These materials have been shown to control a variety of common storage insect pests. They are most effective in conditions of low humidity because they induce mortality by causing desiccation; water is lost because the dusts remove the waxy layer of the cuticle of the exoskeleton by adsorption. These materials are most effective when applied as dusts but some retain activity even when applied as a water-based slurry.

Modern dusts have overcome some of the health hazards as a result of inhalation, and concerns regarding abrasion of grain handling machinery are lessening. One modern dust, Dryacide, is used widely in Australia to treat the fabric of warehouse and grain handling machinery. However, this dust, like all others, affects the flow characteristics of bulk grain so cannot be used for treatment of grain in bulk storage and handling facilities.

Synthetic dusts are effective in controlling primary pests of cereals and pulses, including *Prostephanus truncatus*, the Larger Grain Borer, a new and important pest on African farms. Thus as well as being increasingly used in commercial farms, these materials may well replace conventional chemicals as protectants of stored grain in developing countries.

The paper examines recent research related to the use of inert dusts and discusses their potential for use in large-scale, commercial storage and in small-scale applications in the developing world.

Introduction

Inert dusts have been used traditionally as stored grain protectants. The Aztecs of ancient Mexico are said to have mixed maize with lime to preserve their grain (Quintana, R, *pers. comm.*). It is, however, only in the last fifty years that specific attempts have been made to commercialise these materials for use in modern grain protection technology.

These dusts primarily exert their effects on insects through physical means and, although they do not effect metabolic pathways by chemical action, they may well be chemically active under some circumstances. There are five groups of inert dusts which can be differentiated by their chemical composition or by their level of activity.

- *Non-silica dusts* include katelsous (rock phosphate and ground sulphur), lime (calcium hydroxide), limestone (calcium carbonate) and common salt (sodium chloride). For example, lime is layered with maize cobs in the Philippines and is also used to protect grain in Honduras (Golob and Webley, 1980); katelsous has been tested as a carrier dust for conventional insecticides in Egypt (El Halfaway and El Attal, 1973) though it possesses insecticidal properties as well (Mostafa and Al'Moajel, 1988; Fam *et al.*, 1974).

- *Sand, kaolin, paddy husk ash, wood ash* and *clays* constitute a group of materials which are used commonly by small-scale farmers in the developing world as grain protectants. Characteristically, large quantities, in excess of 5% by weight, are required for application in order to exert an effect (Golob and Webley, 1980).

- *Diatomaceous earths* (or *diatomite*) are the fossilized remains of diatoms, composed mainly of amorphous hydrated silica but having other minerals including aluminium, iron oxide, magnesium, sodium and lime. Sources of these dusts are either of marine or fresh-water origin; the former are said to be more effective. Diatomaceous earths of marine origin are effective against storage insects at about 0.1% (w/w) but commercially available products are often enhanced by other compounds, e.g. ammonium fluorosilicate; products of fresh-water origin require at least twice the dosage to produce similar levels of insect control (Subramanyam *et al., unpublished information*).

- Diatomaceous earths usually contain about 90% SiO_2 but very high quality *synthetic silicates* and *precipitated silicas* are now manufactured, which have a SiO_2 content of 98% or more. These purified compounds are both dense and expensive and have many industrial applications, including as anti-caking and free- flow agents, but not as grain protectants.

- *Silica aerogels* are produced by drying aqueous solutions of sodium silicate. They are very light, hydrophobic powders which are effective at lower rates than diatomaceous earths. The very low dust density has prevented the widespread application of these materials in the past because of the potential hazards which would occur as a result of inhalation.

In recent years, awareness of the consequences of environmental pollution, the increasing cost of storage insecticides and the growing problem of insect resistance has led to pest management specialists reappraising inert dusts. Unlike conventional contact insecticides, inert dusts function through their physical properties and are, therefore, generally slower acting (Maceljski and Korunic, 1972). Insect mortality is induced primarily as a result of desiccation: water loss is a consequence of the destruction of the cuticle. Silica aerogels adsorb the waxy particles from the cuticle surface (Maceljski and Korunic, 1972; Le Patourel, Shawir and Moustafa, 1989) and although diatomaceous earths, having small dense particles of silicon dioxide, were said to abrade the cuticle (Alexander, Kitchener and Biscoe, 1944), they also function by adsorption of wax (Ebeling, 1971). However, silica aerogels are more effective than diatomaceous earths or other inert dusts, retaining their activity even at elevated levels of relative humidity (Maceljski and Korunic, 1971). Because the action of these materials is not dependent on metabolic pathways it has been postulated that insects will not be selected genetically by the action of these dusts, so that physiological resistance will not occur. Nevertheless, it may be possible for insects to develop a behavioural response to the dust and avoid contact (Ebeling, 1971).

Another advantage over conventional insecticides is the low mammalian toxicity of these materials (e.g. for Insecto the acute oral rat $LD_{50} > 5000$ mg/kg; Subramanyam *et al.*, 1994). In the USA diatomaceous earths are "Generally Recognised as Safe" by the US Food and Drug Administration and are registered as food additives (Banks and Fields, 1995).

Studies on insect mortality and development

Various studies on the efficacy of inert dusts have been reported. Attapulgite-based clay dust was shown to control *Corcyra cephalonica* (Stainton), *Tribolium castaneum* (Herbst) and *Caryedon serratus* (Olivier) when applied to groundnuts at 0.5% (w/w) (Mittal and Wightman, 1989) and *Callosobruchus chinensis* (L.), *Sitophilus oryzae* (L.), *Oryzaephilus surinamensis* (L.), *Rhyzopertha dominica* (F.) and *Lasioderma serricorne* (F.) on other seeds (Varma and Siddiqui, 1977) . Activated kaolin clays (aluminium silicate) have been shown to be effective against a range of stored product beetle pests (Permual and Le Patourel, 1990; Swamiappan, Deivaval and Jayaraj, 1976). Silicophosphates at 1% and above have been found to control *Trogoderma granarium* Everts (Bhavnagary, Singh and Majumder, 1988). Hydrated amorphous silica has been found to control *Acanthoscelides obtectus* (Say) (Coulon and Barres, 1966). Several workers have used the commercial aerogel, Dri-Die, and found it provided good control against different storage pests including *Sitophilus granarius* (L.) (Maceljski and Korunic, 1971), *Tribolium confusum* J. du Val and *Oryzaephilus mercator* (Fauvel) (Loschiavo, 1988).

A relatively new diatomaceous earth of marine origin, Insecto, has been extensively assessed in the USA (Subramanyam *et al.*, 1994 and *unpublished data*). Dosages up to 0.15% (w/w) induced completely mortality of adult insects exposed to small quantities of treated wheat or barley in the laboratory. Secondary pest feeders, such as *O. surinamensis, O. mercator, C. ferrugineus* (Stephens) and *C. pusillus* (Schönherr) were particularly sensitive. Similar treatments to maize were not as effective, particularly against internal feeders including *S. oryzae* and *R. dominica.* These authors also found Insecto to be effective against larval stages of *T. castaneum, O. surinamensis* and *Plodia interpunctella*, reducing the percentage of adult emergence.

A recent study by McLaughlin (1994) compared the efficacy of several diatomaceous earths, silica aerogels and a synthetic silica, all of which are commercially available but which varied considerably in particle size. The fumed synthetic silica, Aerosil R974, was the most toxic when applied as a dust to wheat or as a dust application to aluminium surfaces. This material contains more than 99% SiO_2 and has relatively dense (50 g/l), small (0.012 µm) particles. Insecto and other diatomites, Perma-guard (fresh-water) and Insectigone (marine), all with SiO_2 contents varying between 80 and

90%, with heavier (350 g/l), larger (up to 20 μm) particles were very much less effective. The silica aerogel, Dri-Die, and the combined diatomite/aerogel, Dryacide, were intermediate in effect. These latter two materials were much more effective than all the others, including Aerosil, when applied in aqueous solutions as surface treatments. However, when applied as dusts, efficacy is clearly dependent on particle size.

The insects tested in McLaughlin' s work were *S. granarius* and *S. oryzae*. Of the common storage pests, *S. granarius* appears to be one of the most tolerant to inert dusts (Desmarchelier and Dines, 1987; Le Patourel, 1986). In contrast to the effects of neurotoxic contact insecticides, which induce rapid immobilisation and kill, the action of an inert dust is progressive and extended exposure to treated grain for 20 days or longer may significantly reduce dosages required to kill insect populations (see Figure 1; McLaughlin, 1994).

Exposure to inert dusts results in a loss of insect body weight mainly through water loss. Silica aerogels cause heavier mortality than diatomaceous earths (e.g. LaHue, 1970; McLaughlin, 1994) primarily because they result in much more rapid water loss. Relative humidity affects water loss and therefore determines the effectiveness of inert dusts. Maceljski and Korunic (1972) found that the presence of Dri-Die (95% silica aerogel + 5% ammonium fluorosilicate) prevented the regeneration of the waxy layer of the epicuticle altogether but that removal of the aerogel allowed regeneration to occur, particularly at elevated humidities.

The effect of relative humidity is directly related to that of grain moisture content (mc). Le Patourel (1986) exposed *S. granarius, O. surinamensis* and *T. castaneum* and to wheat having 9-18% moisture content, treated with a precipitated silica dust, Sipernat 22S (Figure 2). Against *S. granarius,* at 16% mc, a 37-fold increase in dosage was needed to give a seven-day LD_{50} compared to the dosage required at 11% mc; for the other species, a 6-8 fold increase was required. Fam *et al.* (1974) similarly found that mortality of *S. oryzae* decreased as the moisture content of wheat, treated with either Dri-Die or katelsous, increased. McLaughlin (1995) has identified the safe storage limits for the use of Dryacide as a long-term (12 months or more) grain protectant as: wheat, oats and barley, 12% mc; sorghum and maize, 13% mc; and paddy 14% mc.

Le Patourel (1986) found that, in the absence of food and inert dust, insect mortality decreased as the relative humidity increased but that when provided with food all the species were able to counteract the effects of humidity (e.g. Figure 3). In a similar manner, Vrba, Arai and Nosal, (1983) found that food consumption enabled *T. confusum* to resist the effects of inert dust. They exposed adults for up to five hours to Aerosil 380, a fumed silica, and then either fed the beetles or deprived them of food for a further 25 days. Mortality was significantly lower in beetles which were fed, implying that death induced by inert dusts is not solely due to wax adsorption and desiccation. White and Loschiavo (1989) also showed that access to food increased the chance of survival of adult *T. confusum* and *O. mercator.* Le Patourel (1986) suggests that, whilst feeding, the individual may be able to compensate for the water loss by the production of metabolic water, which would not be produced whilst the insect is deprived of food or simply unable to feed.

The effect of temperature on inert dust activity is not well documented. Aldryhim (1990, 1993) found that *S. granarius* and *R. dominica* are more susceptible at 30°C than at 20°C but *T. confusum* was more susceptible at the lower temperature. In Australia, Nickson, Desmarchelier and Gibbs, (1994) have used inert dust in combination with cooling to provide control of beetles in bins of wheat in commercial storage.

Commercial application of inert dusts

Field trials in the USA in the 1960s and 1970s showed that long term protection of maize and wheat could be provided by diatomaceous earths or silica aerogels (Quinlan and Berndt, 1966; Redlinger and Womack, 1966; Strong and Sbur, 1963; LaHue, 1965; 1967; 1977; White *et al.*, 1966). Diatomaceous earths were more effective, in terms of the volume of dust to be applied, though for 12 months protection a dosage of 0.35% (w/w) was necessary. However, diatomite has generally been found to be unacceptable commercially because it was seen to abrade handling machinery and so increase wear. Silica aerogels provided similar long-term protection at 0.04-0.1% (w/w) but these were very light, tended to float in air and could have caused respiratory illnesses. Although Loschiavo (1988) developed a method for cementing silica aerogel to solid substrate with no significant loss of activity, use of inert dusts for storage protection has not really developed in the USA because of these potential complications.

The development of resistance in stored-grain insects to organophosphate insecticides registered for use as grain protectants has led, in the USA, to a search for newer diatomite formulations which might replace conventional chemicals. Insecto is a new diatomaceous earth which was registered by the United States Environmental Protection Agency in June 1984 for application to grain at 0.5-1.0 g/kg and to empty grain stores at 5 g/m² (Subramanyam *et al.*, 1994). Despite the ability to effect reasonably good control against a series of insect pests (see above), small scale trials with Insecto-treated wheat (lots of 109 kg) stored in metal bins showed that significant numbers of live adult *R. dominica* and *S. oryzae* were continually found in samples collected for up to 250 days after insects were introduced to the grain. These observations were contrary to laboratory data which demonstrated that these species exhibited 100% mortality when exposed for seven days to wheat treated with 0.05% Insecto. The authors, who also obtained excellent control when the adults were exposed to treated plywood, postulated that the reduced mortality in the small bins may have been due to poor distribution of the dust throughout the grain bulk, allowing insects to survive in areas of low dust concentration. However, the grain sustained sufficient damage to warrant downgrading in terms of the US Federal Grain Inspection Standard, so that further improvement in control must be achieved if the treatment is to become commercially viable.

In Australia, inert dusts are being used on a very large scale, in the grain industry. This is primarily due to the development of Dryacide, a diatomaceous earth which is modified with a silica gel coating. In small-scale trials, Desmarchelier and Dines (1987) found 100% adult mortality of *R. dominica, T. castaneum* and *S. oryzae* could be achieved at 25°C and 65% rh with 0.1% (w/w) Dryacide, but that *S. granarius* was more tolerant and required up to twice the dosage; similar rates of application controlled F1 progeny. By applying a layer of 100 g of wheat containing 0.1% (w/w) Dryacide over 900 g of wheat infested with eggs of *Ephestia cautella* (Walker), development of the adult population was suppressed by 97% in comparison with the control; this 'mothproofing' method has found commercial application in wheat stores.

Dryacide is used widely in storage sheds and silos, as a structural treatment. However, because it alters the angle of repose, bulk density and flow characteristics of grain it finds little use outside the farm storage system for direct treatment of bulk grain. Its use in bulk handling systems in Australia has been prohibited; similar problems have been encountered with Insecto and other diatomaceous earths in the USA (Subramanyam *et al.*, 1994 and *unpublished data*). Jackson and Webley (1994) found that as little as 0.05 and 0.02% (w/w) Dryacide significantly reduced the bulk densities of wheat and maize; other crops including barley, rye and pulses were similarly affected, though grain size was not related to the observed changes (Table 1). Other inert dusts, including Cabosil (synthetic silica), diatomite and Amosil (paddy husk ash), also reduced bulk densities. Flow rates of maize and hard wheat were reduced by nearly 40% and 22%, respectively, by addition of 0.05% Dryacide. It was clear that, even given a 20-fold reduction in rates of application required to exert biological control, the effects on the physical properties of grain remain a major problem which has to be overcome if inert dusts are to gain greater acceptance in the grain industry.

Recent work in Western Australia has allayed the fears regarding machine abrasion to some extent. Tests, in which a paddle agitator operated in a closed chamber to which Dryacide dust had been added, resulted in the bearing of the paddle-shaft sustaining very small loss due to abrasion, not sufficient to adversely affect performance, when stripped down and examined after 200 h of operation (McLaughlin, *pers. comm.*)

In recent years, the effectiveness of conventional contact insecticides as fabric treatments for grain stores has been called into question (Gudrups, Harris and Dales, 1994). Dryacide has replaced these compounds and is now widely used in Australia for structural treatment in wheat and rice stores (Desmarchelier, Wright and Allen, 1993). It is applied either as a dust at 2 g/m^2 or as a 10% aqueous slurry to provide 6 g/m^2. Dust application is confined to grain-handling machinery, ducts and vertical silos, and slurries are applied to horizontal grain stores. Slurries are particularly useful where there is a need for personnel to avoid exposure to very dusty atmospheres which would be created if the dry dust was applied. Although Dryacide remains sufficiently active to exert control when applied as an aqueous suspension, other inert dusts loose their efficacy when applied in this way (Maceljski and Korunic, 1971; McLaughlin, 1994).

Small-scale use of inert dusts

If added in sufficient quantities, sand or wood ash can effectively protect grain stored in small lots on traditional African farms (Golob *et al.*, 1982). The quantities must be as much as 20% or more, in order to submerge the grain almost completely, since the greater the amount applied, the more effective the protection (Figure 4). Although the abrasive properties of the materials may play some part in preventing the development of pests, it is more likely that the dusts inhibit insect behaviour, affecting movement and reproduction by blocking air spaces between grains.

Locally-available dusts will continue to play an important role as grain protectants in farm stores in Africa and developing countries in other parts of the world because of their low cost and because they are readily available. However, such methods will remain for small-scale use only, particularly for the preservation of small quantities of seed grain, because of the excessive quantities of dust required. Furthermore, removing the dusts in order to process grain for consumption can be tedious. These dusts are therefore being replaced by methods which either require smaller quantities of material or use materials that do not need to be removed before the grain is consumed. Berrato *et al.* (1983) in laboratory studies with beans in Brazil and Golob *et al.* (1982) in small-scale simulated field trials with maize in Malawi showed that dolomite at application rates of 1% (w/w) or less could protect the commodity against insect pest damage. Paddy husk ash, which contains a high proportion of silicates, has also been found to be an effective protectant when admixed with maize at 1% (Golob and Hanks, 1990). The effectiveness of vegetable oils and powdered dried plant parts, which do not need to be removed before milling or cooking, is being investigated by many workers; oils and botanical insecticides have also been used as traditional protectants (Golob and Webley, 1980; Rees, Dales and Golob, 1993).

It is possible that use of sand and ash could be supplanted by the more efficient silica-based dusts discussed above, if they were cost effective. Research is being undertaken to assess the potential of using synthetic silicas, diatomaceous earths and aerogels as grain protectants in Africa. For example, laboratory experiments in Zimbabwe (Giga and Chinwanda, 1994) showed that Dryacide at 0.2% (w/w) caused more than 90% mortality of two major pests of stored beans, *Acanthoscelides obtectus* (Say) and *Zabrotes subfasciatus* (Boheman) within two days of exposure and completely prevented the emergence of an F1 generation. Other experiments undertaken at the Natural Resources Institute (NRI) in the UK (K. Adesalu, *unpublished data)* showed that Dryacide at 0.125% and Gasil 23D (a synthetic silica) at 0.05%, applied to cowpeas and red kidney beans, could induce 100% mortality of *Callosobruchus maculatus* and *A. obtectus* and prevent progeny production when adults were exposed to the pulses nine months after treatments were applied.

In recent years, *Prostephanus truncatus* (Horn) has become a major pest of stored maize and dried cassava in Africa. This beetle is indigenous to meso-America but was introduced to Africa about 15 years ago. It is responsible for causing losses that are as much as five times greater than those due to indigenous insect pests. Consequently, much effort has been expended to develop measures with which to control it. Inert dusts have begun to show significant promise to this end. In Mexico, volcanic ash from Mt. Chichonal produced good control of *P. truncatus* when applied to maize at 1% (Sanchez Arroyo, Lagunes Tejeda and Llanderal Cazares, 1989). These same workers and Hoppe (1986) found that 1% lime was also an effective protectant for three months but by six months storage the damage sustained by maize was very heavy; lime is commonly used as a storage protectant in Mexico and Central America because it is cheap and widely available.

A series of precipitated and fumed silicas were screened at NRI and found to be effective in causing mortality of adult *P. truncatus* (Barbosa *et al.*, 1994). The persistence of two of the dusts, Gasil 23D and Aerosil R972, was then assessed over 40 weeks, a period equivalent to a storage season in much of tropical Africa. Table 2 illustrates the results, which demonstrated the potential of these dusts for long-term storage. Very few progeny emerged from any of the four dosages applied. In other experiments at NRI, Gasil 23D was found to be much quicker acting than Dryacide, 100% adult mortality was obtained within 48 h exposure to 0.1% compared with 95% mortality only after14 days exposure to 0.15%, whereas a 48 h exposure to Dryacide resulted in 45% mortality. Even so, Dryacide was much more effective than a standard diatomaceous earth obtained from Kenya, Kensil F, which produced only 3% mortality after 28 days when adult *P. truncatus* were exposed to maize with 0.5% dust (J.N. Mbugua, *unpublished data*). Unpublished data by Subramanyam *et al.*, showed that Insecto was also not particularly effective in causing adult mortality and that as much as 0.5% (w/w) was required in order to approach 100% kill. However, lower dosages of 0.1 and 0.15% did significantly restrict the development of progeny.

Preliminary simulated field trials have been conducted in Ghana to assess the potential of Gasil 23D and Dryacide as protectants of maize against *P. truncatus* infestation. Batches of 10 kg of maize grain or husked maize cobs were treated with the two dusts at 0.1% or 0.2% (w/w) on grain and 0.2% or 0.4% on cobs, and examined after 3 and 6 months storage in jute sacks. Weight loss of stored grain after three months was about half that on controls for both treatments. After six months Gasil-treated grain was less damaged than untreated grain but there were no differences between Dryacide-treated grain and controls. One factor which may have masked any effect of Dryacide was the high variability in the data. Furthermore, during the latter period of the trial the ambient relative humidity increased with the onset of the rainy period which may have reduced the efficacy of the dusts. Although Desmarchelier and Dines (1987) have shown Dryacide to be effective even at 65% rh, it is likely that on many days the ambient rh in Ghana was considerably in excess of this. Undoubtedly, climatic conditions will play an important role in determining the efficacy, and therefore the usefulness, of inert dust in tropical environments and more work is needed to define conditions where they could be used successfully.

Future prospects

Environmental concerns are facilitating growth in the use of synthetic inert dusts, such as Insecto and Dryacide, particularly in Australia. Recently, a desiccant dust has been approved there as a protectant of stored paddy in order to conform to 'organically grown' produce requirements (McLaughlin, 1994). No doubt, the use of these dusts will continue to grow for those applications which do not depend on grain handling properties. However, the need for relatively large dosages, in comparison with conventional insecticides, that affect the physical properties of grain, will remain a drawback to the expansion of their use for large-scale applications.

The application of amorphous silica presents a minimal health hazard but inhaled dusts which contain crystalline silica can result in silicosis and other respiratory diseases such as emphysema and pneumoconiosis. Rats, whose lungs were exposed to 5-80 mg of naturally-occurring diatomaceous earth, showed little reaction but a strong reaction to material which had been calcined, that is crystallised by exposure to high temperatures (work cited by Quarles, 1992). Diatomite of marine origin, although being more biologically active against insects, frequently contains high quantities of crystalline silica; some marketed materials may contain up to 60% (Quarles, 1992). Clearly, there is little future for dusts which contain crystalline silica so that the incorporation of more marine diatomite into commercial formulations, in order to increase efficacy, may be difficult to achieve

Although particle size is a key factor in determining efficacy, the dusts with smaller particles, such as Aerosil R974, are considered to be respirable dusts and therefore represent a potential health hazard to users. However, Dryacide, Insecto and other dusts with larger particle sizes, comparable to those of dust formulations of conventional insecticides, do not suffer from this problem. Nevertheless, applying large quantities of dust requires care and the wearing of appropriate face masks to prevent inhalation. The USA Environmental Protection Agency regards these materials as safe and has permitted registration of Insecto for use on stored grain and grain-handling facilities. Similar approval for Dryacide is imminent.

The introduction of aqueous-based slurries, eliminating the need for dust applications, will continue to expand for fabric treatment of stores under conditions of low relative humidity. However, in countries where there are no stringent requirements for very low tolerances of insects, such use of inert dusts will probably not be cost-effective.

There are indications that these dusts may find further use in more novel treatment methods, such as in association with aeration systems. For example, in Australia, Dryacide is applied as a thin surface coating to grain in silos for enhancing the effect of fumigation with the SIROFLO system (Winks, 1993). The dust, added at 100 g/m^2, acts as gas barrier, reducing the rate of loss of gas through the top layers of grain so allowing open topped silos to be fumigated successfully (Winks and Russell, 1994).

Cost-efficiency will be the overriding concern if these dusts are to be introduced for small-scale applications. For the subsistence farmer, local available materials are likely to be used for the foreseeable future as grain protectants. Diatomites and silica aerogels may find a niche with progressive farmers as alternatives to conventional insecticides; they will provide additional options for control when access to synthetic insecticides becomes difficult or when prices rise. Even now, such compounds as Dryacide are cost-competitive with organophosphorus insecticides and they are as effective for many farm-storage requirements. With the ever-increasing emphasis on reduction of environmental contamination, inert dusts (with very low mammalian toxicity) will play a significant role in replacing synthetic conventional chemicals as grain protectants.

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Table 1. Change in bulk density (kg/hl) for a range of commodities treated with Dryacide

Dust (g/t)	Maize	Hard wheat	Barley	Chickpea	Sorghum
0	78.3	80.5	73.5	75.7	78.2
50	75.3	78.7	71.3	73.7	77.3
200	73.3	75.8	69.5	72.2	76.2
500	71.3	74.3	68.2	71.2	75.3
Change %	8.9	7.7	7.2	5.9	3.7
Seeds/g	3.9	29	24	5.4	36

From: Jackson and Webley, 1994

TABLE 2 - Percentage mortality of unknown age adults of *Prostephanus truncatus* after exposure to maize treated with activated silicates

Silica	Conc. (%w/w)	Duration of exposure to treated grain							
		24 hours				48 hours			
		Time (weeks) between treatment of grain and exposure of adults							
		0	13	20	40	0	13	20	40
Gasil 23D	0.1	82	81	64	70	97	100	94	95
	0.2	94	87	86	80	100	98	98	96
Aerosil R972	0.1	22	23	4	6	98	100	97	99
	0.2	44	51	9	12	99	100	100	100

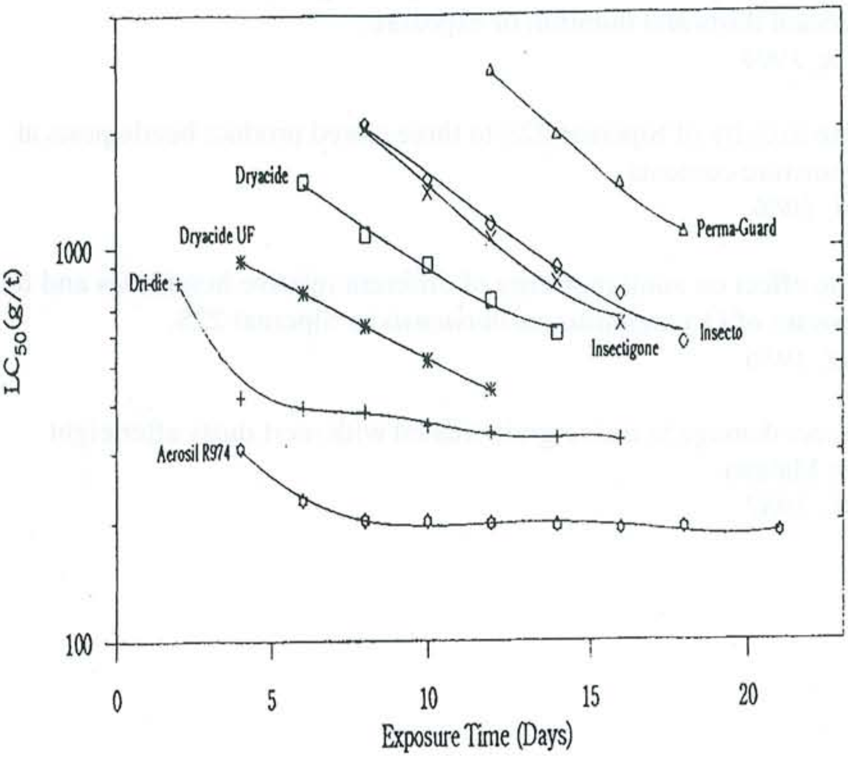
Each datum represents the mean of four replicates.
Control mortality was less than 3% throughout.
From: Barbosa *et al.*(1994)

Figure 1. Relationship between LC50 of *Sitophilus granarius* on wheat treated with various desiccant dusts and duration of exposure.
From McLaughlin, 1994

Figure 2. The toxicity of Sipernat 22S to three stored product beetle pests at different wheat moisture contents.
From LePatourel, 1986

Figure 3. The effect on adult mortality of different relative humidities and food after a 7-day exposure of *Oryzaephilus surinamensis* to Sipernat 22S.
From Le Patourel, 1986

Figure 4. Insect damage to maize grain treated with inert dusts after eight months storage in Malawi.
From Golob et al., 1982



Dryacide
Dryacide UF
Dri-die
Aerosil R974
Perma-Guard
Insectigone
Insecto
1000
100
LC_{50}(g/t)
0
5
10
15
20
Exposure Time (Days)