Field and laboratory experiments with Protect-It™, an enhanced diatomaceous earth, in P.R. China

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Abstract

The effectiveness of Protect-It™, an enhanced diatomaceous earth (DE), was studied under field and laboratory conditions in Sichuan and Guangdong provinces, P. R China, in 1997 The tests were conducted using three stored-grain insect pests in paddy rice and wheat

The insect species used in the experiments were maize weevil (*Sitophilus zeamais* Motsch.), red flour beetle (*Tribolium castaneum* Herbst) and lesser grain borer (*Rhizopertha dominica* F) The test grains were soft wheat, produced in Sichuan (12.0% m c), No 1 Canada Western Hard Red Spring wheat (12.0% m c.) and paddy rice, produced at Sichuan and Guangdong provinces (12.9% m. c.). The commodities were treated with Protect-It™, produced in Canada, or Fenitrothion 65% EC (fenitrothion), produced in China, and were compared against untreated controls.

The conditions at the Sichuan grain storehouse ranged from 24.0 to 28.0℃ with 66 to 76% relative humidity (rh) At Guangdong, the air temperature of the wheat storehouse ranged from 26.0 – 30.5℃ and the relative humidity ranged from 69 to 88% The paddy rice storehouse ranged from 27.0 to 31.0℃ with relative humidity ranging from 69 to 92%.

The bioassay results for both field-treated and laboratory-treated grain showed good residual activity for Protect-It™ Protect-It™ controlled (more than 90% mortality) maize weevil at both test sites with a dose rate of 500 ppm and an exposure of 21 days. Concentrations of 500 ppm in paddy rice showed control of lesser grain borer for the majority of samples (700 ppm gave control for all samples) In comparison, 500 ppm of Protect-It™ on wheat controlled lesser grain borer in only 2 out of 10 cases, after 21 days

Application rates of 500 ppm gave control of red flour beetle for a majority of wheat samples and in all samples of paddy rice It was concluded that the variability in the efficacy of Protect-It™ in the field-treated grain primary was due to its uneven distribution within the grain mass and the loss of Protect-It™ to air during treatment

The highest tested concentrations of Protect-It™ on both wheat (500 ppm) and paddy rice (700 ppm) gave efficacy results similar (no significant difference) to 8 ppm of Fenitrothion 65% EC The only exception was for the lesser grain borer on wheat where Fenitrothion was more effective than Protect-It™ Protect-It™ concentrations which controlled adult insects substantially reduced the progeny (over 90 to 100%) of all three tested species on both commodities

Introduction

Diatomaceous earth, which is composed almost entirely of amorphous silicon dioxide, is formed from fossilised diatoms. Amorphous silicon dioxide is non-toxic to mammals (Anon , 1986) and registered in many countries as a food additive (Anon., 1981, 1991). DE is probably the most efficacious natural dust used as an insecticide DE adheres to the body of the insect and damages the protective waxy layer of the insect cuticle by sorption, and to a lesser degree, by abrasion

The result is the loss of water from the insect's body resulting in death (Ebeling, 1971) DE is also known to repel insects (White et al., 1966).

The grain industry wants to reduce its reliance on synthetic insecticides because of increased government regulation (de-registration of insecticides), developing insect resistance to insecticides and growing consumer concerns over insecticide residues (Subramanyam et al 1994). One alternative to chemical control of stored-grain insects may be diatomaceous earth DE has long been known, as a potentially useful grain protectant because it is safe to use, does not affect grain end-use quality, provides long-term protection and is comparable in cost to other methods of grain protection

Most DE research has centred on the field of protection of stored agricultural products The effect of diatomaceous earth from different sources on various stored product insects has been studied by numerous researchers (Korunic,

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1998) Although different and sometimes contradictory results have been obtained, general conclusions about the sensitivity of stored product insects to DE were in agreement with results obtained by Korunic et al (1997) Given the same commodity, there was a significant variation in species susceptibility to Protect-It™, in order of most susceptible to least: rusty grain beetle > saw toothed grain beetle > granary weevil > rice weevil > lesser grain borer > red flour beetle > larger grain borer The concentrations required to achieve 90% reduction of offspring were similar or, in some cases, significantly higher than the concentrations required to reduce parent populations by 90%

DE efficacy also varies by the commodity treated. Korunic et al. (1997) showed that efficacy by commodity, in order of the highest to lowest dose (LD_{50}) was: rice > corn > oats > barley > wheat

Until recently, DE use has been limited because the required dose rates of 1000 to 3500 ppm (parts per million) for most DE products significantly reduced grain bulk density, flowability and left visible dust residues (Golob, 1997). Hedley Technologies Inc., in conjunction with Agriculture and Agri-Food Canada, Cereal Research Centre (Winnipeg, Canada) has developed a new diatomaceous earth-based insecticide, Protect-It™, that can be used at lower concentrations with acceptable efficacy against insects and with reduced adverse effects on grain handling and bulk density (Korunic and Fields, 1995)

Because of its mode of action, the efficacy of diatomaceous earth is greatly dependent on grain moisture content and temperature which are in turn affected by prevailing ambient air relative humidity and temperature. Grain of higher moisture content, especially above 14%, reduces the efficacy of DE (Korunic and Fields, 1998) The local grain type, moisture content, air relative humidity and insect species must be considered when determining the appropriate application dosage for a given DE formulation.

The objectives of this study were to: (a) determine the concentrations of Protect-It™ needed to control maize weevil, lesser grain borer and red flour beetle on wheat and paddy rice under field conditions in P. R China, and (b) compare the concentrations of Protect-It™ needed to control test insects on laboratory treated wheat and paddy rice with the concentrations found to control the same insect species under field conditions.

Materials and Methods

The effectiveness of Protect-It™, an enhanced diatomaceous earth (EDE), was studied in 1997 under field and laboratory conditions in Sichuan and Guangdong provinces, P. R China. The tests were conducted using three stored-grain insect pests on paddy rice and wheat. The insect species used in the experiments were: maize weevil (*Sitophilus zeamais* Motsch), bred in the laboratory at 25℃ and 60% relative humidity, and red flour beetle (*Tribolium castaneum* Herbst) and lesser grain borer (*Rhizopertha dominica* F.) bred at 30℃ and 70% rh. All insects were 1 – 2 weeks old at the time the tests were initiated.

Two insecticides were tested: Protect-It™, produced in Canada, and Fenitrothion 65% EC (fenitrothion), produced in China.

Site Guangzhou, Guangdong Province

Field tests

Grade No. 1 Canada Western Hard Red Spring wheat, with 12.0% moisture content, was treated with Protect-It™ at the rates of 200 ppm, 300 ppm and 500 ppm and Fenitrothion at 8-ppm (2 L of 0.4% suspension per tonne). Each treatment consisted of a single 1 tonne bagged lot of wheat. After the Protect-It™ or Fenitrothion was mixed with the wheat manually, the treated wheat was put into bags and stacked. The bags were stacked separately by treatment with gaps left between the individual treatment stacks according to the available space. One tonne of untreated wheat was put into bags and stacked in a manner similar for the treated wheat

Paddy rice produced locally in Zhejiang province, (12.9% m c), was treated with Protect-It™ at the rates of 300 ppm, 500 ppm and 700 ppm and Fenitrothion at 8 ppm. Treatment lot sizes and application methods were similar to those used for the wheat experiments

The test insects (1 insect/species/kg grain) were introduced around the stacked bags on the same day the treatments were applied.

One 1 kg sample was taken from each stack at 14, 25, 42, 56, 70, 84 and 98 days after the introduction of insects. The samples were sieved, and the dead and living insects were counted and recorded.

Tests with storehouse-treated grain

One 3 kg sample of grain taken from each treatment stack was brought to the laboratory every month to evaluate the residual activity of the insecticide treatments Each 3-kg sample was divided into 9 jars and 50 adults of a single insect species were introduced into each jar. There were 3 jars for each insect species. Dead insects were counted 21 days after the insects were first added to the jars.

Tests with laboratory treated grain

Wheat and paddy rice (same as material used in field tests) were weighed in 500 g portions and put into 1000-ml jars. The wheat was treated with Protect-It™ at the rates of 200, 300 and 500 ppm and Fenitrothion at 8 ppm The paddy rice was treated with 300, 500 and 700 ppm of Protect-It™ and 8 ppm of Fenitrothion The appropriate amount of insecticide was added to each jar and the jars were capped and shaken for 2 minutes. In the case of

Fenitrothion, 4500 g of either wheat or paddy rice was treated first and then separated into jars (500 g/jar) There were nine jars per treatment.

One day after the insecticide application, 50 adults of either maize weevil, lesser grain borer or red flour beetles were introduced into the jars. There was one species per jar and 9 jars for each insect species (3 jars for each dose rate) The top of each jar was sealed with a piece of cloth to allow the passage of air, but prevent the escape of insects.

As controls, 500 g of untreated wheat or paddy were put into 9 – 1000 ml jars The test insects were introduced into the jars with 50 insects/jar and 3 jars for each insect species. The top of every jar was sealed with a piece of cloth

All jars were kept in the lab for 8 weeks at 26 to 29℃ and 70 to 82% R. H. The first assessment was made 14 days after the initial treatment. Subsequent assessments were made once every week for a total of 7 assessments The laboratory test commenced 10 June 1997.

Sites Chengdu and Majia Grain Stations, Xindu County, Sichuan Province

Field tests

The wheat used in the tests was newly harvested local soft wheat of low quality (12.0% m. c.). The paddy rice was also locally produced and had a moisture content of 12.9% Wheat in 1 tonne lots was treated with Protect-It™ at the rates of 200, 300 and 500 ppm and with Fenitrothion at 8 ppm. Similar sized lots of paddy rice were treated with Protect-It™ at 300, 500 and 700 ppm and Fenitrothion at 8 ppm There were three replications per treatment except for the Fenitrothion treatments in which there were two for each of wheat and paddy rice

The insecticides were applied by placing 1 tonne of grain on the floor and having two people mixing in the appropriate insecticide using spades. The treated grain was then put into 8 flex-bags, which were placed in a semi-circle adjacent to a wall. The remaining grain was piled into the enclosure formed by the bags and the wall.

Two-1000 kg portions of untreated wheat or paddy were used as comparisons with the treated grains

After treatment, 500 maize weevil, 300 red flour beetle and 200 lesser grain borer were introduced to each treatment replication and control.

Temperature detectors were installed both in the upper and lower parts of each replicate grain pile. The grain and air temperatures and air relative humidity in the grain storage house was recorded when the experiment began The grain temperature was monitored once per month and the moisture content was checked each time, samples were taken for bioassay (monthly)

Thirty days after the initial treatment, three composite 1-kg samples were taken from the bags and from the top, middle and bottom of the bulk of each replication Two samples were used in the lab to set up laboratory bioassays and one sample was sieved with a 2.5-mm sieve to separate the insects from the grain. Dead and living insects were counted and recorded. The same procedure was repeated monthly, from June to October 1997

Tests with storehouse-treated grain

The composite samples obtained from the granaries (see previous section) were combined, separated into 9 equal portions and put into 9 jars. Insects were introduced, 50 insects/species/ jar, and there were three replications per insect species. The jars were kept in the lab at a controlled temperature of 28℃ and a relative humidity of 70% After 21 days, the number of dead insects was recorded.

Tests with laboratory treated grain

Wheat and paddy rice were weighed in 500 g portions and put into 1000-ml jars The wheat was treated with Protect-It™ at the rates of 200, 300 and 500 ppm and Fenitrothion at 8 ppm (1-ml). The paddy rice was treated with 300, 500 and 700 ppm of Protect-It™ and 8 ppm of Fenitrothion The appropriate amount of insecticide was added to each jar and the jars were capped and shaken for 5 minutes.

The jars were let stand for 2 minutes after treatment before 150 specimens of a single insect species were introduced in each per jar There were 3 replications/ insect/treatment, where a treatment consisted of either wheat or rice and specific application of insecticide. All three insect species were tested.

Control jars were set up for comparison using 500 g of wheat or rice per 1000-ml jar. Each species of insect was tested in three control replications. All jars were sealed with cloth and placed in the lab at a controlled temperature of 28℃ and a relative humidity 70% Efficacy was assessed weekly

Results and Discussion

Cross-infestation effects

Because there were no insect barriers between field treatments (1 tonne stacks or piles), certain results were likely affected by the cross-infestation of treated lots in the storehouses. Insects could have dispersed from the untreated grain to adjacent treated grain The effect of cross-infestation was especially noticeable for the 84th and 98th day samples at the Guangdong site (Table 1) and the 60th and 90th day samples days at the Chengdu site (Table 6).

Because Protect-It™ is relatively slow acting, it is possible that some of the live insects recorded in the bioassays were more recent introductions originating from the untreated controls. However, in spite of the possible cross infestation, the number of live insects, especially at higher concentrations of Protect-It™ and on Fenitrothion treated grain, were almost always much lower than on untreated grain (Tables 1 and 6) The highest concentrations of Protect-It™ on wheat and paddy rice gave results comparable to 8 ppm of Fenitrothion

Laboratory efficacy results from field treated and lab treated grain (Tables 2 – 5 and 7 – 10) show higher efficacy than the grain where insects were introduced in the field This indicates that mortality could have been higher (especially for higher concentrations of Protect-It™) in the field if cross-contamination were not a factor.

Storehouse-treated grain

Maize weevil mortality was very high for the wheat and rice treated at both Guangdong and Chengdu when the grains were treated using the highest tested doses of Protect-It™ and 8 ppm of Fenitrothion (Tables 2,3, 7 and 8)

The mortality results for the lesser grain borer were more variable than for maize weevil. At the Guangdong site, the mortality of lesser grain borer on wheat ranged from 40.7% to 70 0% for the highest tested dose of Protect-It™ (500 ppm) and from 37.0% to 52.3% for 8 ppm of Fenitrothion (Table 2) For paddy rice in Guangdong, the mortality ranged from 91.9% to 100% and from 49% to 76.5% for Protect-It™ and Fenitrothion, respectively (Table 3). At Chengdu, the mortality for lesser grain borer on wheat ranged from 56% to 98.7% for the highest tested dose of Protect-It™ (500 ppm) and from 56.7% to 96.7% for Fenitrothion (Table 7) On paddy rice, the mortality ranged from 94. 7% to 98% for Protect-It™ and from 95 9% to 100% for Fenitrothion (Table 8)

At Guandong the mortality of red flour beetle on wheat ranged from 91.4% to 100% for the highest dose of Protect-It™ and 100% for Fenitrothion (Table 2) The mortality results for paddy rice at Guangdong were 96% to 100% for Protect-It™ and 100% for Fenitrothion (Table 3) At Chengdu site the mortality for red flour beetle in wheat ranged from 59.3% to 100% for the highest test dose of Protect-It™ and from 48% to 100% for 8 ppm Fenitrothion (Table 7) The mortality of red flour beetle on paddy rice at Chengdu was 100% for Protect-It™ and from 95.9 to 100% for Fenitrothion (Table 8)

For the majority of tests conducted in the laboratory on storehouse-treated grain (i e., 1 tonne lots with insecticides applied manually), 500 ppm of Protect-It™ on wheat and 500 and 700 ppm of Protect-It™ on paddy rice gave efficacy results comparable to Fenitrothion applied at 8 ppm. Protect-It™ and Fenitrothion had good stable residual efficacy during the 90 day test at Guangdong and the 120 day test at Chengdu (Tables 2, 3, 7 and 8).

For the laboratory bioassays of storehouse treated grain (insects introduced in the lab only) it was noticed that there was a large degree of variability in the efficacy of Protect-It™ between sampling periods. One possible reason for this was an uneven mixing of the insecticides with the grain during application. Since the consecutive samples were taken from different locations in the treated lot, there was likely considerable sample variation in the concentrations of pesticides even though theoretically there was only one dose rate In the laboratory, Protect-It™ was precisely measured and thoroughly mixed, producing more consistent results between replications

Tests with laboratory treated grain

Adult insects

At the Guangdong laboratory the mortality of maize weevil on laboratory treated wheat and paddy rice was well above 90% at the highest concentration of Protect-It™ and 100% on grain treated with Fenitrothion. In this case there was no statistical difference between Protect-It™ and Fenitrothion. The efficacy of Protect-It™ at 200 and 300 ppm for maize weevil was significantly lower, from 69.3% to 72.7% (Table 4) However, the efficacy against maize weevil on wheat and rice at the Chengdu laboratory was at or just below 100%, even at applied the lowest concentrations of Protect-It™ – 200 ppm for wheat and 300 ppm forpaddy rice (Table 9).

At the Guangdong laboratory, the mortality of the lesser grain borer was somewhat lower than that of the maize weevil On wheat treated with Protect-It™ (highest concentration) and with 8 ppm of Fenitrothion the mortality of the lesser grain borer was 85.3% and 84.7%, respectively (Table 4). On paddy rice the mortality was 97.3% for Protect-It™ and 94.7% for Fenitrothion (Table 4). Alternatively, at the Chengdu site, the relatively low dose of 300 ppm for Protect-It™ on wheat and paddy rice generated very high mortality of the lesser grain borer, which was not significantly different than the efficacy of fenitrothion (Table 9).

At the Guangdong site, the efficacy of the highest tested dose of Protect-It™ for red flour beetle on wheat, 61.3% was significantly less than that of Fenitrothion, 100% (Table 4). However, the efficacy of Protect-It™ and Fenitrothion for the red flour beetle on paddy rice were both 100% (Table 4). At Chengdu, 300 ppm of Protect-It™ was effective on the red flour beetle, 97.1% on wheat and 100% on paddy rice (Table 9)

The efficacy of Protect-It™ on lab treated grain, especially wheat, was noticeably higher in Chengdu than in Guangdong The results were contrary to expectations, since better results were obtained on the lower quality wheat used at the Chengdu laboratory. Korunic (personal communication) has results showing that Protect-It™ was less effective in lower quality wheat than in good quality wheat. The differences between Guangdong and Chengdu laboratories cannot be explained, but may be attributable to differences in laboratory conditions and procedures.

Progeny

The progeny efficacy results are presented in Table 5 (Guangdong) and Table 10 (Chengdu) The maize weevil progeny were by better than 90% (in comparison with untreated grain) by using 500 ppm of Protect-It™ on wheat and 700 ppm on paddy rice. Progeny of the lesser grain borer on wheat were not reduced by over 90% using 500 ppm, but would likely achieve this result at doses of 600 to 700 ppm. More than 90% of lesser grain borer progeny were controlled on paddy rice using 700 ppm of Protect-It™ (Table 10) The progeny of red flour beetle were reduced by over 90% using 200 ppm of Protect-It™ on wheat and 300 ppm on paddy rice

The progeny results obtained with 8 ppm of Fenitrothion were comparable to the results obtained using the highest tested concentrations of Protect-It™ (no significant difference) The one exception to this was the results on lesser grain borer at Guangdong Fenitrothion reduced the number of progeny by 98% while Protect-It™ at 500 ppm reduced the number of progeny by 68.9% (Table 10)

Comparison of storehouse-treated and laboratory-treated grain

In the field studies (storehouses), there was noticeable variability in the efficacy of Protect-It™ at dose rates of 200 and 300 ppm for wheat and 300 ppm for paddy rice (Tables 2, 3, 7 and 8). In many cases, the efficacy of Protect-It™ at lower doses was lower on field treated grain than on grain treated in the laboratory This was especially evident with the lesser grain borer At higher concentrations (500 ppm on wheat; 500 and 700 ppm on rice) however, the efficacy results of Protect in the field and in the lab were mostly equivalent. These results indicate that concentrations of Protect-It™ that generate acceptable efficacy under laboratory conditions may have to be increased to achieve the same results under field conditions

At the Guangdong wheat storehouse the air temperature ranged from 26.0 – 30.5℃, and air relative humidity ranged from 69 to 88% rh The moisture content of wheat was approximately 12.0% The air temperature at the paddy rice storehouse ranged from 27 to 31℃ with a relative humidity from 69 to 92% The moisture content of the paddy rice was approximately 12.4% Experiments in the laboratory were carried out under temperatures of 26.1 to 29℃ and 70 to 82% rh

At the Chengdu site, the grain temperature was from 35.4 to 38 5℃ in June and from 23 to 24℃ in October The air temperature was from 28℃ in June to 20℃ in October The grain moisture content increased from 11.5 to 12 5% in the wheat and 13.7 to 14.5% in the paddy rice Experiments in the laboratory were carried out under a controlled temperature of 28℃ and relative humidity of 70%

The effect of various factors in grain, particularly moisture and temperature, on the efficacy and degradation of residual synthetic insecticides in grain is well-studied (Strong and Sbur, 1960; Desmarchelier et al. 1980; Rowlands, 1985; Snelson, 1984) An increase in the moisture content of grain results in a decrease of the efficacy of most insecticides The same occurs for DE-based insecticides According to the results of Carlson and Ball (1962), LaHue (1965), Maceljski and Korunic (1972), Deschmarchelier and Dines (1987), Aldryhim (1990 and 1993), Subramanyam et al (1994), Korunic and Fields (in press) the efficacy of DE formulations decrease as grain moisture content and relative humidity increase The effectiveness of 'Perma Guard®' (fresh water DE) appeared to be greatly enhanced when wheat was relatively dry (LaHue, 1965) An increase in grain moisture from 14 2 to 18.6% had a considerably stronger influence on the efficacy of fresh water DEs, 'Kenite' and 'Diatomite', than an increase from 11.3 to 14 2% Higher temperatures (30℃) generally increased the efficacy of these DEs, but the influence of temperature was considerably less than the influence of grain moisture and relative humidity Korunic and Fields (in press) tested the effectiveness of eight DE deposits from Australia, Japan, Macedonia and the USA (marine and freshwater) against several stored-grain pests at different moisture and temperature conditions They concluded that, although there was significant variation in DE efficacy, all those tested showed reduced efficacy at grain moistures over 15%

Grain moisture content and temperature at both Chengdu and Guangdong sites were optimal for the insecticidal action of diatomaceous earth throughout the experiments Changes in grain temperature and moisture content between successive samplings probably did not have had a significant influence on the variability in the efficacy of Protect-It™ applied at lower concentrations Grain temperature and moisture was fairly consistent during the test periods at both Guangdong and Chengdu.

The significant variability in the efficacy of Protect-It™ from consecutive interval sampling was probably due to inadequate mixing and loss of insecticide to air during application. This resulted in an uneven distribution of Protect-It™ in the grain mass which affected the actual amount of Protect-It™ present in each sample For example, for the 30 day sampling at Chengdu (grain treated in the field and insects introduced in the lab), wheat treated at 200 ppm gave only 8% mortality for the lesser grain borer whereas the 90th day sample gave 80.7% (Table 7). Similarly, on paddy rice treated at 300 ppm, the mortality for lesser grain borer was 0.7% for the day 1 sample and 94.7% for the sample collected on day 120 (Table 8).

At higher concentrations, 500 ppm for wheat and 500 ppm and 700 ppm for paddy rice, the difference in efficacy between sampling intervals was much less and in many cases not significantly different (Tables 2, 3, 7 and 8). In spite of the loss of Protect-It™ to air during mixing and inadequate mixing, the concentrations of Protect-It™ in the grain mass were sufficient to cause very high mortality of the maize weevil and red flour beetle. Protect-It™ at higher concentrations was less active against the lesser grain borer in wheat, than for the other insect species tested.

Table 1. The number* of live adult maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) by direct bioassay of field-treated grain (Guangdong site)

Treatment	Sampling interval (days)	Number of insects per 1 kg							
		Wheat				Paddy Rice			
		ppm	MW	LGB	RFB	ppm	MW	LGB	RFB
	14		0	0	5		0	0	0
	25		0	0	0		0	0	0
	42		0.7	8.7	0		0	0.3	0
Protect-It	56	200	0	0	0	300	0	0	0
	70		2.7	4	0		0	0	0
	84		27	78	0		0	2	0
	98		17.3	37.7	0.7		0	4	0
	14		0	0	0		0	0	0
	25		0	0	0		0	0	0
	42		0.7	2.7	0.3		0.3	0	0
Protect-It	56	300	0	0	0	500	0	0	0
	70		1	0	0		0	0	0
	84		0	42	1		0	6	0
	98		1.7	18.3	0.3		0	5.7	0
	14		0	0	0		0	0	0
	25		0	0	0		1	0	0
	42		1	3.3	0		0	0	0
Protect-It	56	500	0	0	0	700	0	0	0
	70		0.7	0	0		0	0	0
	84		2	21	0		0	3	0
	98		3.7	7.7	0.3		0	1.7	0
	14		0	1	0		0	0	0
	25		0	0	0		0	0	0
	42		0.3	0	0		0	0	0
Fenitrothion	56	8	0	0	0	8	0	0	0
	70		0	0	0		0	0.3	0
	84		3	3	1		0	5	0
	98		1	0.3	0		0	2.7	0
	14		1	0	4		0	3	0
	25		0	1	0		0	4	0
	42		7	5	1.7		1.3	6	0
Untreated	56	0	2	12	0	0	2	12	0
	70		5	4.7	1.7		1.7	8	0
	84		150	110	2		0	82	0
	98		52.7	40.7	3.3		1.7	35.7	0.7

* One 3-kg sample taken from each treatment at each sampling date

The analysis of adult and progeny mortality show that the following concentrations of Protect-It™ were comparable in efficacy to 8 ppm of fenitrothion, and generated 90 to 100% mortality of test insects:

(a) 300 – 500 ppm to control maize weevil and red flour beetle on wheat and paddy rice

(b) 500 ppm, to as much as 700 ppm, to control lesser grain borer on wheat

(c) 300 – 500 ppm to control lesser grain borer on paddy rice

The results of the field and laboratory tests in China are compatible with the results obtained by other researchers in Canada, Italy, and Croatia Hamel (1997, personal communication) conducted laboratory experiments with Protect-It™ on rice weevil, lesser grain borer and red flour beetle on wheat (12% m. c) using two application methods. One method was dry application at 200 ppm and the other was a water spray suspension of 300-ppm Protect-It™ using 2 L of suspension per tonne After 21 days exposure, the mortality of rice weevil was 95%, lesser grain borer over 80% and the red flour beetle 80% for the dry application. Protect-It™ applied as a suspension gave 80% mortality for rice weevil, 90% for lesser grain borer and 75% for red flour beetle (21 days). In field tests conducted by Fields and Timlick (1995), 300 ppm of Protect-It™ in Canadian Hard Red Spring wheat (13 – 14% m c) reduced the red flour beetle population over 95%. Contessi and Mucciolini (1997) conducted laboratory tests with Protect-It™ on rice weevil, red flour beetle and lesser grain borer on wheat (12% m c) To control these species, they recommended concentrations of 300 ppm for rice weevil and 600 ppm for lesser grain borer and red flour beetle. Korunic et al (1997) found that 500 – 600 ppm of Protect-It™ on wheat up to 14% m. c. reduced red flour beetle numbers by 100% after 4 to 5 weeks and gave 90% mortality of the lesser grain borer In the same series of lab experiments Protect-It™ at 400 to 600 ppm gave 90 to 100% control of the lesser grain borer on three varieties of paddy rice

Table 2. The 21 day mortality (%) of maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) using insects introduced in the laboratory on field-treated wheat (Guangdong site).

Treatment	Sampling interval (days)	ppm (g/tonne)	Mortality (mean percentage ± SEM)		
			MW	LGB	RFB
Protect-It	0	200	60.9±4.6 c,d,e	34 4±4.8 b,c,d	55.7±4.8 c,d
	28		51.7±3.6 c,d	11.7±1.5 a,b	23.7±0.8 b
	42		100.0±0.0 g	67.1±0.8 f,g,h	69 3±6.3 d,e
	70		26.7±1.5 b	37.0±2.1 c,d,e	82.0±1 0 e,f
	90		8.0±1.7 a	10.9±1.6 a	48.0±2.6 c
Protect-It	0	300	97.5±0.6 g	57.5±5.6 e,f,g	70.7±13.0 d,e
	28		89.9±1.0 g	40.3±1.5 c,d,e	12.5±4.1 a,b
	42		96.0±1.0 g	45.6±2.6 d,e,f	95 5±2.4 f
	70		83.9±3.7 f,g	48.0±1.9 d,e,f,g	83.7±2.0 e,f
	90		71.7±3.9 e,f	21.4±1.7 a,b,c	62.1±2.4 c,d
Protect-It	0	500	98 0±8.2 g	70.0±3.0 g,h	98.0±0.9 f
	28		100.0±0.0 g	48.4±5.9 d,e,f,g	91.4±0.6 f
	42		100.0±0.0 g	96.1±1 4 i	100.0±0.0 f
	70		84.6±0.5 f,g	56.1±4.9 f,d,e,f,g	91.9±1.2 f
	90		92.7±1.1 g	40.7±5.0 c,d,e	93.0±0.4 f
Fenitrothion	0	8	100.0±0.0 g	41.5±6.8 c,d,e	100.0±0.0 f
	28		100.0±0.0 g	37.1±7.5 c,d,e	100.0±0.0 f
	42		100.0±0.0 g	39.5±0.8 c,d,e	100.0±0.0 f
	70		100.0±0.0 g	37.0±2.5 c,d,e	100.0±0.0 f
	90		100.0±0.0 g	52.3±5.2 d,e,f,g	100.0±0.0 f
Untreated	0	0	4.0±1.0 a	4.6±0.5 a	0.0±0 0 a
	28		7.2±0.5 a	11.4±1.6 a	0.0±0.0 a
	42		26.4±4.6 b	5.0±1 0 a	0.0±0.0 a
	70		2.8±0.5 a	9.9±3.9 a	0.0±0.0 a
	90		1.4±0.6 a	4.1±1.0 a	0.0±0.0 a

ANOVA $P = 0\ 050$ Means in the same column followed by the same letter are not significantly different

Table 3. The 21 day mortality (%) of maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) using insects introduced in the laboratory on field-treated paddy rice (Guangdong site)

Treatment	Sampling interval (days)	ppm (g/tonne)	Mortality (mean percentage ± SEM) MW	LGB	RFB
Protect-It	0	200	91.9±2.8 d	53.9±4.0 b,c	77.0±0.2 d,e
	28		93.5±0.6 d	88.0±1.0 e,f	90.8±1.4 d,e,f
	42		94.2±0.9 d	99.4±0.5 f	88.6±2.0 d,e,f
	70		29.0±2.2 b,c	80.0±1.0 c,d,e,f	82.8±2.1 d,e
	90		84.2±5.2 d	56.9±17.3 b,c,d	37.6±2.2 b,c
Protect-It	0	300	97.4±0.4 d	93.1±0.8 e,f	100.0±0.0 f
	28		85.6±2.3 d	84.0±1.0 d,e,f	96.0±0.0 e,f
	42		98.7±0.5 d	98.1±0.9 e,f	100.0±0.0 f
	70		46.0±5.0 c	87.0±2.6 e,f	100.0±0.0 f
	90		90.9±1.5 d	84.5±1.0 d,e,f	93.4±0.0 e,f
Protect-It	0	500	99.3±0.6 d	95.3±2.5 e,f	98.7±0.6 f
	28		98.7±0.5 d	98.7±0 6 e,f	96.0±2.0 e,f
	42		98.0±0 9 d	100.0±0 0 f	99.4±0.5 f
	70		87.5±1.6 d	99.4±0.5 f	100.0±0.0 f
	90		96.8±0.5 d	91.9±0.3 e,f	98.0±0.0 f
Fenitrothion	0	8	100.0±0.0 d	54.6±4.7 b,c	100.0±0.0 f
	28		100.0±0.0 d	71.0±4.6 b,c,d,e	100.0±0.0 f
	42		100.0±0.0 d	75.0±7.2 b,c,d,e,f	100.0±0.0 f
	70		100.0±0.0 d	49.0±1.0 b	100.0±0.0 f
	90		100.0±0.0 d	76.5±5.0 b,c,d,e,f	100.0±0.0 f
Untreated	0	0	9.0±1.5 a	9 1±5.0 a	5.8±1.0 a
	28		28 9±6.0 b,c	16.2±4.1 a	29.6±1.1 b
	42		6.5±1.5 a	16.4±0.2 a	4.0±1.0 a
	70		9.8±4.8 a	10.7±2.4 a	10.0±5.0 a
	90		7.5±1.6 a	8.7±3.2 a	2.9±0.5 a

ANOVA. $P=0.050$ Means in the same column followed by the same letter are not significantly different

Table 4. Mortality (%) after 21 days for maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) on grain treated in the laboratory (Guangdong site)

Treatment	ppm		MW		LGB		RFB	
			Wheat	Paddy Rice	Wheat	Paddy Rice	Wheat	Paddy Rice
	Wheat	Paddy	Mean±SEM	Mean±SEM	Mean±SEM	Mean±SEM	Mean±SEM	Mean±SEM
Protect-It	200	300	72.7±2.0 b	88.6±2.9 b	65.3±6.4 b	81.3±1.5 b	15.3±5.1 a	81.3±1.5 b
	300	500	69.3±8.9 b	88.7±1.5 b	66.7±2.3 b,c	84.0±1.0 b	17 3±1.5 a	88.7±5.1 b,c
	500	700	96.0±1.0 c	94.7±1.2 b	85.3±2.0 c	97.3±0.5 c	61.3±6.6 b	100.0±0.0 c
Fenitrothion	8	8	100.0±0.0 c	100.0±0.0 b	84.7±1.0 c	94.7±1.2 c	100.0±0.0 c	100.0±0.0 c
Untreated	0	0	6.7±0.5 a	30.7±6.4 a	4.0±1.7 a	16.7±2.0 a	10.0±5.1 a	10.7±3.2 a

ANOVA. $P=0.050$. Means in the same column followed by the same letter are not significantly different.

Table 5. Eight week progeny assessment (lab treated grain) a percentage of untreated* wheat and paddy rice (Guangdong site)

Treatment	ppm		MW		LGB		RFB	
			Wheat	Paddy Rice	Wheat	Paddy Rice	Wheat	Paddy Rice
	Wheat	Paddy Rice	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM
Protect-It	200	300	36.3±1.0 c	12.1±6.4 a	44.6±8.1 b	25.1±6.1 b	1.6±0.0 b	0.0±0.0 a
	300	500	24 5±9.0 b,c	5.0±0.6 a	38.6±6.2 b	16.2±1.4 a,b	0.5±0.4 a,b	0.0±0 0 a
	500	700	9.2±0.5 a,b	0.5±0.2 a	31.1±3.2 b	8.1±1.2 a	0.0±0.0 a	0.0±0.0 a
Fenitrothion	8	8	0.0±0.0 a	0.0±0.0 a	2.0±0.5 a	6.9±0.2 a	0.0±0.0 a	0.0±0.0 a

ANOVA $P = 0\ 050$ Means in the same column followed by the same letter are not significantly different

* The number of progeny on untreated grain is expressed as 100% Wheat: MW-2045; LGB-937; RFB-531, Paddy rice: MW-181; LGB-247; RFB-62

Table 6. The number* of live adult maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) by direct bioassay of field-treated grain (Chengdu site).

Treatment	Sampling interval (days)	Number of insects per 1 kg							
		Wheat				Paddy Rice			
		ppm	MW	LGB	RFB	ppm	MW	LGB	RFB
Protect-It	3	200	0.0	0.0	0.0	300	0.0	0.0	0.0
	30		5.5	2.0	0.0		1.5	0.0	0.0
	60		22.5	4.5	3 5		1.0	0.0	0.0
	90		130.0	1.0	0.5		3.0	0.0	0.0
Protect-It	3	300	0.0	0.0	0.0	500	0.0	0.0	0.0
	30		4.0	2.5	0.0		0.0	0.0	0.0
	60		29.5	1.0	2.5		1.5	0.0	0.0
	90		370 0	1.0	2.5		4.5	0.5	0.5
Protect-It	3	500	0.0	0.0	0.0	700	0.0	0.0	0.0
	30		0.0	1.0	0.0		0.0	0.5	0.0
	60		8.5	0.0	8.5		0.5	0.0	0.5
	90		77.5	0.5	1.0		2.0	0.5	0.0
Fenitrothion	3	8	0.0	0.0	0.0	8	0.0	0.0	0.0
	30		0.0	0.0	0.0		0.0	0.0	0.0
	60		0.0	0.0	0.0		0.0	0.0	0.0
	90		5.5	2.0	0.0		1.0	1.0	1.0
Untreated	3	0	0.0	0.0	0.0	0	0.0	0.0	0.0
	30		11.0	2.5	11.0		0.0	1.5	0.5
	60		132.0	5.0	7.5		2.0	1.0	0.5
	90		218.5	3.5	3.5		5.0	2.5	0.5

* Average of two 1-kg samples taken from each treatment at each sampling date.

Table 7. The 21 day mortality (%) of maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) using insects introduced in the laboratory on field-treated wheat (Chengdu site).

Treatment	Sampling interval (days)	ppm (g/tonne)	Mortality (mean percentage ± SEM)		
			MW	LGB	RFB
	3		99.3±0.5 d	88.0±1.7 e,f,g,h,i	84.6±4.7 f,g,h,I
	30		75.3±1.5 b	8.0±1.0 a	10.0±2.0 a
Protect-It	60	200	75.3±2.1 b	14.0±1.0 a	14.7±1.5 a
	90		94.0±1.0 d	80.7±1.5 d,e,f,g	42.7±2.0 b
	120		96.7±2.0 d	67.3±2.0 c,d	50.0±2.6 b,c d
	3		100.0±0.0 d	96.7±1.5 h,i	95.3±0.6 h,i
	30		84.7±3.0 c	93.0±1.9 a	52.0±2.6 b,c,d,e
Protect-It	60	300	80.3±1.2 b,c	50.7±6.8 b	69.3(4.7 c,d,e,f,g,h
	90		98.7±1.1 d	95.3±1.5 f,g,h,i	52.7±0.6 b,c,d,e
	120		94.0±1.0 d	59.3±1.5 b,c	60.0±2.0 b,c,d,e,f
	3		100±0.0 d	98.7±0.5 i	100.0±0.0 i
	30		83.7±1.2 c	56.0±2.0 b,c	79.3±3.2 f,g,h,i
Protect-It	60	500	85.3±2.3 c	86.0±2.6 e,f,g,h,i	96.7±1.5 i
	90		75.3±1.5 b	78.7±2.3 d,e	59.3±3.0 b,c,d,e,f
	120		100.0±0.0 d	83.3±2.3 e,f,g,h	76.7±7.6 e,f,g,h,i
	3		100.0±0.0 d	96.7±1.5 h,i	100.0±0.0 i
	30		100.0±0.0 d	60.7±4.0 b,c	100.0±0.0 i
Fenitrothion	60	8	100.0±0.0 d	83.3±1.5 e,f,g,h	94.0±2.6 h,i
	90		100.0±0.0 d	56.7±3.5 b,c	48.0±2.0 c,d,e
	120		100.0±0.0 d	61.3±3.0 b,c	75.3±8.6 f,g,h
	3		3.3. ±0.5 a	1.3±0.5 a	0.0±0.0 a
	30		0.0±0.0 a	0.0±0.0 a	0.6±0.5 a
Untreated	60	0	5.3±2.1 a	4.0±1.0 a	0.0±0.0 a
	90		2.0±1.0 a	0.6±0.5 a	0.0±0.0 a
	120		3.0±1.3 a	2.0±1.0 a	0.0±0.0 a

ANOVA. $P=0.050$ Means in the same column followed by the same letter are not significantly different

Table 8. The 21 day mortality (%) of maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) using insects introduced in the laboratory on field-treated paddy rice (Chengdu site).

Treatment	Sampling interval (days)	ppm (g/tonne)	Mortality (mean percentage ± SEM) MW	LGB	RFB
Protect-It	3	200	100.0±0.0 e	0.7±0.5 a	100±0.0 e
	30		98.7±0.5 d,e	30.7±3.5 b	94.0±1.0 d,e
	60		85.3±2.5 b,c	74.7±4.6 c	97.3±1.1 e
	90		94.7±0.5 d,e	96.7±0.5 e,f	99.3±0.5 e
	120		80.0±2.0 b	94.7±1.2 e,f	84.7±1.0 c
Protect-It	3	300	100.0±0.0 e	99.3±0.5 e,f	100±0.0 e
	30		100.0±0.0 e	80.0±4.5 c,d	98.7±1.1 e
	60		91.3± c,d	86.7±5.7 c,d,e	96.0±1.0 d,e
	90		94.7± d,e	97.3±1.1 e,f	98.0±1.0 e
	120		85.3± b,c	96.7±0.5 e,f	100.0±0.0 e
Protect-It	3	500	100.0±0.0 e	98.0±1.0 e,f	100.0±0.0 e
	30		98.0±1.7 d,e	95.3±0.5 e,f	100.0±0.0 e
	60		97.3±1.5 d,e	94.7±1.1 e,f	100.0±0.0 e
	90		98.7±1.5 d,e	98.7±1.1 e,f	100.0±0.0 e
	120		100.0±0.0 d	98.7±1.0 e,f	100.0±0.0 e
Fenitrothion	3	8	100.0±0.0 d	100.0±0 0 f	100.0±0.0 e
	30		100.0±0.0 d	94.7±1.1 e,f	100.0±0.0 e
	60		100.0±0.0 d	97.3±1.5 e,f	98.7±1.1 e
	90		100.0±0.0 d	95.3±1.0 f	95.9±1.7 d,e
	120		100.0±0.0 d	100±0.0 f	100.0±0.0 d
Untreated	3	0	2.0±1.7 a	2.0±0.0 a	6.0±1.0 a,b
	30		2.0±1.0 a	0.0±0.0 a	6.0±1.7 a,b
	60		4.7±1.5 a	4.0±1.0 a	0.7±0.5 a
	90		2.7±0 5 a	1.3±0.5 a	0.7±0.5 a
	120		2.7±0 5 a	0.0±0.0 a	1.3±0.5 a

ANOVA. $P = 0\ 050$ Means in the same column followed by the same letter are not significantly different

Table 9. Mortality (%) after 21 days for maize weevil (MW), lesser grain borer (LGB) and red flour beetle (RFB) on grain treated in the laboratory (Chengdu site).

Treatment	ppm		MW		LGB		RFB	
			Wheat	Paddy Rice	Wheat	Paddy Rice	Wheat	Paddy Rice
	Wheat	Paddy	Mean±SEM	Mean±SEM	Mean±SEM	Mean±SEM	Mean±SEM	Mean±SEM
Protect-It	200	300	99.6±0.3 b	100.0±0.0 b	81.8±3.5 b	98.4±0.5 b	82.8±5.6 b	100.0±0.0 b
	300	500	98.9±0.8 b	100.0±0.0 b	98.2±0.9 c	98.6±0.5 b	97.1±1.8 b	100.0±0.0 b
	500	700	100.0±0.0 b	100.0±0.0 b	99.6±0.2 c	99.8±0.2 b	100.0±0.0 c	100.0±0.0 b
Fenitrothion	8	8	99.6±0.3 b	100.0±0.0 b	100.0±0.0 c	100.0±0.0 b	100.0±0.0 c	100.0±0.0 b
Untreated	0	0	6.7±1.2 a	11.5±5.1 a	8.8±0.9 a	11.5±5.1 a	1.3±0.3 a	3.9±0.9 a

ANOVA. $P = 0\ 050$. Means in the same column followed by the same letter are not significantly different

Table 10. Eight week progeny assessment (lab treated grain) a percentage of untreated* wheat and paddy rice (Chengdu site).

Treatment	ppm		MW		LGB		RFB	
			Wheat	Paddy Rice	Wheat	Paddy Rice	Wheat	Paddy Rice
	Wheat	Paddy	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM	Mean ± SEM
	200	300	9.06 ± 1.3 b	8.2 ± 1.5 b	20.1 ± 2.3 c	10.4 ± 1.9 b	2.5 ± 1.0 a	0.0 ± 0.0 a
Protect-It	300	500	3.1 ± 0.5 a	1.3 ± 0.8 a	6.7 ± 0.6 b	4.7 ± 1.6 a,b	0.5 ± 0.3 a	0.0 ± 0.0 a
	500	700	0.6 ± 0.1 a	0.0 ± 0.0 a	1.1 ± 0.4 a,b	2.3 ± 0.2 a	0.0 ± 0.0 a	0.0 ± 0.0 a
Fenitrotion	8	8	0.01 ± 0.05 a	0.0 ± 0.0 a	0.0 ± 0 0 a	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a

ANOVA $P = 0\ 050$. Means in the column followed by the same letter are not significantly different

* The number of progeny on untreated grain is expressed as 100% Wheat. MW-3550; LGB-490; RFB-154, Paddy rice: MW-48; LGB-554; RFB-9

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References

Aldryhim Y. N. 1990 Efficacy of the amorphous silica dust, Dryacide, against *Tribolium confusum* Duv. and *Sitophilus granarius* (L.) (Coloptera: Tenebrionidae and Curculionidae). Journal of Stored Product Research 26 (4): 207 – 210

Aldryhim Y N. 1993. Combination of classes of wheat and factors affecting the efficacy of amorphous silica dust, Draycide, against *Rhyzopertha dominica* (F). Journal of Stored Product Research , 29 (3): 271 – 275.

Anon. 1981. Federal Register 1981 (Nov 10) 46(217), 55511 – 12. USA

Anon. 1986. Silica and Some Silicates. IARC Monograph Series: 42, WHO, Lyons, 289.

Anon 1991. EPA R. E D. FACTS: Silicon dioxide and Silica Gel;. 21T – 1021, 1 – 4, September 1991.

Carlson S. D. and Ball H. J. 1962. Mode of action and insecticidal value of a diatomaceous earth as a grain protectant. Journal of Economic Entomology 55(6):964 – 970

Contessi A and Mucciolini G 1997 Prove comparative insetticida di polveri siliceea base di zeoliti e di farina fossile diatomee. Report Regione Emilia Romagna, Servizio fitosanitario, Ravenna, Italy. 11 pp.

Desmarchelier J. M , Bengston M., Connell M., Minett W , Moore B., Phillips M., Snelson J., Sticka J and Tucker K. 1980 A collaborative stydy of residues on wheat of methacrifos, chlorpyrifos-methyl, fenitrothion, malathion and pirimiphos- methyl. II Rates of decay. CSIRO Devision of Entomology Report No. 20 21 pp

Desmarchelier J M and Dines. J. C. 1987 Dryacide treatment of stored wheat: its efficacy against insects, and after processing. Australian Journal of Experimental Agriculture 27:309 – 312.

Ebeling W. 1971 Sorptive dust for pest control Annals Review Entomology. 16:123 – 158.

Fields P. G and Timlick B 1995. Efficacy assessment of Super Insecolo Report of Agriculture and Agri-Food Canada, Cereal Research Centre, Winnipeg, Mb, Canada

Golob P 1997. Current status and future perspectives for inert dusts for control of stored product insects. Journal of Stored Products Research, 33 (1): 69 – 80

Korunic Z. and Fields P G. 1995 Diatomaceous Earth Insecticidal Composition. Canadian and U. S. A. Patent Pending, 1995.

Korunic Z., Fields P G , Kovacs M I. P., Noll J. S., Lukow O. M., Demianyk C J and Shibley K. J. 1996 The Effect of Diatomaceous Earth on Grain Quality. Postharvest Biology and Technology, 9 (1996) 373 – 387.

Korunic Z., P G. Fields, B Timlick, P. Ormesher and van Natto C 1997: The Enhanced Diatomaceous Earth, a Safe, Effective and Long Lasting Grain Protectant. Food and Agriculture Organization, VIII Round Table on Prevention of Post-Harvest Food Losses, Columbia, Cartagena, August 13 – 15, 1997.

Korunic Z. and P. G. Fields In press. The effect of moisture content of grain and temperature on the efficacy of six diatomaceous earths against three stored-product beetles. Proceedings of 7th International Working Conference on Stored-product Protection (IWCSPP), Beijing, China, 14 – 19 October 1998

Korunic Z In press Diatomaceous earth, a group of natural insecticide. Journal of Stored Product Research

La Hue D W 1978. Insecticidal dusts: grain protectants during high temperature-low humidity storage. Journal of Economic Entomology 71(2):230 – 232.

Rowlands D. G. 1985. Background Studies on Matabolism of Residual Pesticides in Stored Grain. In: B R Champs, E G Highley Pesticides and Humid Tropical Grain Storage Systems, Manila, Philippines, 139 – 149.

Snelson, J T 1985. Regulatory Requirement for Pesticides Use In: B. R. Champs, E G Highley Pesticides and Humid Tropical Grain Storage Systems, Manila, Philippines, 101 – 120.

Subramanyam Bh., Swanson C. L, Madamanchi N. and Norwood S. 1994. Effectiveness of Insecto(r), a New Diatomaceous Earth Formulation, in Suppressing Several Stored-Grain Insect Species. In: Proceedings of the 6th International Conference on Stored-Product Protection, Canberra, Australia. Ed. E. Highley, E. J Wright, H. J Banks and B. R. Champ, Vol. 2, pp. 650 – 659. University Press, Cambridge, U K.

Strong R. G. and Sbur D. E 1960 Influence of grain moisture and storage temperature on the effectiveness of malathion as a grain protectant Journal of Economic Entomology, 53, 341 – 349

White G. D., Berndt W. L., Schesser J. H and Wilson J L. 1966. Evaluation of four inert dusts for the protection of stored wheat in Kansas from insect attack. USDA/ARS Report No 51 – 8., 22 pp.