Silica aerogels as alternative protectants of maize against *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) infestations

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Abstract

Laboratory experiments were conducted to determine the effects of five different silica aerogels on maize grain infested with different strains of *Prostephanus truncatus*. Effective control was obtained of adult populations in three weeks but there were differences between materials.

In determining the persistence of the effects, two of the aerogels, Gasil and Aerosil, prevented F_1 emergence from parent adult populations placed on grain more than six months after treatment. It is likely that these materials could be used in combination with reduced dosages of conventional chemicals to provide long-term protection of grain.

Introduction

Prostephanus tuncatus (Horn) is a major pest of stored maize in Africa, affecting the food security of both individual farm families and of nations (Mallya 1991; Golob 1988, 1992). The current strategy for controlling the pest on the farm relies upon the use of contact insecticides. Golob and Hanks (1990) reported that although the use of pyrethroids has reduced storage losses caused by *P. truncatus*, other problems have been created which have reduced the potency of treatments. These problems include infestation by *Sitophilus* species which has increased as farmers have changed from storing maize on the cob, a form which is more readily infested by *P. truncatus* than by *Sitophilus* spp., to storing loose maize that is readily infested by the latter species. Unfortunately, pyrethroids are not particularly effective in controlling *Sitophilus* species. Mixtures of a pyrethroid and an organophosphorous (OP) compound are being used to control the pest spectrum. However, *P. truncatus* is highly tolerant of OPs and is also likely to develop resistance to pyrethroids relatively quickly (Golob et al. 1990; Haubruge 199). The likelihood of residues of pyrethroids (especially deltamethrin) remaining on the grain many months after treatment also makes these conventional treatments undesirable.

This paper describes experiments to assess the efficacy and persistance of inert dusts — activated silicates — for the control of *P. truncatus*. Experiments were conducted to determine whether, when used in combination with the conventional insecticides, the silicas would act synergistically and thus allow a reduction in dosages of the chemicals.

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Materials and Methods

Insects, activated silicates and dust insecticides

The adult beetles were of a strain from Tanzania kept under laboratory conditions since 1988. The experiments lasted 17 months during which time the insects were reared on insecticide-free yellow maize in a room maintained at 31 ± 1°C and 67 ± 4% r.h. Adults of unknown age and sex were used for bioassays.

The precipitated and pyrogenic silica aerogels, Gasil 23D (Gasil) and Aerosil R972 (Aerosil), respectively, were obtained from Crosfield Chemicals Ltd, England and were used as supplied. Gasil 23D has a specific surface area of $290 m^2/g$ (B.E.T.), bulk density of 120 g/L and an oil sorption capacity of 3.6 g Risella EL oil/g silica. Aerosil R972 has a specific surface area of $120 m^2/g$, bulk density of 50 g/L and an oil sorption capacity of 3.8 g Risella EL oil/g silica (Le Patourel and Singh 1984). Each dust was applied to maize grain at between 0.0125 and 0.2% by weight. In preliminary experiments, three other materials were used: Sipernat 22, Neosyl TS and Cab-O-Sil.

Conventional insecticides were formulated on Gasil 23D by dissolving the appropriate amount of technical grade insecticide in hexane and adding silica to form a slurry. The suspension was stirred frequently during evaporation to dryness in a fume cupboard when the remained solid substrates were crushed into dust and air-dried for a further 24 hours. The formulations contained 1.83% pirimiphos-methyl (Zeneca), 0.43% permethrin (Zeneca) and 0.06% deltamethrin (Roussel-Uclaf); approximately the same active ingredients were contained in conventional dilute dusts supplied by the manufacturers and used for comparison.

Grain was treated with the different types of dust by mechanically tumble mixing 200 g with the dust in a 300 g capacity glass cylindrical jar for 10 minutes to ensure good distribution.

Preliminary experiments

Four strains of *P. truncatus*, from Mexico, Tanzania, Togo and Costa Rica were exposed to grain treated with 0.2% of one of five activated silicates. Observations on adult mortality were made during a 3-week period. Each test was performed in duplicate.

Effect of long-term exposure to activated silicates: persistence of effects

On farms, *P. truncatus* may remain in contact with treated maize for many weeks. An experiment was undertaken to assess the effect on parent mortality and progeny production of exposing adults to treated grain for 3 weeks. An assessment was also made of the persistence of the treatment.

Dusts were applied to grain at 0.1 and 0.2% by weight. Forty adults were exposed to each of the four treated and untreated control replicates at various intervals up to 40 weeks after treatment. Observations on mortality were made for up to 22 days after exposure when both live and dead adults were removed and the numbers recorded. Samples were then incubated for a further 32 days after which an assessment was made of progency (F_1) production.

Short-term exposure to grain treated with activated silicates

Fifty adults were exposed to grain treated with a range of dosages, 0.0125-0.20% w/w. Individuals were deprived of food for 1 hour before being exposed for 5 hours to the grain, after which they were removed and kept in separate glass jars without food. Mortality was observed 2 days after exposure to allow any recovery to take place.

Exposure to conventional insecticides formulated on silicas

Adults were exposed to grain treated with pirimiphos-methyl (0.625–10.0 mg/kg), permethrin (0.0125–2.0 mg/kg) or deltamethrin (0.0375–0.6 mg/kg) all formulated on Gasil 23D. Results were compared with those obtained from grain treated with conventional dust formulations obtained from the manufacturers. Further experimentation was undertaken to determine the optimum combination of pirimiphos-methyl or deltamethrin dusts with Gasil 23D which would provide adequate control of adults.

Results and Discussion

P. truncatus is a difficult insect to work with because its vigorous boring and tunneling prevent easy observation and examination of kernels. To ensure a complete record of insect adult numbers it is essential to excise individuals from within grains and this necessitates destruction of the kernel and likely death of juvenile stages within. In order to prevent larval and pupal mortalities, grains were left intact and adults were counted when they were found outside the kernels or could be gently teased out. It was not always possible, therefore, to recover all the parent adults so that data for mortality are derived only from those which could be observed, though percentages were then corrected to reflect the initial number of individuals added to the treatment. Thus estimates of mortality may underestimate actual mortality.

Preliminary experiment

Figure 1 illustrates the survival rate of two of the strains tested. Clearly, the materials had a marked effect on mortality, with Gasil 23D and Aerosil 972 perhaps the most effective. These two compounds were selected for more intensive study.

Effect of long-term exposure and persistence of effects

Mortality of adults after two exposure periods to two concentrations of the silicates is shown in Table 1. The analysis of variance on data from all treatments, and the results of a multiple comparison test using Tukey's method for 95% confidence intervals, are shown in Table 2. On the first day of exposure, Gasil 23D was more effective than Aerosil R972 at both concentrations, and at each period of storage after treatment. However, when exposed for 22 days there was very little difference in effect between treatments.

Relatively few adults emerged from any of the treated grain and those observed were mostly dead (Table 3).

Short-term exposure

Observed mortalities of adults subjected to maize treated with a range of dosages of the silica dusts were subjected to probit analysis. The results are shown in Table 4. The LC_{50} of Aerosil was greater than that of Gasil by a factor of four. This contrasts with the observations of Le Patourel and Singh (1984) who found these two dusts to be equally effective against *Tribolium castaneum* adults, though after a longer 48 hour exposure period; LC_{50}s were 0.013% w/w and 0.011% w/w for Gasil 23D and Aerosil R972, respectively.

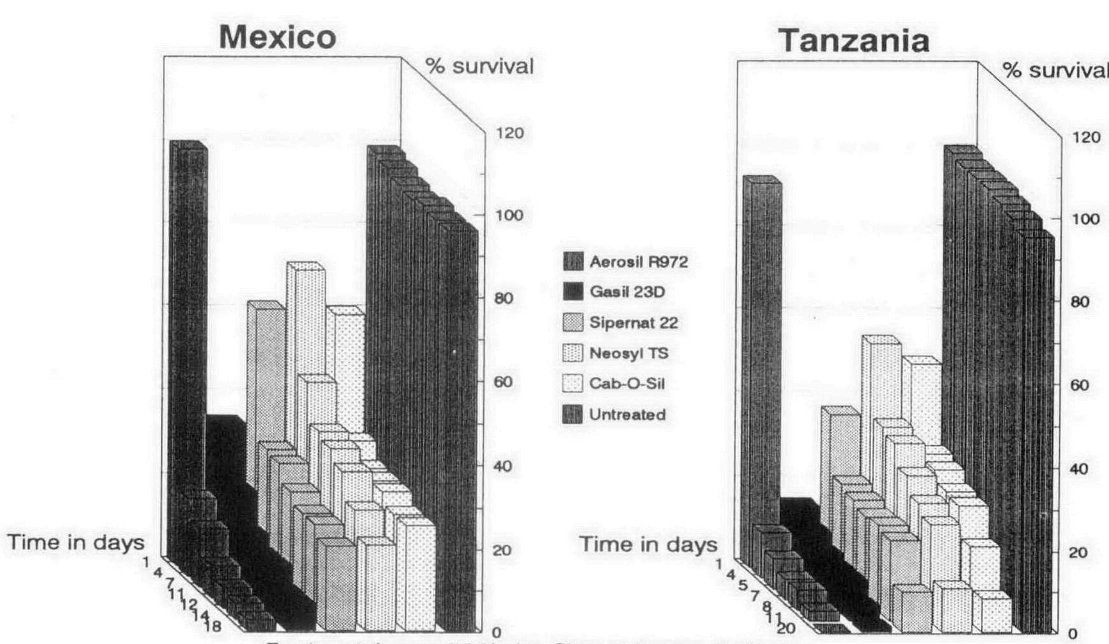

Fig. 1. Survival of two strains of *Prostephanus truncatus* adults subjected to maize treated with activated silicates.

Table 1. Percentage mortality of *Prostephanus truncatus* adults after exposure to maize treated with activated silicates. Each datum represents the mean of four replicates.

Silica	Conc. (%w/w)	Duration of exposure to treated grain													
		1st day							22nd day						
		Time (weeks) between treatment of grain and exposure of adults													
		0	8	13	16	20	31	40	0	8	13	16	20	31	40
Gasil 23D	0.1	82	–	81	74	64	95	70	97	97	100	100	94	100	95
Gasil 23D	0.2	94	–	87	90	86	98	80	100	100	98	99	98	99	96
Aerosil R972	0.1	22	–	23	4	4	12	6	98	93	100	99	97	100	99
Aerosil R972	0.2	44	–	51	8	9	35	12	99	99	100	99	100	100	100

– = No observation recorded
Control mortality was less than 3% throughout.

Table 2. Analysis of variance of the persistence of effectiveness of Gasil 23D and Aerosil R972

Effect and interaction		1st day observation		22nd day observation	
		Mean	F value and significance	Mean	F value and significance
Silica	Gasil 23D	83.52 a	1000 ***	98.05 b	4.005 *
	Aerosil R972	19.08 b	98.81 a		
Concentration (% w/w)	0.1	44.81 b	62.29 ***	97.75 b	13.11 ***
	0.2	57.79 a	99.11 a		
Time (weeks)	0	60.31 a	24.72 ***	98.38 bc	4.95 ***
	8	-	97.25c		
	13	60.63 a	99.44 ab		
	16	43.94 b	99.31 ab		
	20	40.75 b	97.19 c		
	31	60.25 a	99.81 a		
	40	41.94 b	97.63 c		
Silica × concentration			0.95 ns		1.009 ns
Silica × weeks			7.47 ***		4.30 ***
Concentration × weeks			0.72 ns		5.33 ***

Significant at* 5%, ** 1%, ***0.1%
ns not significant
values followed by the same letter are not significantly different at the 5% level.

Table 3. Emergence of F_1 adults of *Prostephanus truncatus* from parents exposed to maize treated with activated silicates. Each datum represents the mean for four replicates.

Silica	Conc. (%w/w)	Duration of exposure to treated grain													
		1st day							22nd day						
		Time (weeks) between treatment of grain and exposure of adults													
		0	8	13	16	20	31	40	0	8	13	16	20	31	40
Gasil 23D	0.1	4	0	15	10	25	1	58	85	77	130	54	76	57	86
Gasil 23D	0.2	0	0	0	0	2	0	0	13	103	15	7	16	0	68
Aerosil R972	0.1	3	0	0	0	3	0	0	42	23	22	23	54	0	18
Aerosil R972	0.2	0	0	0	0	0	0	0	6	4	32	8	1	1	0
Control		892	828	991	690	1317	788	1559	–	–	–	–	–	–	–

– = No observation recorded

Exposure to conventional insecticides

A control experiment was undertaken to ascertain whether the addition of hexane to Gasil 23D and its subsequent evaporation would have a detrimental affect on the insecticidal properties of the dust. The hexane treatment lowered the slope of the regression (4.46±0.40) and reduced the LC_{50} (0.022% w/w) but had only a marginal effect on Gasil. Le Patourel and Singh (1984) found that the addition of hexane to the pyrogenic silica Cab-O-Sil M5 and its subsequent evaporation, increased the bulk density of the product from 50 g/L to 130 g/L but did not affect its toxicity; LC_{50}s were 0.0129% w/w and 0.0134% w/w.

The highest concentration of permethrin, 2 mg/kg, produced only limited mortality of adults; the mean did not exceed 32%. Thus only the data for pirimiphos-methyl and deltamethrin were subjected to probit analysis (Table 5).

There was little difference between pirimiphos-methyl treatments but Gasil did enhance the action of deltamethrin.

Shawir et al. (1988) in determining the joint action of a precipitated silica, Sipernat 22, with pirimiphos-methyl and malathion against adult *Sitophilus oryzae* (L), *Tribolium confusum* J. du Val and *T. castaneum* (Herbst), found the commercially-available dust insecticides to be more effective than when the active ingredient was adsorbed on to the silica. For example, with pirimiphos-methyl formulated on Sipernat 22, the LC_{50}s for *S. oryzae* on wheat at 25°C ranged from 3.1 mg/100g to 28.7 mg/100g, depending upon grain moisture content. With the commercial dust the corresponding LC_{50}s were 1.5 mg/100g to 1.7 mg/100g. These treatments are much less effective than was observed against *P. truncatus*, despite the longer exposure period of 3 days. This would not be expected as *S. oryzae* is much more susceptible to OPs, such as pirimiphos-methyl, than are Bostrichidae (various citations in Golob et al. 1985). The type of food media — wheat and maize — may have been responsible for some of the difference.

Le Patourel and Singh (1984) reported the joint action of pyrethroids and Cab-O-Sil M5 and Aerosil R972 on adults of *T. castaneum*. They found that low and intermediate concentrations of the pyrethroids substantially reduced the 48-hour LC_{50}s of the silicas, while high concentrations antagonised the toxic action due to knockdown effects. They hypothesised that the reasons for the observed additive action being enhanced included improved pick-up and exchange of dust during the preliminary phase of pyrethroid intoxication, and enhanced rates of pyrethroid penetration into insects with a proportion of their cuticular wax removed.

Mixtures of Gasil 23D with commercial dust insecticides

Mixtures of pirimiphos-methyl or deltamethrin were produced with Gasil 23D such that the active ingredients of both covnentional insecticides varied as did the quantity of silica used. Pirimiphos-methyl ranged from 0.625–10.0 mg/kg, deltamethrin from 0.375–0.6 mg/kg and Gasil from 0.0125–0.2% w/w; a total of fifty combinations was assayed. Figure 2 illustrates the effects from a comparison test of mean percentages, obtained following a 5-hour exposure of adults and then a 2 day recovery period. Optimum mixtures were 1.25 mg/kg + 0.025 % for pirimiphos-methyl + Gasil 23D and between 0.075 mg/kg + 0.025 % and 0.15 mg/kg + 0.05% for deltamethrin + Gasil 23D.

Conclusions

Clearly, these activated silicas have potential in storage for the protection of maize against *P. truncatus* infestation. Of the two tested here, Gasil 23D was the most effective. Whether it could be used by farmers would depend on cost. Similarly, the use of activated silicates as carriers on which to formulate deltamethrin or other chemicals will depend ultimately on production costs.

References

Golob, P. 1988. Current status of the larger grain borer *Prostephanus truncatus* (Horn) in Africa. Insect Science and Its Application, 9, 737–745.

Golob, P. 1992. Implications of the larger grain borer for the farmer. In: Proceedings of CTA meeting, Extension of strategies for the

Table 4. Regression analysis of probit mortality as a response to maize grain treated with activated silica dusts. Adults were exposed to treated grain for 5 hours then allowed a 2-day recovery period before observations were recorded. Data were derived from four replicates.

Silica	Regression	Slope	LC_{50} (% w/w) and 5% fiducal limits	$LC_{99.9}$ (% w/w)	Heterogeneity		Paralellism	
					Chi sq	P	Chi sq	P
Gasil 23D	y=9.43x+19.39	9.43=/-0.86	0.03(0.028–0.031)	0.06	0.829	0.3–0.5		
							79.82	<0.001
Aerosil R972	y=3.11x+7.87	3.11+/-0.24	0.12(0.110–0.132)	1.18	4.938	0.5–1.0		

Table 5. Mortality of adult *Prostephanus truncatus* exposed to grain treated with commercially available insecticide dust and to insecticides formulated on the activated silica Gasil 23D. Data were derived from four replicates of each dosage tested.

Treatment	Regression	Slope	LC_{50} (% w/w) and 5% fiducal limits	$LC_{99.9}$ (mg/kg)
Pirimiphos–methyl (1.85%) (commercial)	y=1.84x+4.54	1.84=/-0.14	1.77(1.49–2.06)	84.76
Pirimiphos–methyl(1.83%) (Gasil 23D)	y=1.84x+4.21	1.84+/-0.14	2.70(2.21–3.33)	129.01
Deltamethrin (0.06%) (commercial)	y=2.05x+5.81	2.05+/-0.18	0.40(0.35–0.477)	13.09
Deltamethrin (0.06%) (Gasil 23D)	y=3.31x+7.59	3.31+/-0.23	0.17(0.15–0.18)	1.41

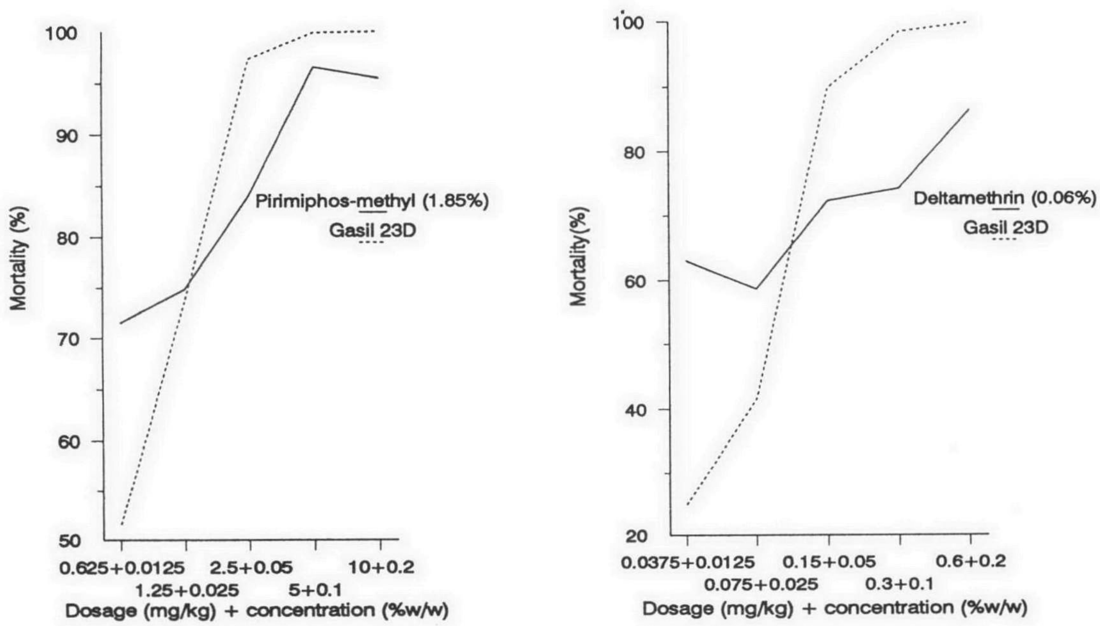

Fig. 2. Affect of varying concentrations of insecticide and Grasil 23D combinations on mortality of adult *Prostephanus truncatus*.

control of the larger grain borer, Ede, The Netherlands, 23–24 October 1991, 13–14.

Golob, P., Broadhead, P. and Wright, M 1990. Development of resistance to insecticides by populations of *Prostephanus truncatus* (Horn) (Coleoptera; Bostrichidae). In: Fleurat-Lessard, F. and Ducom, P., ed., Proceedings of 5th International Workshop Conference on Stored Products Protection, Bordeaux, France, 9–14 September 1990:999–1007.

Golob, P., Changjaroen, P., Ahmed, A. and Cox, J. 1985. Susceptibility of *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae) to insecticides. Journal of Stored Products Research, 21, 141–150.

Golob, P. and Hanks, C. 1990. Protection of farm stored maize against infestation by *Prostephanus truncatus* (Horn) and *Sitophilus* species in Tanzania. Journal of Stored Products Research, 26(4), 187–198.

Haubruge, E. 1990. Toxicite et resistance de *Prostephanus truncatus* (Horn) (Col., Bostrychidae), a la permethrine. In: Fleurat-Lessard, F. and Ducom, P., ed., Proceedings of 5th International Workshop Conference on Stored Products Protection, Bordeaux, France, 9–14 September 1990:1009–1018.

LePatourel, G.N.J., and Singh, J. 1984. Toxicity of amorphous silicas and silica pyrethroid mixtures to *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Journal of Stored Products Research, 20(4): 183–190.

Mallya, G.A. 1991. *Prostephanus truncatus* (Horn), the larger grain borer (LGB), and its control of Tanzania. In: Proceedings of FAO/GTZ Coordination Meeting, Implementation and further research on biological control of the larger grain borer, Lome, Togo, 5–6 November 1990:4–13.

Shawir, M., Le Patourel, G.N.J. and Moustafa, F.I. 1988. Amorphous silica as an additive to dust formulations of insecticides for stored grain pest control. Journal of Stored Products Research, 24(3), 123–130.