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Susceptibility of three species of *Sitophilus* to diatomaceous earth

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Abstract

Diatomaceous earth (DE) is toxic to stored-product insects because it absorbs the cuticular waxes and insects die from desiccation. There is considerable variation in sensitivity to DE between different species. Some studies have shown up to a 6-fold difference between species, other studies have shown similar 2-fold differences between strains of the same species, and strains increase their tolerance to DE under DE-selection experiments. We tested the sensitivity of adult *Sitophilus zeamais*, *Sitophilus oryzae* and *Sitophilus granarius*, towards DE. We used two natural DE, Diafil 610 and Celatom MN 23, both freshwater DE containing less than 1 % crystalline silica and over 80 % amorphous silicon dioxide. Insects were placed on wheat with 5 concentrations of DE (0, 250, 500, 750 or 1,000 ppm) and mortality assessed after 4, 14 and 21 days. After 21 days, all adults were sieved off the wheat and offspring counted after an additional 21 days. Wheat had 13.3 % moisture content at the beginning of the experiment, the temperature was 30 °C and the relative humidity was 70 ± 5 % through-out the experiment. For both DE, *S. zeamais* was the most sensitive, followed by the *S. oryzae*, with *S. granarius* being the most resistant. Celatom MN 23 was slightly more effective than Diafil 610. At the highest concentration, 1,000 ppm, offspring production was reduced to 50 to 30 % of the untreated wheat. Possible reasons for these differences are discussed.

Key words: *S. zeamais, S. oryzae, S. granarius,* DE, efficacy.

Introduction

Diatomaceous earth (DE) is toxic to stored-product insects because it absorbs the cuticular waxes and insects die from desiccation. DE from different geological sources or even from the same location have different physical properties (SiO_2 content, tapped density, oil absorbency, particle size and pH) that are correlated to their insecticidal efficacy against stored-product insects (Korunic, 1998). In general, although there are several discrepancies in the literature, the order of sensitivity to natural and enhanced DE from most to least sensitive species are as follows: *Cryptolestes* spp, *Sitophilus* spp, *Oryzaephilus* spp, *Rhyzopertha dominica* (F.), *Tribolium* spp and *Prostephanus truncatus* (Horn). (Maceljski and Korunic, 1971; Desmarchelier and Dines, 1987; Fields and Korunic, 2000; Subramanyam et al., 1998). Also, there can be variation in sensitivity to DE between different strains of the same species (Rigaux et al., 2001).

There are several published papers about the effectiveness of DE against *Sitophilus* spp

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(Korunic, 1997; 1998; Korunic and Fields, 1998; Mewis and Ulrich, 2001; Cook, 2003; Athanassiou et al., 2003; Fields et al., 2003; Athanassiou et al., 2004; Athanassiou at al. 2005). However, in all papers, only one species, usually *Sitophilus oryzae* (L.), was tested. There are no side by side comparisons of the sensitivity of *Sitophilus* spp to DE. The objective of our study was to determine if there are differences in efficacy between *Sitophilus zeamais* Motschulsky, *S. oryzae* and *Sitophilus granarius* (L.) using two natural DE on wheat.

Materials and methods

Diatomaceous earths

DiaFil 610 is a white fresh water DE containing 89 % amorphous silicon dioxide, 4.0 % Al_2O_3, 1.7% Fe_2O_3, 1.4 % CaO, less than 1 % of MgO and K_2O and 3 % moisture (as shipped by the producer Celite Corporation). The median particle size is 10 microns, specific gravity is 2.2, a surface area is 35.7 m^2/g, pH is 8 and crystalline silica is >0.1 % (Celite Corporation Technical Data DiaFil 610; 14 December 2001).

Celatom MN 23 is a beige fresh water DE containing 83.7 % SiO_2, 5.6 % Al_2O_3, 2.3 % Fe_2O_3, and less than 1 % of CaO and MgO and other oxides. Specific gravity is 2.0, pH (10 % slurry) is 7, free moisture is less than 5 % and crystalline silica (quartz) less than 1 % (Eagle Pitcher Minerals, Inc. Technical Data Sheet and Material Safety Data Sheet; 7 January 2001).

Test insects

The species tested were: the rice weevil, *S. oryzae*, the maize weevil, *S. zeamais* and the granary weevil, *S. granarius*. Insects were reared at 30 ± 1 °C and 70 ± 5 % r.h. in the dark on whole Canadian western hard wheat. Unsexed, mixed-age adults 2 to 3 weeks old were used in all experiments. All insects were obtained from cultures maintained in the laboratory for at least three years, with no history of exposure to insecticides.

Bioassay

Canadian Western Hard wheat at 13.3 % m.c. was used in the bioassay. Moisture content was measured using a dielectric moisture meter (model 919, Labtronics, Winnipeg) following AACC (1995) method 44-11. The dockage was removed by sieving the grain by using the U.S.A. standard testing sieve No. 8 with the 2.36 mm of opening (Tyler equivalent 8 mesh). We used 5 concentrations of both DE (0, 250, 500, 750 and 1,000 ppm).Three hundred g of wheat was placed with the appropriate weight of DE in a jar, sealed and shaken by hand for 1 m. After shaking, the wheat was divided into 100 g lots for each replicate. There were 3 replicates per treatment, with one hundred adults per replicate. Insects were held in an incubator at 30 ±1 °C; 70 ± 5 % r.h.

Adults were sieved off the wheat after 4, 10 and 21 days. The number live and dead were noted and for the counts on 4th and 10th days, the live adults were returned to the jars, whereas all adults were removed on the 21st day. The grain was held for an additional 21 d, the wheat sieved off and the emerged offspring adults counted. After each sieving, all grain and dust was replaced in the jar.

Results

With both of the DE tested, there were large differences in sensitivity to DE between the three species. *Sitophilus zeamais* was the most sensitive to DE, followed by *S. oryzae*, with *S. granarius* being the least sensitive (Table 1, Figure 1-3). Celatom MN 23 was slightly more effective than Diafil 610 (Table 1). For *S. zeamais*, 90 % or greater mortality was achieved after 14 d at 750 ppm (Figure 2), and after 21 d at 500 ppm (Figure 3). For *S. oryzae*, 90 % or greater control was only achieved after 21 at 750 ppm (Figure 3). For *S. granarius*, mortality was

never greater than 60 % (Figure 3).

Table 1. The lethal dose for 50 and 90 % of the population and 95 % confidence interval of *S. zeamais*, *S. oryzae*, *S. granarius* adults held on wheat treated with Diafil 610 or Celatom MN 23 diatomaceous earth after 21 days.

Diatomaceous Earth	Insect	LD_{50}	95 % CL	LD_{90}	95 % CL	Chi^2	g (95 %)	slope	slope SE
Diafil 610	*S. zeamais*	232	213 - 248	418	391 - 452	10.0	0.02	5.0	0.4
	S. oryzae	547	503 - 585	794	736 - 883	31.5	0.06	7.9	0.5
	S. granarius	926	881 - 984	*	*	14.5	0.07	7.0	0.7
	Celatom								
MN 23	*S. zeamais*	211	-	353	-	197	0.99	5.7	0.6
	S. oryzae	421	394 - 448	700	653 - 759	15.8	0.02	5.8	0.3
	S. granarius	776	705 - 869	*	*	15.7	0.04	2.9	0.2

* = greater then 1,000 ppm.

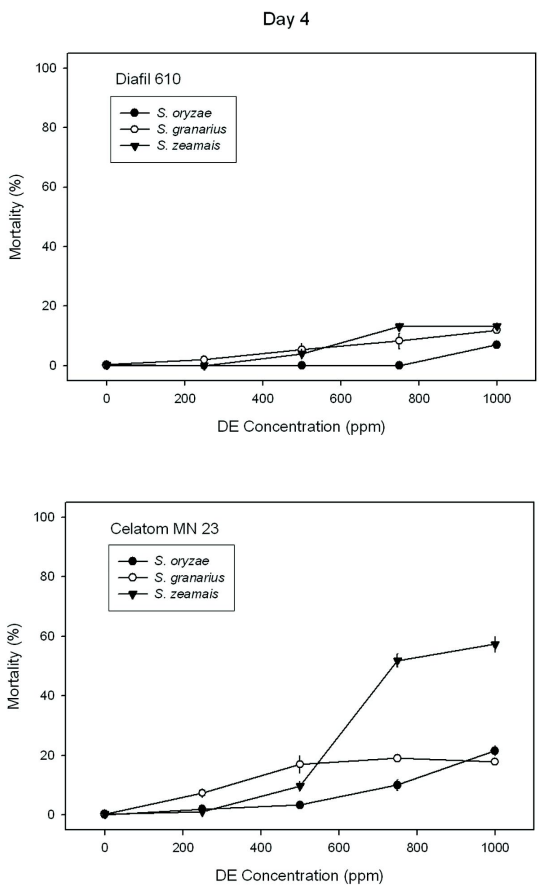

Figure 1. The mortality (± SEM) of adult *Sitophilus* spp at different concentrations of Diafil 610 and Celatom MN23 after 4 days exposure.

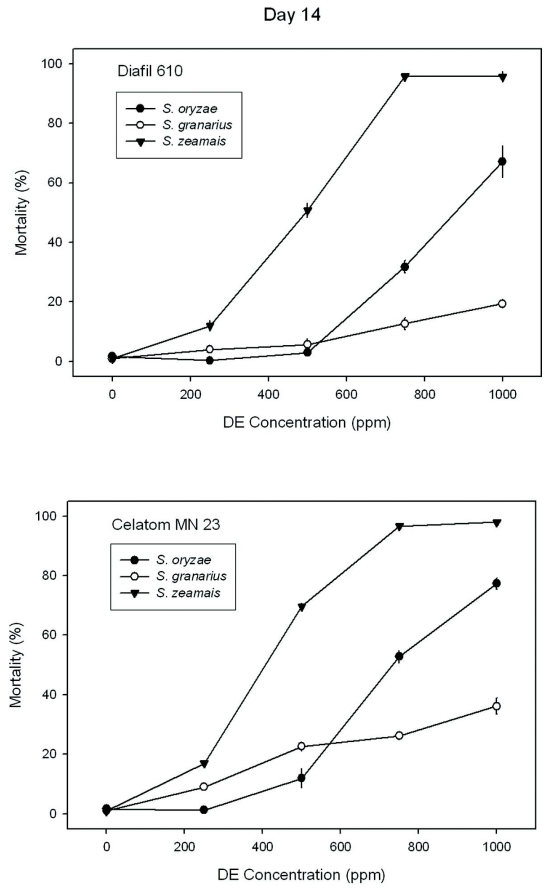

Figure 2. The mortality (± SEM) of adult *Sitophilus* spp at different concentrations of Diafil 610 and Celatom MN23 after 14 days exposure.

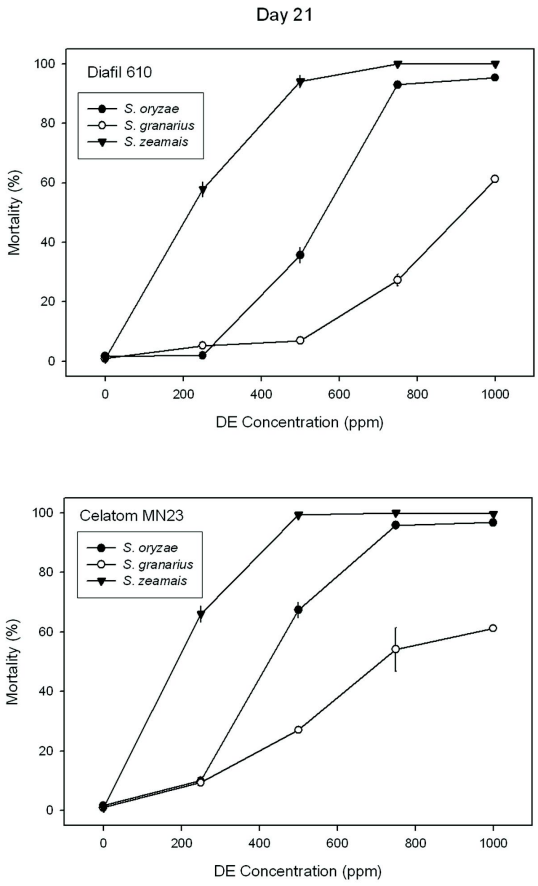

Figure 3. The mortality (± SEM) of adult *Sitophilus* spp at different concentrations of Diafil 610 and Celatom MN23 after 21 days exposure.

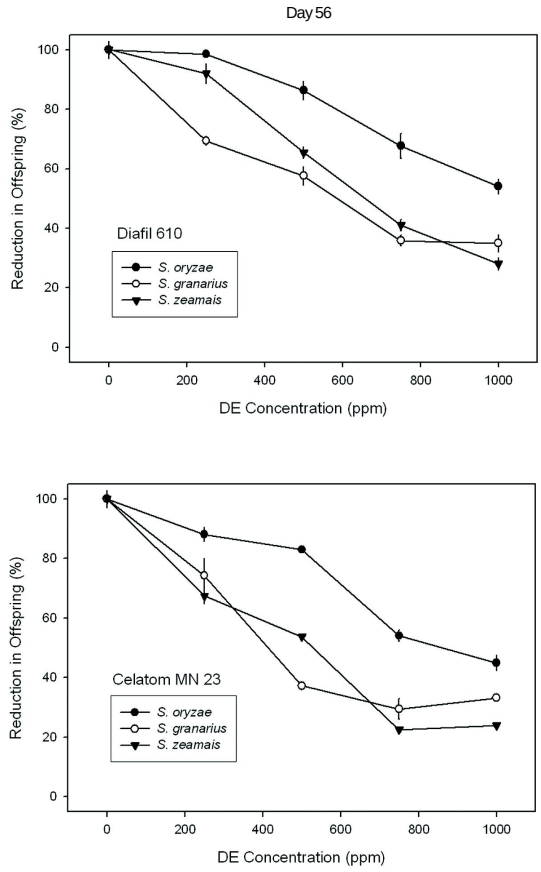

Figure 4. The reduction of offspring (± SEM), measured as emerged adults 56 days after treatment as a percentage of control. There were 733+15 *S. zeamais*, 1,018+10 *S. oryzae* and 486+15 *S. granarius* adults that emerged from the untreated wheat.

Although there were large differences in the adult mortality, the number of offspring that successfully emerged as adults was very similar between *S. oryzae* and *S. granarius*. As expected because of the high mortality with the parental generation, *S. zeamais* had lower offspring production than the other two species.

Discussion

It is difficult to compare the efficacy of DE from different studies as there are a number of factors that effect efficacy: type of DE, concentration, grain moisture content, temperature, insect species, insect strain, insect density and grain treated (Korunic, 1997; Rigaux et al., 2001; Fields et al., 2003).

Korunic (1997, 1998) conducted numerous experiments with more than 40 different formulations of natural DE in order to determine its efficacy against *S. oryzae* on wheat. The experiment was conducted at 25 °C and 55 – 65 % r.h. and the exposure period was 5 days. The results clearly showed the great difference in the effectiveness of natural formulations of DE from different locations towards *S. oryzae*. Lethal concentration for 50 % of the population of *S. oryzae* was from a low of 270 ppm, (213-340 ppm confidence interval (CL), Celite 209, marine DE); 438 ppm, (346-553 ppm CL, DE Australia, fresh water DE); 1,755 ppm, (1,278-2,408 ppm CL, fresh water DE from China) to zero mortality of *S. oryzae* at 1,700 ppm (DE

from China, fresh water DE). Arthur (2002) did an extensive study of *S. oryzae*, showing that at 300 ppm of an enhanced DE Protect-It, 30 °C, 75 % r.h. after 7 d there was no survival. The enhanced DE, Protect-It, that is a mixture of natural DE and silica gel, is probably more effective that natural Diafil 610 or Celatom MN 23. Fields and Korunic (2000) showed that for *S. oryzae* at 300 ppm, 14 % m.c. at 30 °C after 3 d there was 15 to 25 % mortality with enhanced DE formulations Insecto (natural DE plus food grade bait), Dryacide (natural DE with silica gel) and Protect-It, whereas in this study with natural DE formulations there was no mortality under similar conditions. Fields et al. (2003) tested the enhanced DE Protect-It and natural DE formulation Perma Guard, similar in physical and chemical characteristic to DiaFil 610 and Celaton MN 23, and found Protect-It significantly more effective against *S. oryzae* than Perma Guard.

There are number of possible reasons why we found large differences in sensitivity between the three *Sitophilus* spp. Rigaux et al. (2001) found that a strain of *T. castaneum* with increased susceptibility to DE moved faster than a more resistant strain. There could be other differences between the species that are responsible for the differences in susceptibility such as: size, rate of eating, cuticular waxes, adhesion of DE to cuticule, absorbance of water from the hind gut or tolerance to low internal water. Further studies would be required to determine which, if any of, these factors are responsible for the differences in susceptibility. Given that there could be differences between species and strains, we recommend that additional work be done to verify if these trends hold true for field populations. If these results hold true, then lower rates could be used when treating grain that is only infested with *S. zeamais.*

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