Field trials with the diatomaceous earth SilicoSec® for treatment of empty rooms and bulk grain

Schöller, M.*#, Reichmuth, C.
Julius Kühn-Institut - Federal Research Centre for Cultivated Plants, Institute for Ecological Chemistry, Plant Analysis and Stored Product Protection, Section Stored Product Protection; Königin-Luise-Str. 19, D-14195 Berlin, Email: Matthias.Schoeller@jki.bund.de

* Corresponding author
\# Presenting author

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Abstract

Diatomaceous earths (DE) are fossil diatoms (phytoplankton) that contain silicon dioxide (SiO_2), the particles absorb the waterproof lipids from the arthropod cuticle resulting in death through desiccation. The DE SilicoSec® is registered in Germany. The field trials presented here were performed in order to determine (1) the efficacy of SilicoSec® under temperate Central European climatic conditions, (2) the distribution in empty rooms and (3) the possible effect of different surface materials. For empty room treatment, a 41 m² storage room was treated with 20 g/m², the total surface treated including walls was 145 m². At 19 sampling points the amount of DE on the floor was determined. Distinctly less DE attached to the walls compared to the floor, and an uneven distribution on the floor ranging from 2.6 to 49.5 g/m² with a mean±SD of 15.4±14 g/m² per sampling point was measured. Additionally, test pieces with 5 different surface types were placed in the treatment room prior to the treatment. Adult *Tribolium confusum* and *Cryptolestes ferrugineus* were placed on all surfaces at 15 to 19°C and 65-81% r.h.. Mean corrected mortality after 14 d in *T. confusum* and *C. ferrugineus* was 94% and 65%, respectively. No significantly different mortality was recorded for *T. confusum* depending on surface type, but in *C. ferrugineus* significantly less beetles (20%) died on concrete flagstone compared to natural flagstone, glazed ceramic flagging, plywood and porcelain stoneware. For bulk grain, 10 t of wheat were treated with either 0.7 kg/t or 2 kg/t DE. *Sitophilus granarius, Oryzaephilus surinamensis* and *C. ferrugineus* adults were placed in vials with treated wheat together with data loggers and placed deep within the bulk for 19 d. Corrected mortality was around 90% for all treatments except for *S. granarius* at the lower dose where 60% mortality was achieved only.

Keywords: Diatomaceous earth, Efficiency, *Cryptolestes ferrugineus, Sitophilus granarius, Oryzaephilus surinamensis*

1. Introduction

Diatomaceous earth (DE) originates from fossil diatoms (Eucaryota: Bacillariophyta. The living diatoms are single-celled algae that secrete silica, and only the silica remains after the diatoms die and decay. The insecticidal effect of DE is due to physical damage to the protective wax layer of the insect's cuticle (Zacher and Kunike, 1931; Korunic, 1998; Subramanyam and Roesli, 2000; Mewis and Ulrichs, 2001). DEs applied for pest control are amorphous dusts and are not considered hazardous to human health in contrast to crystalline dusts. DE have been reported to be effective pesticides for control of stored product pests, e.g. when applied to grain or to the floor and walls of storage facilities (Korunic, 1998; Arthur, 2003).

Several DE products are commercially available and registered for stored product protection, the product SilicoSec (Biofa GmbH) was first approved for use in Germany in 1997 (Mewis and Ulrichs, 2001). However, still few data from field trials are available. The field trials presented here were performed in order to determine the efficacy of SilicoSec® under temperate Central European climatic conditions, to estimate the distribution in empty rooms and to elucidate possible effects of different surface materials.

2. Materials and methods

2.1. Surface treatment.

The field trials were conducted in a store in Temmen, Uckermark, Brandenburg that had not been treated with synthetic chemical insecticides for several years. The storage rooms, untreated control and room for trial, were cleaned. The treated room had a total surface including walls of 145 m² (floor: 41.12 m²). SilicoSec® was applied with the help of a sucking and forcing pump gun, at a concentration of 20 g/m² calculated for the total surface (3 kg SilicoSec® total).The amount of DE was determined at 19 sampling points on the floor. For each sampling point, a filter paper (15 cm diameter, surface 177 cm^2) and a sealable plastic bag was weighed and numbered in the laboratory. After deposition of the DE in the field trial, the filter papers were carefully transferred into the plastic bags and weighed again in the laboratory to determine the amount of DE on the filter paper.

Additionally, test pieces (15 cm x 15 cm) with 5 different surface types were placed in the treatment room prior to the treatment, i.e. concrete flagstone, natural flagstone, glazed ceramic flagging, plywood and porcelain stoneware (Fig. 1). The test pieces were placed horizontally on the floor prior to the DE treatment (Fig. 2). After treatment, plastic cages were placed on top of the pieces and glued onto the pieces. The cages had an opening for inserting the test insects, and lateral perforations (diameter 1 mm) for aeration. Adults originating from the laboratory colonies of *Tribolium castaneum* (Herbst) maintained at the Institute (50 adults per trial) and *Cryptolestes ferrugineus* (Stephens) (100 adults per trail), also from laboratory colonies, were introduced into the cages and the opening sealed with tape. After 14 d, the insects were removed from the cages, transferred to glass vials and brought to the laboratory.

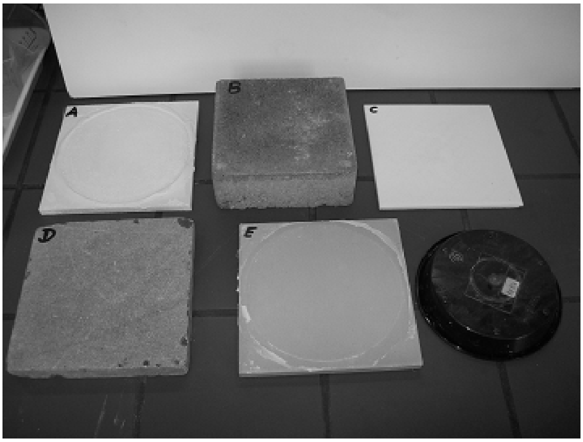

Figure. 1 Surface materials studied, (A) plywood, (B) concrete flagstone, (C) glazed ceramic flagging, (D) natural flagstone, and (E) porcelain stoneware, right to (E) plastic top for caging the insects.

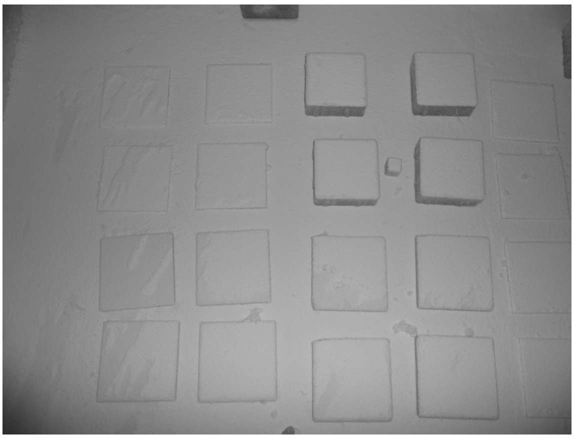

Figure. **2** Different surface materials after empty room treatment with diatomaceous earth SilicoSec in field trial, before exposing and caging of insects.

A total of 10 data loggers were distributed close to the test pieces at random on the floor. The untreated controls also received a data logger. Another logger transported together with the test insects to the laboratory. The temperature ranged between 15 and 19°C and the relative humidity between 65 and 81% r.h. during the field trial.

2.2. Grain treatment

Field trials were conducted on two farms in Germany, in Temmen-Ringenwalde, Brandenburg, and Finkenthal Güstrow, Mecklenburg-Western Pomerania, respectively. Ten tones of wheat were treated with SilicoSec on each of the farms by mixing the DE into the whole bulk. The wheat was treated with 0.7 kg/t and 2.0 kg/t in Temmen and Finkenthal, respectively. Wheat was taken from the treated bulk out of various depths and filled into 250 ml glass jars. Laboratory-reared beetles were placed into the jars onto the wheat and the jars closed insect-tight, but had a metal gauze for ventilation. A piece of string was attached to the jars, the jars were placed ca. 40 cm deep into the bulk, and the string tied to a rod in order to recover the samples. Consequently, the samples were exposed to the temperature and humidity conditions in the bulk for a period of 19 days. A data logger was placed close to each sample.

Three beetle species were tested, *C. ferrugineus*, *Oryzaephilus surinamensis* (L.) and *Sitophilus granarius* (L.). In every experiment, 100 adults of *S. granarius*, and 50 adults of *C. ferrugineus* and *O. surinamensis* were tested, respectively. For every species, ten replications and one untreated control (wheat not treated with SilicoSec) were exposed to the environmental conditions in the bulk and left there for four weeks. One untreated control was brought back to the laboratory in Berlin immediately after treatment. The mortality of the exposed adults was recorded. During the field trial, the temperature ranged between 15°C and 20°C and the relative humidity between 51 and 70% r.h. in Temmen, in Finkenthal environmental conditions were 18.5 to 24.8°C and 55.1 to 60.2% r.h.

2.3. Data analysis

For the mortality on different surface materials, the mortality counts were corrected by using Abbot's (1925) formula. The data were analysed with the help of SigmaStat-software (version 3.11.0) by using the non-parametric Kruskal-Wallis one way-analysis of variance, with insect mortality as the response variable and type of surface as main effect. Means were separated by using the Tukey-test at $p = 0.05$. Data from the results of the field trial with bulk grain were also corrected by using Abbot's (1925) formula. The GLM procedure was applied with insect mortality as the response variable and dose rate and insect species as main effects. Means were separated by using the Holm-Sidak test at $p = 0.05$.

3. Results

3.1. Surface treatment

A mean and SD of 0.027±0.25 g SilicoSec® was traced per filter paper (15 cm diameter), equalling 15.4 g/m². The distribution of SilicoSec® in the empty room fitted a normal distribution (Shapiro-Wilk-Test, $p = 0.002$) but was uneven, illustrated by the range of DE found (minimum: 0.05 g, maximum: 0.88 g) and the standard deviation. The distribution of the amount found at the 19 sampling points converted to g/m² is given in Figure 3. Calculated for all surfaces, the amount of SilicoSec® was 20 g/m² (total surface: 41.12 m²), however, the floor received much more DE compared to the walls. The maximum dosage on the floor was 73 g/m².

The different surface materials did not affect the mortality of *T. confusum* (Kruskal-Wallis One Way ANOVA on Ranks, $P = 0.427$) (Fig. 4), but had significant impact on the mortality of *C. ferrugineus* (Kruskal-Wallis One Way ANOVA on Ranks, $P = 0.034$) (Fig. 5). However, the latter was only due to the low mortality on concrete flagstone.

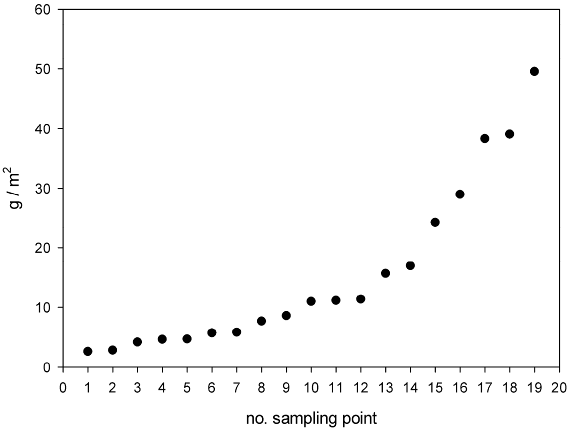

Figure. 3 Amount of DE at 19 sampling points (15 cm diameter, surface 177 cm^2) on the floor of a grain store converted to g/m².

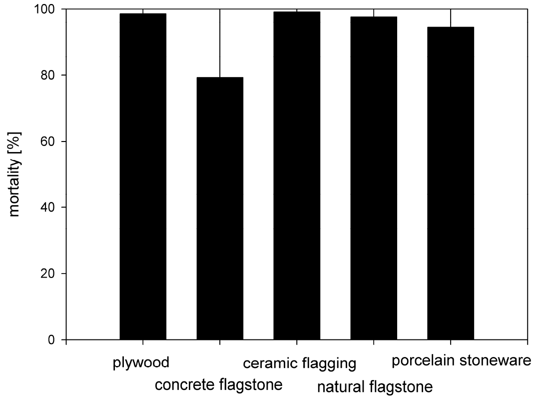

Figure. 4 Mortality of *Tribolium confusum* on five different surface types treated with 15 g/m² diatomaceous earth SilicoSec in a field trial.

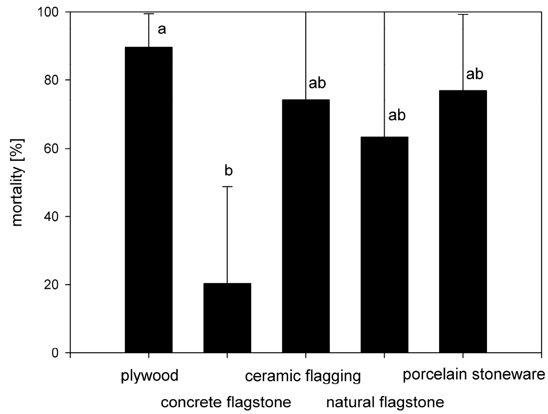

Figure. 5 Mortality of *Cryptolestes ferrugineus* on five different surface types treated with 15 g/m² diatomaceous earth SilicoSec in a field trial.

3.2. Grain treatment

The mortality of beetles in bulk grain was significantly different depending on species (P<0.001) and dosage of DE (P=0.001). There was an interaction between species and dosage (P<0.001). Combining the data of both sites, significantly higher mortality was recorded for *O. surinamensis* and *C. ferrugineus* compared to *S. granarius*, but no different mortality was found between *O. surinamensis* and *C. ferrugineus*. Comparing the two experimental sites, significantly more beetles of all species were controlled in Finkenthal (2.0 kg/t DE) compared to Temmen (0.7 kg/t DE), and specifically more *S. granarius* were controlled at 2.0 kg/t DE. However, no different mortality was found between *O. surinamensis* and *C. ferrugineus* depending on dosage.

The analysis of the mortality within the respective experimental sites revealed no difference in mortality for the three species in Finkenthal (2.0 kg/t DE) (Fig. 6) were mortality exceeded 90%. In Temmen (0.7 kg/t DE) mortality of *S. granarius* was significantly lower compared to *O. surinamensis* and *C. ferrugineus* (Figure. 7).

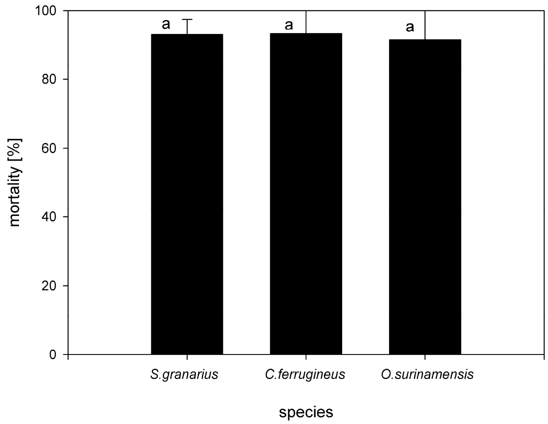

Figure. 6 Mortality of *Sitophilus granarius*, *Cryptolestes ferrugineus* and *Oryzaephilus surinamensis* in grain treated with 2.0 kg/t diatomaceous earth SilicoSec in a field trial in Finkenthal, Germany.

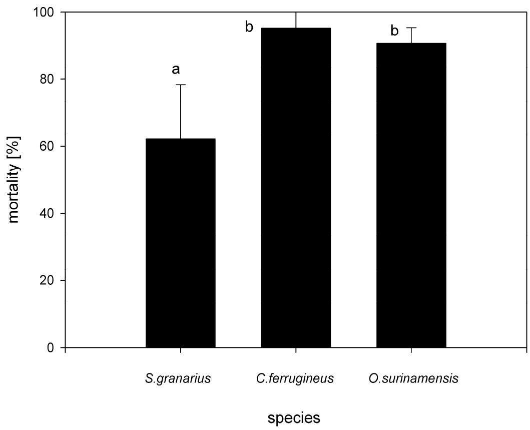

Figure. 7 Mortality of *Sitophilus granarius*, *Cryptolestes ferrugineus* and *Oryzaephilus surinamensis* in grain treated with 0.7 kg/t diatomaceous earth SilicoSec in a field trial in Temmen, Germany.

4. Discussion

The empty room treatment was effective against *T. confusum*, but only partly effective against *C. ferrugineus*. This result was not expected, because *T. confusum* was found to be less susceptible to diatomaceous earths than other stored-product beetles (Korunic, 1998; Arthur, 2000; Athanassiou et al., 2005) and *Cryptolestes* spp. are thought to be generally the most sensitive stored-product insects (Korunic, 1998). Complete control of *C. ferrugineus* at 300 ppm (300 g/t) within 24 h was achieved, while 100% mortality did not occur even after 21 days in *T. castaneum* under the same conditions (Korunic, 1998). Trials with DE produced different and often completely opposite results for stored-product insects (Korunic, 1998). On the one hand, this shows the need for further standardisation of experimental design, but conditions of temperature, humidity and substrate also have to be carefully examined. For the case of *T. confusum* and *T. castaneum*, a greater tolerance towards DE was found with a temperature of 30°C than at 22 to 24°C (Maceljski & Korunic, 1972; Aldryhim, 1990). However, this result was not confirmed in more recent studies by Arthur (2000) and Vayias and Athanassiou (2004) and discussed in detail in Vayias and Athanassiou (2004). An exceptional susceptibility at low temperatures could be the reason for the good control effect in the field trial presented here.

A low amount of DE adhered to the vertical surfaces only, this could be a problem for the control of stored-product pests seeking refuge on walls, especially for last-instar larvae of moths. The distribution on the floor was very variable, 1/3 of the sample points had less than 10 g/m². The application technique has to be improved to get a more even distribution for empty room treatment. However, it was not shown yet if an uneven distribution really affects efficiency of DE. Insects moving around from spots with low dosages to those with high dosages could still pick up sufficient amounts of DE to achieve control.

DE effectiveness is known to be influenced by the type of commodity treated, i.e. effectiveness is lower in maize than in wheat or barley (Athanassiou et al., 2008), but such an effect was not known for the type of surface material in empty rooms yet. In this study, a significant lower efficiency of DE against *C. ferrugineus* was found on concrete flagstone compared to plywood. The lowest mortality of *T. confusum* was found on concrete flagstone, too, even though this treatment did not significantly differ from the other surface materials. These results suggest the study of the influence of surface materials under more controlled laboratory conditions. An influence of surface materials on effectiveness is well known for synthetic chemical contact insecticides (Arthur and Peckman, 2006). However, the possible mechanism of influence is not clear for DE, as this light material piles up to several centimetres at 20 g/m² or more, preventing the contact of the insects moving on this layer to the ground.

Many studies examined the efficiency of DE at relatively high temperatures of 25°C or more, and relatively low relative humidity of 55 to 65 % (e.g. Athanassiou et al., 2005; 2008), because DE is known to be generally less effective at cool and humid conditions (Mewis and Ulrichs, 2001). However, in Central and Northern Europe cool and humid periods may occur even in summer at time of harvest. These field trials showed that 2.0 kg/t DE results in sufficient control even if temperatures are in the range of 15 to 20°C. If less than 1.0 kg/t DE are applied, *S. granarius* cannot be sufficiently controlled.

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References

Abbot, W.S., 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18, 265–267.

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

Arthur, F.H., 2000. Toxicity of diatomaceous earth to red flour beetles and confused flour beetles (Coleoptera: Tenebrionidae): effects of temperature and relative humidity. Journal of Economic Entomology 93, 526–532.

Arthur, F.H., 2003. Optimization of inert dusts used as grain protectants as residual surface treatments. In: Credland, P.F.A., Armitage, D.M., Bell, C.H., Cogan, P.M., Highley, E. (Eds), Proceedings of the Eighth International Working Conference on Stored-product Protection, 22-26 July 2002, York, UK, CAB International, Wallingford, UK, pp. 629–634.

Arthur, F.H., Peckman, P.S., 2006. Insect management with residual insecticides. In: Heaps, J.W. (Ed), Insect Management for Food Storage and Processing. AACC International, St. Paul, USA, pp. 167-173.

Athanassiou, C.G., Vayias, B.J., Dimizas, C. B., Kavallieratos, N.G., Papagregoriou, A.S. & Buchelos, C. Th., 2005. Insecticidal efficacy of diatomaceous earth against *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and *Tribolium confusum* du Val (Coleoptera: Tenebrionidae) on stored wheat: influence of dose rate, temperature and exposure interval. Journal of Stored Products Research 41, 47-55.

Athanassiou, C.G., Kavallieratos, N.G., Basileios, J., Vayias, B.J., Panoussakis, E.C., 2008. Influence of grain type on the susceptibility of different *Sitophilus oryzae* (L.) populations, obtained from different rearing media, to three diatomaceous earth formulations. Journal of Stored Products Research 44, 279-284.

Korunic, Z., 1998. Diatomaceous earths, a group of natural insecticides. Journal of Stored Products Research 34, 87–97.

Maceljski, M., Korunic, Z., 1972. Trials of inert dusts in water suspension for controlling stored-product pests. Plant Protection (Belgrad) 22, 119-128.

Mewis, I., Ulrichs,C., 2001. Action of amorphous diatomaceous earth against different stages of the stored product pests *Tribolium confusum*, *Tenebrio molitor*, *Sitophilus granarius* and *Plodia interpunctella*. Journal of Stored Products Research 37, 153-164.

Subramanyam, B., Roesli, R., 2000. Inert dusts. In: Subramanyam, B., Hagstrum, D.W. (Eds), Alternatives to Pesticides in Stored-Product IPM. Kluwer, Boston, USA, pp. 321-380.

Vayias, B.J., Athanassiou, C.G., 2004. Factors affecting the insecticidal efficacy of the diatomaceous earth formulation SilicoSec against adults and larvae of the confused flour beetle, *Tribolium confusum* du Val (Coleoptera: Tenebrionidae). Crop Protection 23, 565-573.

Zacher, F., Kunike, G., 1931. Beiträge zur Kenntnis der vorratsschädlinge. untersuchungen über die insektizide wirkung von oxyden und karbonaten. Arbeitsberichte der Biologischen Reichsanstalt 18, 201-231.