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Insecticidal potential of a synthetic zeolite against the cowpea weevil, *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae)

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ABSTRACT

The insecticidal potential of a synthetic zeolite was evaluated against the cowpea weevil, *Callosobruchus maculatus* (Fabricius). The synthetic zeolite was applied to concrete surfaces at 0, 2.5, 5, 10 and 20 g/m^2, and the mortality of adults was assessed after 1, 3, 6, 9, 12, 24, 36, 48, and 72 h at 28 °C and 65% r.h. The residual efficacy of zeolite applied at 5 g/m^2 was evaluated on concrete surfaces at 0, 1, 2, 3, and 4 months post-treatment. Adults of *C. maculatus* were exposed to cowpeas treated with zeolite at 0, 0.1, 0.5, 1, 2, 3, 4, and 5 g/kg. The number of eggs deposited on cowpea kernels and their hatchability were determined after 7 and 14 d, respectively. The cumulative adult mortality was recorded after 1, 2, 3, and 4 d, and adult progeny production after 42 d. The residual efficacy of zeolite on cowpeas was tested at 0, 1, 2 and 3 months after treatment. On concrete, zeolite applied at $\geq$ 5 g/m^2 resulted in 100% mortality of *C. maculatus* adults after 24–72 h of exposure. Zeolite at 5 g/m^2 exhibited high residual efficacy with 100% mortality of *C. maculatus* adults after 36 h exposure on treated surfaces for up to 4 months. The mortality of *C. maculatus* adults exposed to zeolite-treated cowpeas increased with increasing concentration and exposure time. The number of eggs laid by *C. maculatus*, number of kernels with eggs, and adult progeny production decreased with increasing zeolite concentration. Zeolite applied to cowpeas at 1 g/kg produced 100, 99 and 77% adult mortality at 1, 2, and 3 months post-treatment. Progeny production on zeolite-treated cowpeas was significantly lower than that on untreated cowpeas. These results show that the synthetic zeolite is effective on concrete surfaces and on cowpeas in controlling *C. maculatus*.

1. Introduction

Cowpeas, *Vigna unguiculata* (Linnaeus) Walpers, are a staple food legume in the tropical and subtropical areas such as Africa, Asia, Southern Europe, and Central and South America (Cherry et al., 2005). The cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae), is the most destructive insect pest of cowpeas in storage. This pest can contribute to significant quantitative and qualitative losses by creating holes in cowpea seeds, reducing seed germination, and even destroying the whole stored cowpeas (Credland et al., 1986; Seck et al., 1996; Jackai and Asante, 2003).

Conventional pesticides, including contact insecticides and fumigants, have been used for decades to control stored-product insects around the world (Subramanyam and Hagstrum, 1996; White and Leesch, 1996). However, due to the growing concern about insecticide residues in the environment and a rising market demand for insecticide-free foodstuffs, insect resistance to insecticides, and increasingly restrictive policies on conventional pesticides over the past years, the focus is on evaluating and adopting alternatives to conventional pesticides, such as the use of inert dusts (Subramanyam and Roesli, 2000; Kljajić et al., 2010).

Natural and synthetic zeolites are microporous, crystalline aluminosilicates (de Smedt et al., 2015). Zeolites have been widely used for odor adsorption, and in agriculture for improving soil properties, as a slow-release carrier of agrochemicals, and as a feed additive to adsorb mycotoxins (Reháková et al., 2004). An excellent review on potential and actual uses of zeolites in crop protection was published recently (de Smedt et al., 2015). The review did not discuss role of zeolites for stored-product insect management. The use of zeolites in feed supplements, and their use as a food additive suggests that they are not harmful to humans (de Smedt et al.,

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Zeolites are effective against insects because they can abrade or adsorb the epicuticular lipids causing rapid water loss resulting in death by desiccation (Puterka et al., 2000). Abrasion of epicuticular lipids is attributed to hard non-sorptive particles, while adsorption is attributed to sorptive particles (de Smedt et al., 2015). Although there are differences in the size, shape, and structure of zeolite particles compared with particles of diatomaceous earths (DE), the mode of action appears to be similar to that of DE particles (Subramanyam and Roesli, 2000).

There are a limited number of studies that examined effectiveness of zeolites against stored-product insect pests. Haryadi et al. (1994) showed that a natural zeolite found in Indonesia, applied to maize at 5% by weight (50 g of zeolite/kg of grain) effectively controlled the maize weevil, *Sitophilus zeamais* Motschulsky, during three months of storage. This is a very high rate (Andrić et al., 2012) and could result in adverse effects on grain physical properties. Kljajić et al. (2010) reported that natural zeolites originating from Serbia resulted in 97–100% mortality of the rice weevil, *Sitophilus oryzae* (Linnaeus), and 94–100% mortality of the red flour beetle, *Tribolium castaneum* (Herbst), after 21 d of exposure to wheat treated with 0.25, 0.50 and 0.75 g/kg followed by a 7 d recovery period on untreated wheat. Progeny suppression of *S. oryzae* and *T. castaneum* was more than 80% after 21 d of exposure of parental adults to wheat treated with zeolite at 0.75 g/kg. Andrić et al. (2012) also reported 100% mortality of *S. oryzae* and *T. castaneum* after 21 d of exposure to wheat treated with a natural zeolite at 1 g/kg followed by a 7 d of recovery period on untreated wheat. Progeny reduction in the two species ranged from 82 to 97%. A natural zeolite modified by treatment with ammonium (NH_4^+) ions, applied at the same concentration, showed much lower insecticidal potential with 36–56% mortality and 62–71% progeny reduction in *S. oryzae* and *T. castaneum*, respectively.

Information on the effectiveness of synthetic zeolites against stored-product insects is limited (Yao, 2014). Therefore, the present laboratory study was conducted to evaluate the efficacy and residual activity of Odor-Z-Way® (Odor-Z-Way®, Phillipsburg, Kansas, USA), a synthetic zeolite, against *C. maculatus* on concrete surfaces and cowpeas. Concrete surfaces simulated floors of grain storage facilities.

2. Materials and methods

2.1. Test insects

Cowpeas (Kroger Co., Cincinnati, Ohio, USA) were used to rear *C. maculatus* in a growth chamber at 28 °C and 65% r.h. in the Department of Grain Science and Industry, Kansas State University. Cowpeas were purchased from a local supermarket and frozen at −13 °C for at least 7 d prior to use in tests to kill any live insects present. The moisture content of cowpeas used in all experiments was about 10.6% and was determined using the Moisture Analyzer Model 930 (Shore Sales Co., Rantoul, Illinois, USA).

2.2. Zeolite

The synthetic zeolite average particle size was determined by laser diffraction method using Mastersizer 3000 (Malvern Instruments, Worcestershire, UK). Specific surface area of the fine zeolite was 596.0 ± 6.4 m^2/kg. Percentage of particles (D%) at or below a certain mean ± SE ($n = 3$) size (μm) of the zeolite were as follows: $D_{10} = 3.93 \pm 0.05$; $D_{50} = 20.30 \pm 0.13$; $D_{90} = 47.00 \pm 0.30$.

2.3. Concrete-poured petri dishes

Ready-mix concrete (Rockite, Hartline Products Co., Inc., Cleveland, Ohio, USA) was mixed with tap water to make a slurry, which was poured into plastic Petri dishes, 9 cm diameter, 1.5 cm high, and ~62 cm^2 surface area (Fisher Scientific, Denver, Colorado, USA). The slurry was allowed to dry overnight. The inside walls of the Petri dishes were coated with polytetrafluoroethylene (Insect-a-Slip®, BioQuip Products, Inc., Rancho Dominguez, California, USA) to prevent insects from crawling on the sides.

2.4. Treatment of concrete dishes with zeolite and exposure of adults

Concrete-poured Petri dishes were sprinkled with the synthetic zeolite to provide deposits or concentrations of 0 (control), 2.5, 5, 10, and 20 g/m^2. Twenty, unsexed *C. maculatus* adults (0–24 h old) were released into each dish, and dishes were placed inside the growth chamber at 28 °C and 65% r.h. Adult mortality was recorded after 1, 3, 6, 9, 12, 24, 36, 48, and 72 h. Independent replicate samples were examined over time. Each zeolite rate and exposure time combination was replicated four times.

2.5. Residual efficacy on concrete surfaces

The minimum zeolite concentration (5 g/m^2) that was effective against *C. maculatus* adults was used to determine efficacy immediately after treatment (time 0), and at 1, 2, 3, and 4 months post-treatment. The adults were exposed using protocols mentioned above.

2.6. Exposure of adults to zeolite-treated cowpeas

Cowpeas (50 g) were taken in separate 150 ml round plastic containers and treated with synthetic zeolite at concentrations of 0, 0.1, 0.5, 1, 2, 3, 4, and 5 g/kg of cowpeas. There were a total of 224–228 seeds in 50 g of cowpeas (mean ± SE [$n = 6$] number of seeds, 226 ± 1). After applying the required amount of synthetic zeolite, the containers were tightly closed with lids fitted with mesh screens and filter papers and shaken manually to ensure uniform coverage of zeolite powder on cowpeas. Twenty-five unsexed, 0–24 h old *C. maculatus* adults were introduced into each container and the containers were closed with perforated plastic lids covered with plastic mesh screen to allow for air ventilation. The containers were placed inside the growth chamber at 28 °C and 65% r.h. Cumulative adult mortality was determined after 1, 2, 3, and 4 d on the same set of samples. After 7 d, cowpeas in each treatment were examined under a stereomicroscope to record number of eggs deposited on cowpea kernels and the number of kernels with eggs. Hatchability of the eggs was determined after another 7 d (on day 14), and number of adult progeny produced was counted after 42 d. The original number of introduced adults (25) was subtracted from the number of adult progeny produced before subjecting data to statistical analysis. Each concentration of zeolite was replicated four times.

2.7. Residual efficacy of zeolite on cowpeas

Zeolite was applied at 0 (control) and 1 g/kg of cowpeas (50 g/150 ml plastic containers) for testing insecticidal efficacy over time. Cowpeas were treated as explained in section 2.6. above. Untreated and zeolite-treated cowpeas were infested with 25 unsexed adults of *C. maculatus* and placed in a growth chamber at 28 °C and 65% r.h. Efficacy against *C. maculatus* was assessed immediately after treatment (time 0) and at 1, 2, and 3 months post-treatment.