Journal of Stored Products Research 68 (2016) 93–101

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Insecticidal potential of zeolite formulations against three stored-grain insects, particle size effect, adherence to kernels and influence on test weight of grains

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ARTICLE INFO

Article history:
Received 23 March 2016
Received in revised form
16 May 2016
Accepted 16 May 2016
Available online 24 May 2016

keywords:
Insecticidal effect
Zeolite
Particle size
Stored-product insects
Grain protectants

ABSTRACT

Laboratory studies were conducted in order to evaluate the insecticidal potential of three commercially available zeolite formulations against adults of *Sitophilus oryzae*, *Tribolium confusum* and *Oryzaephilus surinamensis* in wheat. For each zeolite formulation, three particle size levels were tested, i.e. 0–50, 0–150 and 0–500 μm. Zeolites were applied at three dose rates, 250, 500 and 1000 ppm, and insect mortality was assessed after 2, 7, 14 and 21 d of exposure. After the final mortality count, dead and alive insects were removed and offspring numbers were determined following an additional period of 65 d. In another series of laboratory bioassays, the effect of zeolite application on the test weight of wheat, maize and barley, as well as the adherence of zeolite particles to wheat, maize, barley and rice kernels was also measured. *Oryzaephilus surinamensis* was the most susceptible species to zeolite application, regardless of the zeolite formulation, dose and particle size level tested, whereas *T. confusum* was the most tolerant. No significant differences in efficacy were recorded among the three tested zeolite formulations. At the same time, particle size did not affect zeolite efficacy, at least for the particle size levels tested. All zeolites caused a significant reduction on the test weight of the treated grains. Moreover, zeolite particles showed different adherence among wheat, maize, barley and rice kernels. The results of the present study indicate that zeolites can be used with success as grain protectants, but there is a considerable effect on some physical properties of the grains. This information aims to encourage further evaluation of zeolites as grain protectants.

1. Introduction

Storage insects are responsible for considerable quantitative and qualitative losses of agricultural products, mainly cereals and legumes (Phillips and Throne, 2010). Current control methods are mainly based on the use of residual insecticides and fumigants (Boyer et al., 2012), however, the development of resistance to commonly used grain protectants and fumigants (Guedes and Pereira, 2008; Pereira et al., 2009; Sağlam et al., 2015; Tay et al., 2016), as well as public concerns about insecticide residues in food stuff, have encouraged the development of alternative methods for the control of storage infestations.

Zeolites are microporous, chemically inactive, aluminosilicate minerals that are found in nature and, like diatomaceous earth, belong to the group of inert dusts that contain natural silica (Holmes, 1994; Subramanyam and Roesli, 2000). Due to their unique physicochemical properties (thermal stability, high sorption and ion exchange capacity etc) zeolites have found various industrial, agricultural and environmental applications (Payra and Dutta, 2003). They are used as soil amendments for the enhancement of soil physical properties (Ramesh and Reddy, 2011), as well as fertilizer carriers that permit slow nutrient release (Reháková et al.,

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http://dx.doi.org/10.1016/j.jspr.2016.05.003
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2004). Moreover, they are used as animal feed additive, as they absorb toxins that can be deleterious to animals (Kolosova and Stroka, 2011; Wu et al., 2013), whereas they have many applications in environmental engineering, such as their use as filters or adsorbents for soil or water remediation (Xiubin and Zhanbin, 2001; Wang and Peng, 2010; Misaelides, 2011; Margeta et al., 2013). Recently, De Smedt et al. (2015) reviewed the use of zeolites as crop protection agents and highlighted their potential to successfully control various insect pests and fungal diseases.

Lately, zeolite has also been evaluated for the protection of durable commodities from post-harvest infestations. However, in contrast with diatomaceous earth, which has been extensively evaluated against stored-product insects (Golob, 1997; Subramanyam and Roesli, 2000; Athanassiou et al., 2014; Kavallieratos et al., 2015; Malia et al., 2016), the available relative studies on the insecticidal potential of zeolite against stored-product insects are generally few (Haryadi et al., 1994; Kljajić et al., 2010; Andrić et al., 2012; Bodroža-Solarov et al., 2012). For instance, Andrić et al. (2012) investigated the insecticidal potential of two natural zeolites against adults of the rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae), and the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), and reported mortality levels that reached 96% and 100% after 21 d of exposure to wheat treated with 1000 ppm for *S. oryzae* and *T. castaneum*, respectively. Similarly, two zeolite formulations caused >91% and >94% mortality of *T. castaneum* and *S. oryzae* adults, respectively, after 21 d of exposure even at 250 ppm (Kljajić et al., 2010).

There are several inert dust properties that have been associated with their insecticidal effect. For example, particle size is an important variable in the case of diatomaceous earths, where, in general, smaller particles provide increased insecticidal effect than larger ones (Korunić, 1997, 1998; Vayias et al., 2009). Nevertheless, it is generally considered that the addition of diatomaceous earths on grains negatively influences their bulk density, while this reduction is associated with particle size (Korunić et al., 1996; Korunić, 1997, 1998). This negative influence is regarded as the major drawback in the wider use of diatomaceous earths, but their effect varies among different types of grains (Korunić, 1998; Athanassiou and Kavallieratos, 2005; Kavallieratos et al., 2005). Still, there are no data available for the effect of zeolites on bulk densities of different grains.

The objective of the present study was to investigate the insecticidal effect of three natural zeolite formulations against adults of the confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae), the saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) and *S. oryzae*. The tested species are major stored-product pests, commonly encountered in commercial mills and grain storage facilities (Athanassiou and Buchelos, 2001; Trematerra et al., 2004, 2007). Moreover, the effect of particle size on the insecticidal efficacy of the tested zeolites was also examined. Finally, the effect of zeolite treatment on the test weight of different commodities, as well as the adherence of zeolite particles to various grains were evaluated.

2. Materials and methods

2.1. Test insects

Adults of *S. oryzae*, *T. confusum* and *O. surinamensis*, less than one-month old, were used for the bioassays. All species were reared at the Laboratory of Entomology and Agricultural Zoology of the University of Thessaly, at 26 °C, 55% relative humidity (r.h.) and continuous darkness. From the species tested, *S. oryzae* was reared on intact hard wheat kernels, whereas *T. confusum* and *O. surinamensis* were reared on soft wheat flour and oat flakes, respectively.

2.2. Commodities

Clean, uninfested and untreated hard wheat (variety Neos Cosmos) with 13% moisture content was used for the mortality bioassays. Moisture content was determined with a Multitest moisture meter (Multitest, Gode SAS, Le Catelet, France). Soft wheat (variety Vergina), maize (hybrid Dias), barley (variety Persephone) and rice (variety Thaibonnet) were used for the test weight and adherence tests. Moisture content of all commodities used in the test weight and adherence tests was adjusted prior to the initiation of the tests and ranged between 11 and 11.4%.

2.3. Zeolite formulations

Three commercial zeolite formulations were used in the bioassays: 1. Zeoprofeed Land 93 (ZeoProfit Hellas P.C., Thesaloniki, Greece) (country of origin: Turkey, particle size: 0–800 μm), 2. Zeofeed (ZeoProfit Hellas P.C., Thesaloniki, Greece) (country of origin: Slovakia, particle size: 0–1000 μm), and 3. a bulk (raw) zeolite (country of origin: Bulgaria, particle size: 0–1000 μm). The first two zeolite products were provided by ZeoProfit Hellas P.C., whereas the third product was purchased from a local agricultural supply store. The first two zeolites tested were for animal feed, while the bulk zeolite was meant for soil amendment. All zeolites were sieved prior to the experiments with the appropriate sieves, in order to achieve three levels of particle size distribution (0–50, 0–150 and 0–500 μm).

2.4. Mortality bioassays

In this series of bioassays, the insecticidal efficacy of all zeolites was assessed against *S. oryzae*, *O. surinamensis* and *T. confusum* adults in hard wheat. One-kg lots of wheat were placed in glass jars and dusted with the tested zeolites at three dose rates, i.e. 250, 500 and 1000 ppm, with separate jars for each zeolite and particle size level. Jars with treated wheat were shaken manually for 2 min to achieve equal distribution of zeolite in the entire wheat mass. An additional series of lots was left untreated and served as control.

The bioassays were conducted in plastic, cylindrical vials (3 cm in diameter, 8 cm in high). Fluon (Northern Products, Rhode Island, USA) was applied on the top quarter of the inside of each vial to prevent insects from escaping and each vial was filled with 20 g of treated wheat. Afterwards, twenty adult beetles were placed in each vial, with separate vials for each species. Subsequently, all vials were placed at 25 °C, 55% r.h. and continuous darkness. Insect mortality was determined after 2, 7, 14 and 21 d of exposure. There were three replicates for each treatment, whereas each bioassay was repeated three times (3 series of vials) by preparing new lots of treated and untreated grains each time (3 × 3 = 9 vials for each treatment). After the final mortality count, all adults (dead and alive) were removed from the vials, and the vials were left in the aforementioned conditions for an additional period of 65 days. After the termination of this interval, the emerged individuals in each vial were recorded.

2.5. Test weight

The zeolite tested here was Zeofeed at two particle size levels (0–50 and 0–500 μm). A modification of a previously proposed protocol for diatomaceous earth formulations (Korunić et al., 1996; Korunić, 1997; Athanassiou et al., 2011) was followed, in order to assess the impact of zeolite treatment to the test weight (bulk