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Insecticidal activity of three diatomaceous earths on lesser grain borer, *Rhyzopertha dominica* F., and their effects on wheat, barley, rye, oats and triticale grain properties

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A B S T R A C T

This study aimed to evaluate insecticidal activity of three diatomaceous earths DEs, two originated from Serbia (DE S-1 and DE S-2) and one commercial formulation (Protect-It, Hedley Technologies Ltd. Canada) applied at rates of 0.5, 1.0 and 1.5 g/kg (500, 1000 and 1500 ppm) on *Rhyzopertha dominica* in wheat, barley, rye, oats and triticale grains and their effects on mass of kernels and several properties: adherence, hectolitre mass, moisture, protein and ash contents. Mortality of *R. dominica* adults increased with exposure duration and DEs rates. In all tested grains after the longest exposure period (21 days), 1.0 and 1.5 g/kg rates of Protect-It, and 1.5 g/kg rate of DE S-1 and DE S-2 (in barley) caused 95–100% mortality. Offspring reduction of ≥95% was recorded after the application of 1.0 and 1.5 g/kg of Protect-It and 1.5 g/kg of DE S-1. The lowest weight of damaged grain was found after applying 1.0 and 1.5 g/kg of DEs to all grain types, and the highest in rye and wheat treated with 0.5 g/kg DE S-1 and DE S-2, respectively. The highest DEs adherence of 83–95% was detected in wheat, and 87–92% in oats, and the lowest of 71–77% in rye and 59–73% in triticale. All DEs significantly reduced hectolitre mass of all grains, especially Protect-It, 3.6–8.8%. No negative effects of DEs were detected on moisture contents, and the contents of proteins and ashes in the grains. The changes were due to the activity of *R. dominica.*

1. Introduction

The lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera, Bostrichidae) is one of the most important primary pests of stored products, which is able to infest all types of cereal grains (Rees, 2004; Mason and McDonough, 2012). Modern methods of protection of stored grains and other plant products from insect pests strive towards optimizing the use of different techniques and methods within integrated pest management (IPM) programmes. Diatomaceous earths (DEs) have been identified as natural materials and promising alternatives to stored-grain protectants, such as residual inseciticides (Athanassiou et al., 2008a, 2014, 2016; Andrić et al., 2012; Kavallieratos et al., 2005, 2010; Korunić, 2013; Shah and Khan, 2014).

Available data show that stored-product insects are variably susceptible to inert dusts, resulting from their different morphological, physiological and ecological characteristics. Among coleopterans, the species most susceptible to DEs include those in the genus *Cryptolestes*, and the somewhat less susceptible genera of *Sitophilus* and *Oryzaephilus*, while species in the genera *Tribolium* and *R. dominica* are the least susceptible (Korunić, 1998; Fields and Korunić, 2000; Subramanyam and Roesli, 2000; Kavallieratos et al., 2010; Athanassiou et al., 2011). Also, the effectiveness of DEs vary depending on their geographic origin (Athanassiou et al., 2011; Andrić et al., 2012) and physical properties (Korunić, 1997; Vayias et al., 2009), presence of damage or broken kernels (Kavallieratos et al., 2007), and on the type of treated grains, i.e. their specific properties (Athanassiou and Kavallieratos, 2005; Athanassiou et al., 2003, 2005, 2008b; Kavallieratos et al., 2005; Davis and Bry, 1985), and differences between cultivars of any particular grain type

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(Kavallieratos et al., 2010). Kavallieratos et al., (2005) tested two commercial DE formulations, Insecto and SilicoSec, against *R. dominica* by applying them to eight grain types and found significant differences between the two formulations and especially among the examined grains.

As reported by Rees (2004) and Edde (2012), *R. dominica* spends most of its life inside kernels, feeding on its endosperm, which causes damage and changes in grain physicochemical properties. Also, research results and some observations from practical uses of DEs as control treatments against stored-grain insects show that DEs, when mixed with grain at the currently recommended rate of 500–3500 g/t (ppm), may affect some physical and mechanical properties of the bulk commodity and/or technological quality of grain and flour (Korunić, 1997; Korunić et al., 1996, 1998; Subramanyam and Roesli, 2000; Bodroža-Solarov et al., 2012; Shah and Khan, 2014). However, insufficient data are available on changes in the properties of infested grain treated with DEs as inert dust, especially in experiments comparing the effects of different DEs and stored-product insect pests on different types of grains. The objective of this study was therefore to assess some grain properties, i.e. adherence on the kernels, hectolitre mass, and contents of moisture, proteins and ashes - in several grains infested with *R. dominica*: wheat, barley, rye, oats and triticale, as influenced by DEs originating from Serbia, and compared with a commercialized DE product, Protect-It, after treatment with rates determined in preliminary trials.

2. Material and methods

2.1. Test insect, diatomaceous earths (DEs) and grains

The trial was carried out on laboratory populations of *R. dominica* reared in an insectary, according to procedures described by Harein and Soderstrom (1966), and Davis and Bry (1985). Insects were reared in 2.5 L glass jars containing soft wheat grain with moisture degree below 12%. Temperature in the insectary was 26 ± 1 °C, and relative humidity 60 ± 5%. Unsexed 2–4 week old adults were used in all trial variants.

Two DE samples from Serbia, DE-S1 and DE-S2, were tested, and a comercial DE formulation, Protect-It (Hedley Technologies Inc. Canada), was used as a standard for comparing the effectiveness of the Serbian DEs. Contents of SiO_2 in DE-S1 and DE-S2 were 78.8% and 63.2%, respectively (Andrić et al., 2012). The product Protect-It contains 83.7% SiO_2 and 10% silica aerogel (Arnaud et al., 2005).

Six commercially available grain varieties originating from Center for Small Grains Kragujevac, Serbia, were used. The varieties were: wheat cultivar Vizija, barley cultivar Rekord, oats cultivar Vranac, rye cultivar Raša and triticale cultivar Favorit. All the tested grain varieties were infestation-, pesticide-, and dockage-free. Some properties of tested grain varieties are shown in Table 1.

Moisture content of all grain varieties at the beginning of the experiments, determined by moisture meter (Motomco Inc, Canada) according to AACC method 44–11 (AACC, 1995), were 11.0–11.8%.

2.2. Insecticidal activity of DEs on R. dominica

Nine 0.5 kg lots were prepared for each grain type, one for each application rate of each DE. The application rates were 0.5, 1.0 and 1.5 g/kg (500, 1000 and 1500 ppm) for all three DEs. The lots were placed in glass jars of 1000 mL volume. In order to secure equal distribution of the DEs, the grain was shaken manually for 2–3 min and then mixed on a rotary mixer for 10 min. The next day, four samples of 50 g were taken from each DE and grain type's lot and each placed into a 200 mL plastic vessel. The quantity of 50 g was weighed on an analytical balance (Mettler 609-B6, Zurich, Switzerland). Subsequently, 25 adults of *R. dominica* were released into each vessel and the vessel was topped with cotton cloth and fixed with a rubber band. The same procedure was applied to untreated grain samples which served as a Control A. All vessels were placed in an incubator (XO 1450 special, Iskra, Loka, Slovenia) set to 26 ±1 °C temperature and 60 ±5% r. h. Insect mortality was determined after 7, 14 and 21 days of contact with treated or untreated grain types. After the last mortality count, both dead and living adults were removed and all vessels were returned to the incubator for 7 additional weeks under the same (described) conditions. Progeny emergence/supression was determined by counting insects in treated and control grain varieties sieved out with different mesh sizes in order to remove only insects, while dusts were returned to each vessel. After progeny count, whole grains, damaged grains and dust were weighed on analytical balance (Mettler 609-B6, Zurich, Switzerland) for each sample (50 g) of treated or untreated (Control A) grain types. The whole procedure was repeated twice.

2.3. Effects on grain properties

A method described by Korunić (1997) was used to determine the adherence of each DE to kernels of each grain type. Initially, six lots of 500 g (six replicates) were prepared of each grain type variety previously cleaned by sieving for 1 min through 2 mm mesh. Next, the cleaned grain type lots were placed in glass jars (1000 mL volume) and 0.5 g/kg (500 ppm) of each DE was applied before the tightly-closed jars were shaken manually for 1 min. The treated grain was sieved for 1 min using the same mesh size, and the sieve had a closed lid at the bottom. Dust was then collected from the lid and weighed on the analytical balance. This quantity was interpreted as the percentage of each DE adhering to the kernels of each type. Test weight of all untreated and treated grain types (each DE was applied at 1.0 g/kg (1000 ppm) rate following the described procedure) was determined using a Schopper scale (Technica-Železniki, Slovenia). Test weight measurements were repeated ten times for each grain type. Whole grain, damaged grain and dust were weighed, combined into the orginal sample of 50 g and

Table 1
Some properties of grain varieties selected in Center of Small Grains, Kragujevac, Serbia.

Grain type	Properties					Kernel shape
	AM (g)[a]	HM (kg/L)[b]	Protein content (%)	Ash content (%)	Kernels (naked/covered)	
Wheat (Vizija)	35.2	85.1	13.0	1.78	naked	ovoid
Barley (Rekord)	39	71.5	11.9	2.42	covered	oval elliptical
Oats (Vranac)	29	50.0	13–14	3.48	covered	needle
Rye (Raša)	36	73.9	15.8	2.0	naked	elongated
Triticale (Favorit)	44	81.0	12.4	1.67	naked	semi-elongated

[a] Absolute mass.
[b] Hectoliter mass.