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Yerli Diatom Toprağının *Sitophilus oryzae* (Linnaeus, 1763) (Coleoptera: Dryophtoridae)'ye Karşı İnsektisidal Aktivitesi

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ÖZET: Bu çalışmada, yerli bir diatom toprağı olan Diaterra®'nın, *Sitophilus oryzae* (Linnaeus, 1763) (Coleoptera: Dryophtoridae), ergin bireyleri üzerindeki insektisidal etkisi, 20 ± 1°C sıcaklık ve %55±5 bağıl nem koşullarında galvanize sac yüzey üzerinde değerlendirilmiştir. Denemeler, dört farklı dozda (0.25, 0.50, 1.00 ve 2.00 g/m²) üç tekerrürlü ve üç tekrar olacak şekilde yürütülmüştür. Ölü böcek sayıları 24, 48, 72, 96, 120, 144, 168, 192 ve 216. saatlerde kaydedilmiştir. İlk 24 ve 48 saatlik uygulama sürelerinde herhangi bir ölüme rastlanmamış, ancak 72. saat itibarıyla ölüm kaydedilmeye başlanmıştır. 72. saatte en yüksek dozda %40.2 olarak belirlenen ölüm oranı aynı dozda 96. saatten itibaren %50'yi aşmıştır. En yüksek ölüm oranı, 2.00 g/m² dozda 216. saatte %83.5 olarak kaydedilmiş olup aynı zaman aralığında diğer dozlardaki mortalite %50'ye ulaşamamıştır. Ayrıca maruz kalma süresinin ölümler üzerindeki etkisini değerlendirmek amacıyla, Diaterra®'nın 2 g/m² dozunda ergin *Sitophilus oryzae* bireyleri için LT_{30}, LT_{50} ve LT_{90} değerleri hesaplanmıştır. Elde edilen tüm bu bulgular genel olarak değerlendirildiğinde, özellikle yüksek doz ve uzun süreli temas koşullarında Diaterra®'nın *S. oryzae* ergin bireyleri üzerinde önemli düzeyde etki gösterdiği görülmüştür. Ancak, bu etkinliğin daha kapsamlı bir şekilde değerlendirilebilmesi için farklı dozların kullanıldığı ve gerçek depo koşullarını yansıtan daha ayrıntılı çalışmalara ihtiyaç duyulmaktadır.

Anahtar Kelimeler *–Diaterra®, Diatom toprağı, insektisidal etki, Sitophilus oryzae*

Investigation of the Insecticidal Activity of Native Diatomaceous Earth Against *Sitophilus oryzae* (Linnaeus, 1763) (Coleoptera: Dryophtoridae)

ABSTRACT: In this study, the insecticidal effect of a locally produced diatomaceous earth, Diaterra®, on adult individuals of *Sitophilus oryzae* (Linnaeus, 1763) (Coleoptera: Dryophtoridae) was evaluated on a galvanized sheet surface under controlled conditions of 20 ± 1°C temperature and 55 ± 5% relative humidity. The experiments were conducted at four different doses (0.25, 0.50, 1.00, and 2.00 g/m²) with three replications and three repetitions per dose. The number of dead insects was recorded at 24, 48, 72, 96, 120, 144, 168, 192, and 216 hours. No mortality was observed within the first 24 and 48 hours of exposure; however, deaths began to occur after 72 hours. At 72 hours, the highest mortality rate was recorded at 40.2% for the highest dose, exceeding 50% at the same dose after 96 hours. The maximum mortality rate (83.5%) was observed at the 2.00 g/m² dose at 216 hours, while mortality at other doses did not reach 50% during the same period. Furthermore, to evaluate the effect of exposure duration on mortality, LT_{30}, LT_{50}, and LT_{90} values were calculated for adult *S. oryzae* individuals exposed to the 2 g/m² dose of Diaterra®. When all these findings are evaluated in general, it has been observed that Diaterra® has a significant effect on adult *S. oryzae* individuals, particularly under conditions of high dosage and prolonged contact. However, to comprehensively assess its efficacy, further detailed studies under different dosages and conditions simulating real storage environments are required.

Keywords *–Diaterra®, Diatomaceous Earth, insecticidal effect, Sitophilus oryzae*

1. Introduction

Sitophilus oryzae (Linnaeus, 1763) (Coleoptera: Dryophtoridae) is a species commonly found in stored grains in tropical and subtropical regions (Kaundal et al. 2023). Adults of *S. oryzae* measure 2.5–4 mm in length, are dark brown in colour, slender and cylindrical in shape, and are characterized by a long rostrum and punctures on the pronotum (Hagstrum et al. 2013). Females use their rostrum to bore holes into intact grains, into which they deposit their eggs. A single female can lay on average 300–400 eggs. The emerging larva feeds and develops inside the grain kernel, then pupates, and finally the adult emerges by exiting from the grain. The developmental duration of *S. oryzae* varies depending on temperature and humidity conditions. Under temperatures of 27–30°C and relative humidity of 70%, the life cycle is completed in approximately 25–30 days (Rees, 2004). *Sitophilus oryzae* causes both qualitative (nutritional loss) and quantitative (weight reduction) damage in stored grains, leading to significant economic losses, particularly in wheat, rice, and maize. Since larvae develop inside the kernel by hollowing it out, the damage is not always externally visible. This concealed feeding reduces the marketability and export value of grains (Campbell and Arbogast, 2004; Hagstrum et al. 2012). According to FAO (2011), losses due to inadequate storage conditions and other biotic and abiotic factors range between 10-30%. To mitigate these losses, integrated management practices are prioritized, including regular cleaning of storage facilities, application of low temperatures, and chemical control through fumigants such as phosphine (Rajendran and Muralidharan, 2001). Insecticides are also widely used in storage facilities, flour mills, and silos in Türkiye and many other countries to control *S. oryzae* populations. In Türkiye, the active ingredients of the registered insecticides used in the control of *S. oryzae* are known to include aluminium phosphide, magnesium phosphide deltamethrin, phosphine, pirimiphos-methyl, malathion and sulfuryl fluoride (Anonymous, 2025). In addition to the benefits provided by insecticides, it is essential to emphasize the potential adverse impacts on non-target species, the environment, and human health (Araújo et al. 2023). Reports indicate that a slight resistance to the active ingredient Malathion has developed in *S. oryzae* populations in Türkiye (Alpkent et al., 2023). Due to their low toxicity, effectiveness even at small quantities, and abundant availability in Türkiye, diatomaceous earths, which are classified among inert dusts, have gained increasing importance in recent years.

Diatomaceous earth (DE), derived from fossilized diatoms (microscopic algae), has attracted considerable attention as a natural insecticide in pest management, particularly within the grain industry (Losic and Korunić, 2017). DE consists primarily of silicon dioxide (SiO_2) and exhibits unique physical properties that contribute to its efficacy against insect pests. Its insecticidal action is largely physical, as it absorbs epicuticular lipids from insects, leading to desiccation and dehydration. Unlike synthetic insecticides, DE is non-toxic to mammals and leaves no harmful chemical residues, making it a safer alternative for grain protection. In recent years, research has increasingly focused on evaluating the effectiveness of DE against agricultural, medical, and urban pests. Integrating DE with other pest control methods, such as biological agents and plant extracts, holds promise for more comprehensive and environmentally friendly pest management strategies (Korunić et al. 2015). Further development of DE-based products that meet grain quality and regulatory standards may enhance their acceptance in the grain industry, particularly as global pest management increasingly shifts toward sustainable and safe alternatives to synthetic pesticides (Korunić, 1998; Saw et al. 2025).

Numerous studies have been conducted to evaluate the efficacy of diatomaceous earth against a wide range of stored product pests. These studies have shown that the efficacy of diatomaceous earth varies depending on several parameters, such as the species of the target pest (Athanassiou et al. 2007; Atay et al. 2023; Ogreten et al. 2025), the structural properties of the DE (Gokavi et al. 2021; Henteş and Işıkber, 2024), its formulation (Athanassiou et al. 2004; Agrafioti et al. 2023), and the type of surface to which it is applied (Ertürk et al. 2020; Baliota and Athanassiou, 2023; Mortazavi et al. 2024).

This study was conducted to demonstrate the effectiveness of Diaterra®, a natural diatomaceous earth obtained from Türkiye, on *S. oryzae* adults on galvanised sheet surface. The aim of this study is not only to demonstrate the effect of Diaterra® on *S. oryzae* adults, but also to contribute to the literature on the effect of diatomaceous earth on galvanized sheet surface. The ultimate goal is to establish an environmentally friendly and sustainable control method against the target pest.

2. Material and Methods

2.1. Insect rearing

Approximately 400–500 adult individuals of *Sitophilus oryzae* were collected from the culture maintained at the Insect Rearing Laboratory of Tokat Gaziosmanpasa University Faculty of Agriculture and placed into 1 liter glass jars containing 300 grams of whole wheat each. The jar lids were covered with muslin cloth to prevent insect escape while allowing airflow. After an oviposition period of 48 hours, the adult *S. oryzae* individuals were removed from the jars. The emergence of new adults was monitored, and once a sufficient number was obtained, the experiments were initiated. Throughout the study, the *S. oryzae* culture was continuously maintained (Alkan et al. 2024).

2.2. Diatomaceous earth

The diatomaceous earth product, Diaterra® (Organo Mineral Agriculture Mining Industry Trade Import Export Limited Company), was utilized in this study. Its composition includes 72.80% SiO_2, 9.00% Al_2O_3, 2.40% Fe_2O_3, 1.70% CaO, 2.40% MgO, 0.10% MnO, 0.20% P_2O_5, 0.20% Na_2O, 0.90% K_2O, and 0.40% TiO_2. The particle size of Diaterra® ranged from 2.594 µm to 39.745 µm, with an average particle diameter of 9.492 µm (Alkan et al. 2024).

2.3. Application of the diatomaceous earth

Bioassay was performed under controlled conditions at a temperature of 20 ± 1 °C and a relative humidity of 65 ± 5%. Four different doses of the treatment (0.25, 0.50, 1.00, and 2.00 g/m²) were applied, each on galvanized sheet surfaces measuring 15 × 13.5 × 0.25 cm. Each dose was arranged in three replicates, with three repetitions per replicate. The diatomaceous earth was evenly distributed over the surface of the galvanized sheet using a glass Drigalski spatula. For each experimental unit, 20 adult insects were introduced. To ensure direct contact between the insects and the diatomaceous earth, the test arenas were covered with plastic petri dish lids measuring 90 mm in diameter. Additionally, 0.5 grams of whole wheat were provided in each unit as a food source for the insects. Insect mortality was recorded at intervals of 24, 48, 72, 96, 120, 144,168, 192 and 216 hours post-application. In control groups, insects were maintained in environments without diatomaceous earth, while a registered insecticide, K-Obiol® (Deltamethrin 25 g/l + Piperonyl Butoxide 250 g/l), was used as a positive control.

2.4. Statistical analysis

Initially, the raw mortality data were converted into percentage values and then subjected to an ArcSine transformation to normalize the proportional data, following the recommendations of Zar (1999) and Warton et al. (2011). The transformed mortality rates were analysed using analysis of variance (ANOVA), and differences among treatment groups were evaluated through Tukey's multiple comparison test at a significance threshold of 0.05. Statistical analyses were performed employing the General Linear Model procedure available in MINITAB Release 18, as outlined by McKenzie and Goldman (2005). Additionally, the analysis of means (ANOM), a variant of ANOVA commonly applied in quality improvement contexts, was utilized to compare group means (Pallmann and Hothorn, 2016).

3. Results

The effects of the commercially available diatomaceous earth, Diaterra®, applied at different doses (0.25, 0.50, 1, and 2 g/m²) on the mortality rates of adult *S. oryzae* were monitored at a constant temperature of 20 °C for up to 216 hours. In the negative control group, mortality remained below 2% throughout the observation period, representing the lowest statistically observed level. This indicates that no experimental effect occurred aside from natural mortality. The low dose (0.25 g/m²) maintained mortality below 1% throughout the observation period and was statistically similar to the control. In contrast, at a dose of 0.50 g/m², an increase in mortality was observed from the 72nd hour, reaching approximately 24.2% by the 216th hour ($F=42.36$, $DF=5.45$, $P<0.05$). Although this increase was statistically significant, it remained limited compared to higher doses. Higher concentrations demonstrated a clear dose–response relationship. At an application rate of 1 g/m², mortality exceeded 25% at 72 hours ($F=43.82$, $DF=5.45$, $P<0.05$) and increased to 41% by 216 hours ($F=42.36$, $DF=5.45$, $P<0.05$). The highest dose, 2 g/m², was the most effective, resulting in mortality exceeding 40.2% at 72 hours and 83.5% at 216 hours ($F=42.36$, $DF=5.45$, $P<0.05$). These findings indicate a positive and statistically significant correlation between diatomaceous earth dosage and exposure duration with insect mortality rate. The reference insecticide, K-Obiol®, achieved 100% mortality at all time points, confirming the expected complete effect (Table 1.)

Table 1. Mortality (±SE) of *Sitophilus oryzae* adults exposed on galvanized sheet surface treated with different Diaterra® diatomaceous earth doses and time

Treatment	**24 h**	**48 h**	**72 h**	**96 h**	**120 h**	**144 h**	**168 h**	**192 h**	**216 h**
Control	0.00±0.00b	0.00±0,00b	0.88±2.23d	1.41±2.26d	1.41±2.26d	1.41±2.26d	1.41±2.26d	1.59±2.76d	1.59±2.76de
0.25 g/m²	0.00±0.00b	0.07±0.63b	0.31±1.08d	0.31±1.08d	0.46±1.66d	0.92±1.85d	0.92±1.85d	0.92±1.85d	0.92±1.85e
0.50 g/m²	0.00±0.00b	0.00±0.00b	9.04±8.19cd	9.67±8.30cd	16.86±4.90cd	19.53±5.63cd	21.56±6.45cd	22.17±7.06cd	24.15±8.48cd
1 g/m²	0.00±0.00b	0.00±0.00b	25.54±16.96bc	30.68±17.51bc	30.68±17.51bc	33.82±15.98bc	34.89±16.18c	37.75±16.47c	41.11±16.28c
2 g/m²	0.00±0.00b	0.00±0.00b	40.21±7.65b	55.78±16.25b	60.65±17.83b	68.16±15.46b	75.54±15.67b	78.03±2.76b	83.45±10.59b
K-Obiol®	100.00±0.00a*	100.00±0.00a	100.00±0.00a	100.00±0.00a	100.00±0.00a	100.00±0.00a	100.00±0,00a	100.00±0.00a	100.00±0.00a

*When examining the columns, the ratios containing the same letter are not statistically different according to the Tukey test ($P<0.05$)

To assess the effect of exposure time on mortality, LT_{30}, LT_{50}, and LT_{90} values of Diaterra® applied at a dose of 2 g/m² on galvanized sheet surfaces against adult *Sitophilus oryzae* were calculated. Based on the data obtained, the LT_{30}, LT_{50} and LT_{90} values for *S. oryzae* were calculated as 84.602, 128.998 and 237.494 hours, respectively (Table 2).

Table 2. Lethal time values (LT_{30}, LT_{50}, and LT_{90}; hours) of Diaterra® applied at 2 g/m² on galvanized sheet surfaces against *Sitophilus oryzae* adults

Slope	**LT_{30} (confidence limits)**	**LT_{50} (confidence limits)**	**LT_{90} (confidence limits)**	**Heterogeneity**	**Chi-square**
0.012±0.001	84.602 (61.301-101.344)	128.998 (113.229-145.408)	237.494 (209.652-283.573)	7.0965	553.53

4. Discussion

Diatomaceous earths obtained from different geological sources, or even from the same region but possessing distinct physical characteristics, may exhibit variable efficacy as insecticides against stored-product pests due to these properties (Korunić, 2013). Moreover, the insecticidal activity of diatomaceous earth is influenced by multiple factors, including particle size and shape, application dose, treated surface, formulation type, insect species, crop type, relative humidity, and temperature (Athanassiou et al. 2007; Rojht et al. 2010; Gokavi et al. 2021; Agrofioti et al. 2023; Ertürk et al. 2020). Islam et al. (2010) reported 98% mortality of *Sitophilus oryzae* after 7 days of exposure at 25°C when applying the Protect-It® formulation at a dose of 300 ppm. Similarly, Athanassiou et al. (2005) observed mortality rates of 33% and 46% at doses of 0.25 g kg^{-1} and 0.5 g kg^{-1}, respectively, after 7 days at 22 °C using SilicoSec®, and noted that increasing the temperature to 25 °C raised mortality at the same low dose to 38%. These findings indicate that higher temperatures can significantly enhance the efficacy of diatomaceous earth, and differences in formulation can also influence the outcomes.

The efficacy of diatomaceous earth depends on factors including particle size, surface area, silica content, and application rate. Athanassiou et al. (2007) reported that application of the diatomaceous earths, Insecto, PyriSec, and Protect-It on wheat at a concentration of 500 ppm resulted in mortality rates of 96.5, 99.0, and 99.7%, respectively, after 7 days of exposure. Aisvarya et al. (2021), determined the LD_{50} value of the diatomaceous earth used against *S. oryzae* to be 1.27 mg/100 g. Furthermore, they achieved a 100% mortality rate at a dose of 15 mg/ 100 g of maize seeds within six days after exposure. Also, Sağlam et al. (2022) stated that Detech diatomaceous earth caused mortality rates of 82.1% and 92.2% at 600 and 900 ppm doses, respectively, against *S. oryzae* adults by the end of the seven days. In addition, Alagöz and Sağlam (2022) confirm this view, stating that five different diatomaceous earths used against *S. oryzae* adults caused different levels of effect at the same doses and exposure periods. They emphasised that the diatomaceous earth with the code FB2N1, which had a low effect, had a high SiO_2 content (92%) and thus highlighted that diatomaceous earth with a high silicon content (<90%) may have low efficacy against insects. The diatomaceous earth used in this study contains 72.80% SiO_2 and has shown a significant effect, causing 83.5% mortality after 216 hours (9 days). There are a limited number of studies specifically addressing the effectiveness of diatomaceous earth products on different surface types. Laboratory experiments have been conducted to evaluate the insecticidal efficacy of various DE formulations when applied directly to surfaces such as concrete, ceramic, plywood, plastic, metal, and other materials (Gowers and le Patourel, 1984; Collins and Cook 2006; Ertürk et al. 2020; Alkan et el. 2024; Mortazavi et al. 2024). The findings generally revealed that the effect of diatomaceous earth varied depending on the surface to which it was applied. According to Ertürk et al. (2020), the mortality rate of *S. oryzae* was significantly higher on concrete surfaces than on wooden surfaces. However, Baliota and Athanassiou (2023) tested diatomaceous earth and zeolite formulations from natural Greek deposits against *S. oryzae*, *R. dominica*, and *T. confusum* on concrete and steel surfaces at 0.5 and 1 g/m². They found that all treatments caused 100% adult mortality after 7 days, even at the lower dose, with no significant differences between surface types. In this study conducted on galvanized sheet surface, the efficacy against *S. oryzae* was determined to be 83.5% after 9 days. These comparisons emphasize the need to optimize diatomaceous earth applications according to environmental conditions and product characteristics for effective management of stored-product pests.

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