Sustainable Storage Pest Management Using Diatomaceous Earth against *Sitophilus oryzae* L.

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Abstract: The rice weevil, *Sitophilus oryzae* L., is a destructive internal feeder in stored grains of strategic crops in Egypt. Diatomaceous earth (DE) is a natural substance as a physical method free of toxic residues in the storage ecosystem. A laboratory experiment was conducted to study the impact of diatomaceous earth (DE) on the *Sitophilus oryzae* L. as well as on wheat seed germination. Various concentrations of DE were selected at 13, 11, 9, 7, 5, 3, 1, 0.5 and 0.25 mg in addition to the control treatment without DE. Mortalities in *S. oryzae* adults reached 100% at rates of 11 and 13 mg DE after 6th and 7th days of adult exposure compared to 0% mortality recorded in untreated grains. Furthermore, the treated grains with DE at 0.25 and 0.5 mg within 1st and 2nd days of exposure were unable to protect the stored grains against *S. oryzae*,while the seventh day of exposure had effective results of protection. Seed germination was only tested on the treated wheat grains within 7 days of exposure. Results indicated that the germination rate was accelerated as it reached 99% at higher doses of DE (11 and 13 mg) compared to 53% in the untreated seeds. Agro-morphological characters of tested seeds were also highly improved. The seedling length reached 59.41 cm compared with 24.30 cm for untreated seeds. The seedling Vigor index at 13 mg DE was greater (5881.59) than the control (1287.9). The present work demonstrated the effectiveness of DE at 13 mg DE/100g on the 7th day of release to combat rice weevil in cereals storage environments on a sustainable basis. DE was found to be an eco-friendly physical method for sustainable pest management in the wheat storage ecosystem.

Keywords: Diatomaceous earth (DE), *Sitophilus oryzae*, Wheat storage

INTRODUCTION

Egypt has a total area of 238 million Feddans, of which only 9.5 million Feddans are agricultural land, and the rest area is still a desert. The cultivated area with wheat is around 3.61 million Feddans with an annual production of 9.5 million tons of wheat grains (FAO, 2021). Wheat crop (*Triticum aestivum vulgare* L.) is one of the three most important cereal grains on the earth worldwide (Cheng *et al.,* 2021), and is the greatest one, especially in Egypt (FAOSTAT, 2019). The Egyptian wheat production represents 20% of agricultural imports and around 10% of total agrarian production (FAOSTAT, 2019; Yigezu *et al.,* 2021). The total cultivated area of Egyptian wheat in 2021 reached about 3.6 million Feddan and the total production is 9.3 million tons (FAO, 2021). This production is insufficient for Egyptian consumption of wheat, and therefore Egypt is considered as the world's biggest buyer from other countries to compensate for the food gap (Yigezu *et al.,* 2021). Around 10-20% of the Egyptian wheat grain production is lost due to insect pests and climate change during the traditional storage (Matouk *et al.,* 2017; Yigezu *et al.,* 2021). Climate change and the negative impact of chemical insecticides on humans and the environment have led to the search for natural alternatives in developing countries (Sakka and Athanassiou, 2021). The use of synthetic pesticides to meet the extensive requirements for protecting stored cereals may cause resistance in insect inhabitants (Agrafioti and Athanassiou, 2018; Yigezu *et al.,* 2021).

The stored cereals, legume grains, medicinal, and aromatic plants are always exposed to destructive infestation by weevil *Sitophilus granarius* (L.) and weevil *S. zeamais* (Cato *et al.,* 2017). This infestation can cause a major reduction in the quality and quantity of stored seeds or grains (Hong *et al.,* 2018). Traditional fumigants, semiochemicals, and chemical pesticides are presently the chief management techniques to combat insects in the storage ecosystem (Nayak *et al.,* 2020). Therefore, their use led to pesticide resistance, high mammalian toxicity, and environmental hitches (Agrafioti *et al.,* 2019). Therefore, research efforts towards eco-friendly management alternatives are currently being developed to eventually eliminate the use of synthetic chemicals against stored grains pests (Vassilakos *et al.,* 2015). Low-priced and chemical-free pesticides are highly demanded by customers (Islam and Rahman, 2016). The diatomaceous earth (DE) material has vital potential in this respect and is considered as physical management for pests in stored ecosystems (Korunic, 2013; Zhanda *et al.,* 2020).

DE is odorless amorphous silica and non-inflammable inert dust substance (Korunic, 2013; Prasantha *et al.,* 2015) and mainly consisted of SiO_2 and Ca^{++} with minor elements of zinc, phosphorous, and sodium (Subramanyam and Roesli, 2000; Shah and Khan, 2014). It is derived from fossilized sedimentation of siliceous marine or freshwater algae (Korunic and Fields, 2020). The dust color of DE ranges from light gray to brownish red (Wille *et al.,* 2019). The particles of DE vary from 2.45 to 30.5 microns (Ertürk *et al.,* 2017). This inert dust is very safe for ecosystem components including the natural enemies for insects and human beings (Korunic *et al.,* 2017) and therefore, DE can be utilized in a storage environment as a natural eco-friendly tool for protecting the stored grain products (Ziaee *et al.,* 2019). It increased the dryness and insect mortality by destroying the physical abrasion and lipid layer of treated insects (Prasantha *et al.,* 2015). Numerous

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materials of DE were formulated to be more effective against *Tribolium confusum* and *T. castaneum* (Athanassiou and Steenberg, 2007). The effective rate of DE is 1000 ppm/tonne to successfully manage pests in stored seeds (Korunic, 2013; Ertürk *et al.,* 2017).

Islam *et al.* (2010) confirmed the mortality efficacy of different formulations of DE on *S. oryzae* and *Callosobruchus maculatus*. Badii *et al.* (2014) studied the effectiveness of specific preparations of DE to manage *C. maculatus* (F.) in the stored groundnut ecosystem. He reported that the effectiveness of used materials of DE against *C. maculatus* at 50% relative humidity was higher than at 80% relative humidity. El-Aziz and El-Ghany (2018) have modified novel creations of DE called Al-DE and Ca-DE. The modified DE has a toxic effect on *S. granarius* adults in wheat kernels compared to the original DE (Agnew and Romero, 2017; El-Aziz and El-Ghany, 2018).

The best-known insect species of *Sitophilus* weevils are the granary weevil (*S. granarius* L.), maize weevil (*S. zeamais* Motschulsky), and rice weevil (*S. oryzae* L.) in stored kernels environments in Egypt (Attia *et al.,* 2020). These weevil insects are occurring throughout semi-arid and arid ecosystems around the world. The adult female of *Sitophilus* weevil lays usually an egg inside a hole in cereal and then hatch to develop the larva. The larvae feed inside the grain then turn into pupa leaving the grain wholly hollow and an insect adult may be developed inside the damaged grain (Hong *et al.,* 2018). *Cryptolestes* was the more subtle genus of insect species to DE whereas the *Prostephanus* genus was the most tolerant pest. Also, *Oryzaephilus, Sitophilus are* less sensitive and less tolerant, respectively (Korunic and Fields, 2006), as well as *Tribolium* and *Rhyzopertha* are considered as the most resistant to DE (Attia *et al.,* 2020).

Omobowale and Akomolafe (2021) concluded that the formulation of DE may be utilized to preserve and enhance the germinability of the stored seeds. Kernels of cereals could be protected against environmental risks and insect attacks through applying eco-friendly methods. Furthermore, wheat kernels are a strategic product for Egyptians. Accordingly, the main objective of the present work was to investigate the influence of a formulation of DE against the insect of *S. oryzae* (rice weevil) on stored wheat kernels either for grain storage or seed germination as an eco-friendly storage pest management method.

MATERIALS AND METHODS

Tested DE formulation, insect, and commodity

The diatomaceous earth (DE) formulation tested in the current experiment has a particle size of 10.3µm. It is composed of 85.3% amorphous silicon dioxide (SiO_2), 3.7% alumina (Al_2O_3), 1.9% ferric oxide (Fe_2O_3), 1.7% calcium oxide (CaO), 1.5% sodium oxide (Na_2O), 1.3% magnesium oxide (MgO), 1.1% others, and 3.5% dry weight. It was applied as a powder on wheat kernels. The studied formulation of diatomaceous earth was obtained from Al-Ahram mining company, Giza, Egypt.

The *Sitophilus oryzae* was collected from the governmental granary storage, Giza, Egypt in 2020. Fresh kernels of wheat, used for the current experimental trials, were completely free of infestation commodity. Before treatments, kernels of wheat were heated to 50°C. The moisture contents of standard heated kernels were hydrated and adjusted to 14±1% using pure distilled water and projected by a calibrated moisture meter according to the standard methods of Kavallieratos *et al.* (2019).

Rearing of *Sitophilus oryzae in* the laboratory

In glass jars, insects of *S. oryzae* were reared on wheat grains under optimal conditions of room temperature at 25±5°C and 67±5% relative humidity and natural photoperiod. Approximately 450 unsexed adult insects were kept in a 500 ml glass jar comprising 500 grams of grains (Halstead, 1963). Insect weevils were permitted to oviposit for seven days and then they were removed directly by sieving (Chaisaeng *et al.* 2010). The afresh developed weevils were returned to the standard insect cultures. These weevils were utilized in the laboratory experiment after 10-15 days. Pieces of muslin cloth were used to cover the experiment units of vials, medium cultures, and stock cultures, then these units were fixed by rubber bands to facilitate aeration and avoid the insects from escaping out (Ahmed, 1996). All experiments were done at the Pesticides Division, Plant Protection Department, College of Agriculture, Zagazig University, Sharkia Governorate, Egypt.

Experimental treatments

A hundred grams of standard wheat kernels were put in a plastic container. Besides the control check, nine treatments at various concentrations of DE were performed under laboratory conditions. These concentrations were 13, 11, 9, 7, 5, 3, 1, 0.5, and 0.25 mg DE, as well as a control treatment without DE. Then the prepared laboratory containers were shaken by hand for 1-2 minutes to attain equal distribution as per the standard given by Subramanyam and Roesli (2000). Forty adults of *S. oryzae* were reared into each prepared container. Five replicates were performed for each treatment unit in the design of a completely randomized plan. Percentages of insect mortalities were recorded at one-day intervals for a week.

The percent mortalities of the studied insect were corrected with the well-known Abbott's formula [corrected mortality (%) = (1 – *S. oryzae* population in the treated wheat kernels / *S. oryzae* population in the control unit) × 100] as per the standard procedures given by Wakil *et al.* (2021).

Germination test

The treated seeds with selected dosages of DE on the seventh day of treatment were only used for germination test studies according to the methodology given by ISTA (1999) and Govindaraju *et al.* (2020). Sodium hypochlorite solution at 10% was used to sterilize the treated seeds (Zhu *et al.,* 2010). A specific quantity of 25 wheat seeds on the germination sheet was maintained in each treated unit (Pradeep, 2018). Germinated seeds number was counted every day during the experiment period. Five parameters of the germinated seedling were determined within the seventh day. The agro-morphological parameters were dry matter production (g), length of the shoot (cm), germination rate (%), length of root (cm), and seedling Vigor index. The parameters of the Vigor index and the rate of seed germination were computed as per the standard procedures using the following equations: (1) germination rate (%) = (Number of seeds germination /total number of seeds) × 100 and (2) Vigor index = germination (%) × seedling length (Zhu and Hong, 2008; Pradeep, 2018).

Data processing and analysis

Programs of Microsoft Excel and SPSS statistical software were used for arranging and processing the obtained data. The standard deviation (SD) and mean values were estimated for the technical treatments and their replicates. The obtained data of the five replicates for each treatment unit were calculated as means and then they were subjected to the statistical analyses. The standard procedures of Finney's methodology (1971) were followed to carry out the probit regression analysis. To determine the significant difference between the obtained values of treated units and control unit means, a two-way analysis of variance (ANOVA) was performed on all values of treatment units with wheat commodity. The significance threshold used was $P < 0.05$. The response variable was done for all insect mortalities calculations.

RESULTS AND DISCUSSION

Effect of diatomaceous earth on *S. oryzae*

The mean values of tested insect mortality percentages on wheat kernels under different treatments of diatomaceous earth are deeply presented in Table (1) and Fig. 1**.** The mortality of *S. oryzae* treated with DE augmented with the increase of days after release and concentration of DE, and full mortality was achieved on the 6th day after release at 11 and 13 mg DE per 100 grams of grains (Table 1). At the rates of 11 and 13 mg DE, the maximum adult mortalities were increasing with increasing the exposure time from 9.99% on the 1st day after release to 100% on the 6th and 7th days after release (Fig. 1). The lower concentration of DE at 0.25 mg on 1st and 2nd days after release didn't affect the adults of *S. oryzae* mortality. Across the treatment units, the dose of 0.5 mg DE has recorded zero mortality on the 1st day, 4.66 on the 2nd day, 6.67 on the 3rd day, 14.64 on the 4th day, 22.01 on the 5th day, 26.67 on the 6th day, and 36.36% within the 7th day of release. The dose rates of DE that achieved 100% mortality were 11 and 13 mg per 100 g tested grains on the 6th and 7th days after release. Within seven days of exposure, the lowest mortality was 24.25% at 0.25 mg DE per 100 g grains. The mortality percentages of the tested pest in treated wheat kernels with 11 and 13 mg have the same trend on all tested exposure days. The results of the control treatment showed 0% mortality with full damage of the stored grains (Fig. 1).

Table (1): Percentages of *S. oryzae* mortality on wheat grains treated with different dosages of diatomaceous earth (DE)

DE dosage (mg) /100g tested grains	Number of insect adults	*S. oryzae* adult mortality (%)						
		1st DAR	2nd DAR	3rd DAR	4th DAR	5th DAR	6th DAR	7th DAR
0.25	40	0.00^{c} ± 0.00	0.00^{f} ±0.00	4.45^{f} ±0.19	8.01^{g} ±0.12	15.65^{j} ±0.94	22.01^{l} ±0.95	24.25^{k} ±1.75
0.5	40	0.00^{c} ± 0.00	4.66^{e} ±0.11	6.67^{e} ±0.14	14.64^{f} ±0.15	22.01^{i} ±1.11	26.67^{h} ±1.03	36.36^{j} ±0.94
1	40	0.00^{c} ± 0.00	4.67^{e} ±0.09	6.67^{e} ±0.11	14.55^{f} ±0.32	22.01^{l} ±1.09	26.67^{h} ±0.54	50.00^{h} ±1.17
3	40	8.94^{a} ±0.01	14.22^{b} ±0.11	22.00^{b} ±0.91	26.67^{c} ±01.01	40.00^{e} ±1.12	46.67^{d} ±1.95	71.95^{e} ±1.75
5	40	9.01^{a} ±0.10	14.22^{b} ±0.15	22.00^{b} ±0.41	26.67^{c} ±0.37	40.00^{e} ±1.01	46.67^{d} ±0.99	75.63^{d} ±1.15
7	40	9.05^{a} ±0.07	14.22^{b} ±0.14	22.00^{b} ±0.61	26.67^{c} ±0.81	43.33^{d} ±1.55	53.05^{c} ±1.38	84.05^{c} ±2.74
9	40	9.67^{a} ±0.06	14.22^{b} ±0.32	33.33^{b} ±0.54	33.33^{b} ±0.94	46.67^{c} ±1.98	69.69^{b} ±2.17	89.55^{b} ±2.75
11	40	9.99^{a} ±0.07	22.00^{a} ±0.51	33.33^{a} ±0.51	46.67^{a} ±0.99	73.33^{b} ±1.79	100.00^{a} ±2.09	100.00^{a} ±1.94
13	40	9.99^{a} ±0.06	22.00^{a} ±0.16	33.33^{a} ±0.32	46.67^{a} ±0.87	80.00^{a} ±2.07	100.00^{a} ±0.89	100.00^{a} ±0.17
Control	40	0.00^{c} ± 0.00	0.00^{f} ± 0.00	0.00^{g} ± 0.00	0.00^{h} ±0.00	0.00^{k} ±0.00	0.00^{i} ± 0.00	0.00^{i} ± 0.00
	SEd	0.071	0.135	0.166	0.205	0.489	0.627	0.945
	CD (0.05)	0.159	0.267	0.327	0.408	0.982	1.446	1.967

Explanations: Mortality percentages were expressed as means ± standard errors (SE); Within each column in this table, the same small superscript letters that followed the means aren't significantly varied at 5% significance level (LSD); Day after release is denoted by DAR.

The same results of rice weevil using various DEs were found by Athanassiou *et al.* (2004). Furthermore, the findings obtained by Kostyukovsky *et al.* (2010) are supported the results of the current research. A new formulation of diatomaceous earth developed in Germany was used on wheat cereals by Kostyukovsky *et al.* (2010) to determine full mortality after three weeks. The higher toxicity of modified DE formulations such as DE plus *abamectin* and DE plus *bitterbarkomycin* may be obtained at lower rates less than 100 ppm as reported by Shah and Khan (2014). Additionally, diatomaceous earth may be mixed with the *Trichoderma harzianum* and spinosad to kill rice weevil in stored wheat grains (Gad *et al.,* 2020). In this context, Wakil *et al.* (2021) investigated the efficiency of a mixture of diatomaceous earth (DE) formulation @ 150 ppm with different concentrations of imidacloprid against four insects (the psocid, the lesser grain borer, rusty grain beetle, and the red flour beetle) on stored grains of wheat, maize, and rice. The combination of imidacloprid plus DE caused higher mortalities than imidacloprid or DE alone within entirely exposure times. The higher mortality was registered on the wheat commodity than other tested grains (maize and rice). Furthermore, the most tolerant pest to all treatments was the red flour beetle while the least tolerant was the psocid (Wakil *et al.,* 2021).

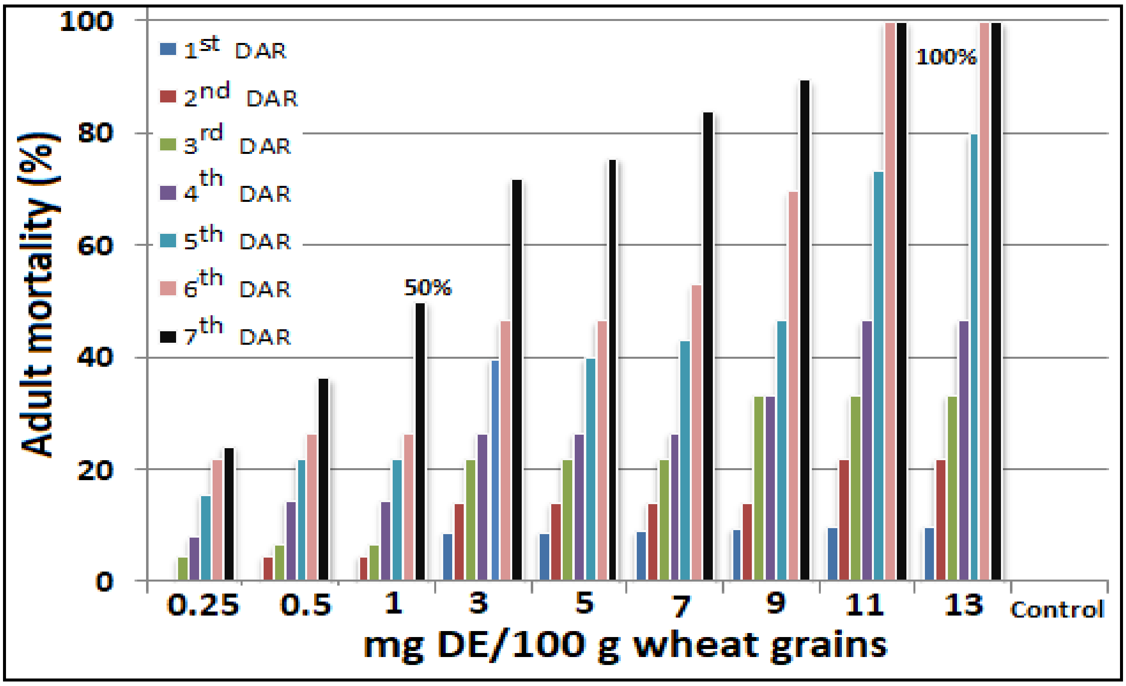

Fig. (1): Mortalities in *S. oryzae* adults exposed to the treated wheat grains with different dosages of diatomaceous earth (DE)

Effect of tested DE on germination of wheat seeds

The agro-morphological characters and parameters of tested grains within 7 days of adult insects release, in the current work, were germination rate, length of seedling, length of root, and length of shoot, as well as initial fresh weight and dry weight. The detailed findings of these characteristics of wheat grains are presented in Table (2) and Figs. (2 and 3). The investigations of wheat grain germination established the significant variances among the treatment units after 7 days of release and compared with the untreated kernels of the control unit. At 7 days of exposure, the grains treated with DE @ 1 mg and 11 mg were capable to control 50% and 100% of the population of insects in 100 g of wheat grains, respectively (Table 1; Figs. 2 and 3). The germination characters of treated grains varied significantly at a 5% level of significance in the different treatment units with regard to untreated grains in the control unit. Germination rate was higher (99%) at 11 and 13 mg DE concentrations, whereas it was only 67% at 0.25 mg DE compared to untreated seed in the control (53%) (Fig. 2). The seedling length was calculated based on the shoot length plus root length. The lengths of shoot and root of germinated grain were significantly varied from 16.09 and 19.66 cm at 0.25 mg DE to 29.32 and 30.09 cm, respectively (Table 2; Fig. 2). Similarly, the values of seedling length ranged from 35.75 cm at the lowest concentration of DE to 59.41 cm at the highest concentration of DE compared with 24.30 cm at untreated seeds in the check unit (Table 2; Fig. 2). Seedling Vigor index registered the highest value (5881.59) at the highest rate of DE (13 mg) in the ninth treatment, while the lower value was 2395.25 at the lowest dose of DE (0.25 mg) in the first treatment compared with the lowest value of untreated seeds in the control unit (1287.9) (Fig. 3). This is attributed to the richness of diatomaceous earth with fertility minerals such as silica, Al, Ca, Mg, K, Fe, Zn, and others. Therefore, DE is a valuable stock for plant nutrients to greatly enhance uptake and growth. In addition, adults of *S. oryzae* were controlled by the DE at different concentrations. These advantages enhanced the germination rate, shoot length, root length, seedling growth, and Vigor index (Zhu and Hong, 2008). Furthermore, the higher seedling growth and germination rates at higher doses of DE may be attributed to the nature of DE composition that enhanced germination rate of the treated seeds and therefore is considered as a protectant against insect attack (Pati *et al.,* 2016; Sun *et al.,* 2021). Likewise, higher fresh weight and dry matter productions were recorded in higher dosages of 9, 11, and 13 mg DE treatments. Meanwhile, the values of initial fresh weight were widely ranged from 10.90 at 0.25 mg DE to 19.47 g at 13 mg compared to 15 g achieved by the untreated wheat grains in the control (Table 2). DE improved the nutrients uptake by crops in the field (Pati *et al.,* 2016) and improved flower and leaf features development in ornamental plants. Zhu *et al.* (2010) studied the agro-morphological criteria of rice seeds related to the energy of germination, rate of germination, parameters of seedling, and Vigor index through treating tested seeds with a mixture of PVA and potassium nitrate (KNO_3). He found that this mixture significantly improved the growth criteria of treated seeds. Ultimately, sustainable pest management in the stored grain ecosystem can be accessed by the application of DE formulations as it has many advantages in enhancing seed germination and controlling insects.

Table (2): Agro-morphological parameters of seed germination for treated wheat kernels after 7 days of treatment

Treatment	Germination rate (%)	Length of the shoot (cm)	Length of root (cm)	Length of seedling (cm)	Seedling Vigor index	Initial fresh weight (g)	Dry weight (g)
T1	67^{ab} ±01.09	16.09^{f} ±0.41	19.66^{f} ±0.91	35.75^{c} ± 0.91	2395.25^{k} ± 2.74	10.90^{k} ±0.14	1.93^{k} ±0.12
T2	74^{b} ±1.24	18.16^{f} ±0.91	20.29^{c} ±0.84	38.45^{b} ± 0.58	2845.3^{i} ± 1.91	12.0^{k} ±0.21	2.01^{b} ±0.31
T3	79^{b} ±1.33	20.14^{f} ±1.01	23.25^{c} ±0.99	43.39^{i} ± 0.49	3427.81^{j} ± 3.58	12.95^{j} ±0.15	2.75h ±0.01
T4	83^{bc} ±0.91	23.09^{fg} ±1.03	24.98^{bc} ±1.01	48.07^{i} ± 1.57	3989.8^{k} ± 3.02	13.45^{j} ±0.17	3.09^{kh} ±0.05
T5	85^{c} ±0.88	25.13^{g} ±1.10	27.16^{i} ±0.74	52.29^{h} ± 0.49	4444.65^{i} ± 3.37	14.28^{hi} ±0.24	3.14^{h} ±0.07
T6	91^{cd} ±1.08	26.98^{g} ±0.75	28.54^{i} ±0.91	55.52^{ih} ± 1.01	5052.32^{ik} ± 1.99	16.45^{h} ±0.64	4.56^{h} ±0.02
T7	93^{d} ±0.79	27.19^{h} ±1.04	29.45^{i} ±0.25	56.64^{i} ± 2.07	5267.52^{i} ± 2.11	17.85^{i} ±0.84	4.98^{j} ±0.66
T8	99^{e} ±1.11	28.08^{h} ±0.91	30.97^{i} ±1.01	59.05^{i} ± 1.12	5845.95^{j} ± 3.04	18.01^{a} ±0.45	4.8^{j} ±0.33
T9	99^{e} ±1.01	29.32^{h} ±1.24	30.09^{h} ±1.40	59.41^{j} ± 1.18	5881.59^{j} ± 5.09	19.47^{j} ±0.22	5.94^{j} ±0.71
Control	53^{a} ±0.29	11.05^{f} ±0.68	13.25^{f} ±0.07	24.30^{c} ± 0.17	1287.9^{c} ± 2.52	9.15^{k} ±0.87	1.34^{k} ±0.08
SEd	1.842	0.267	0.225	0.612	--	0.214	0.039
CD (0.05)	4.123	0.542	0.483	1.416	--	0.480	0.074

Explanations: No significant difference at P <0.05 of (LSD) for the mean values that tailed by the small character(s) in the columns; All treatments for seed germination were done on the tested kernels within only the seventh day after release; **T1** (0.25 mg /100g); **T2** (0.5 mg /100g); **T3** (1 mg /100g); **T4** (3 mg /100g); **T5** (5 mg /100g); **T6** (7 mg /100g); **T7** (9 mg /100g); **T8** (11 mg /100g); **T9** (13 mg /100g); and **Control** (untreated seeds).

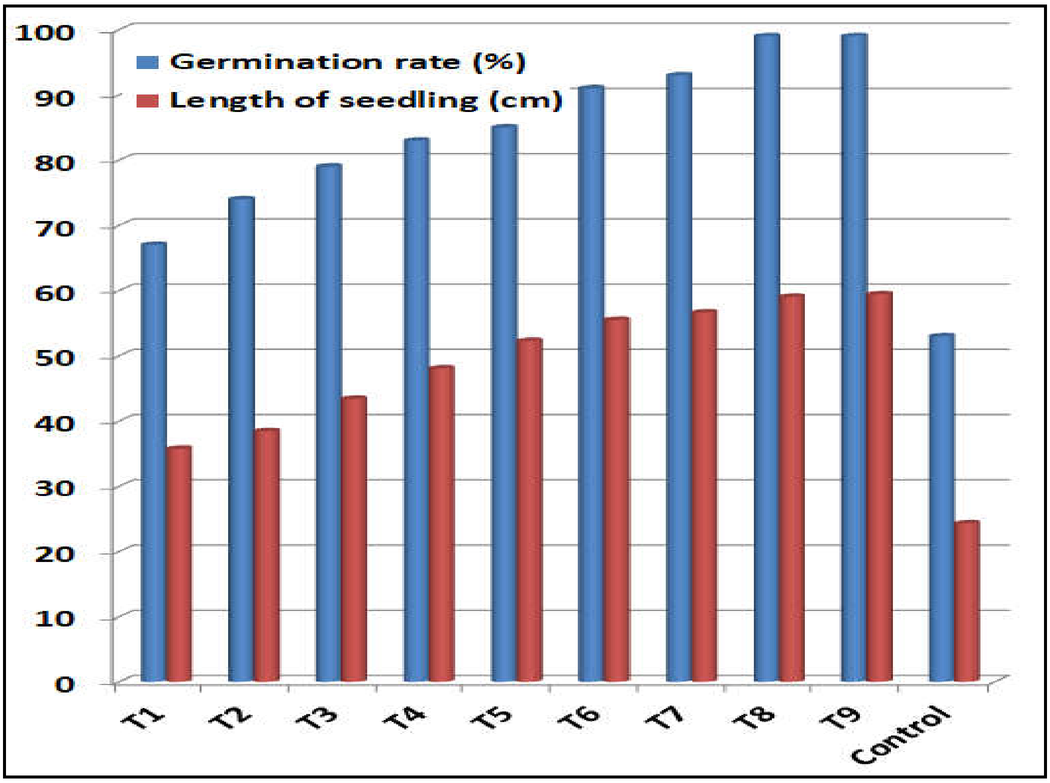

Fig. (2): The rate of seed germination and length of seedling for treated seeds with diatomaceous earth (DE) within 7 days in regard to untreated control

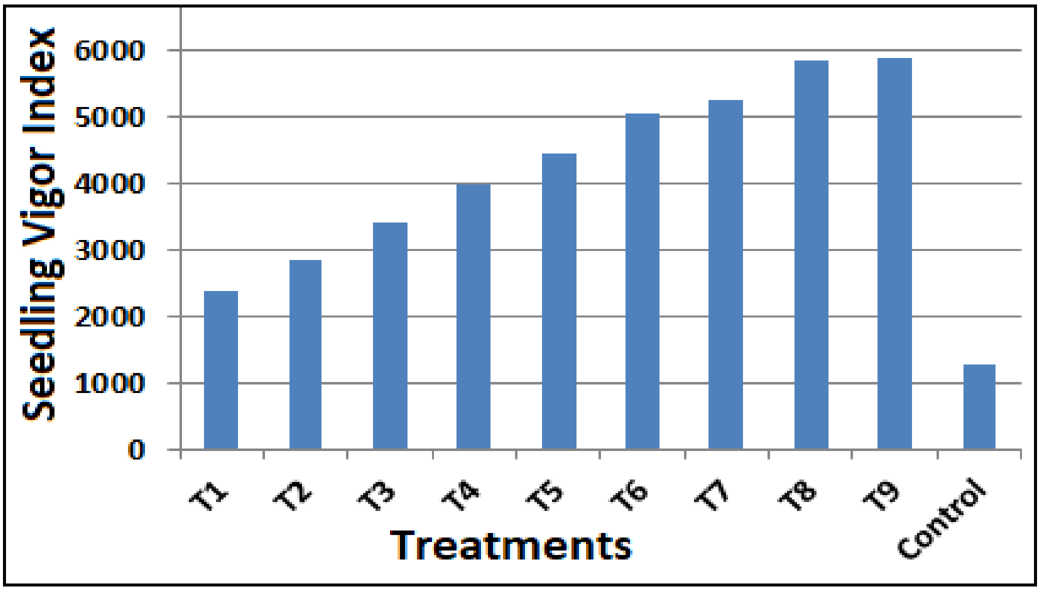

Fig. (3): Seedling Vigor index of treated wheat kernels with concentrations of diatomaceous earth (DE) for 7 days

CONCLUSION

This paper studied the impacts of diatomaceous earth (DE) against *Sitophilus oryzae* on kernels of wheat in respect to their grain storage and seed germination under laboratory conditions in Egypt. In the stored wheat grains, the maximum percentages of adult mortalities of *S. oryzae* were achieved 100% at the rates of 11 and 13 mg DE on the 6th and 7th days after release. In contrast, the results of untreated kernels showed 0% mortality with a full infestation of the stored grains. Furthermore, the lower concentrations of DE at 0.25 and 0.5 mg within 1st and 2nd days of exposure didn't cause any mortality in *S. oryzae* adults. Within seven days of exposure, the germination test studies were carried out on the treated wheat kernels. Germination rate reached 99% at 11 and 13 mg DE doses and 67% at 0.25 mg DE compared to 53% in the untreated grains. The lengths of shoot and root of germinated grain were significantly increased and enhanced with increasing the DE doses. The values of seedling length ranged from 35.75 cm to 59.41 cm based on the treated dose of DE. The seedling Vigor index of wheat was the maximum (5881.59) at 13 mg DE, while the minimum value was 2395.25 at 0.25 mg. This is because diatomaceous earth is rich with plant nutrients of Ca, Na, Mg, K, Fe, Zn, Cu, Al, and others. In addition to the lethal effect of *S. oryzae* adults was caused by the DE formulation. These benefits enhanced seed germination and shoot growth. Accordingly, DE has a positive impact on wheat kernels either for grain storage or seed germination. Therefore, DE can be successfully applied in the storage ecosystem and the field as a forceful seed protectant against *S. oryzae*. This study demonstrated that sustainable storage pest management of *S. oryzae* may be performed in the stored wheat kernels by using the DE as an eco-friendly physical tool and safe protectant leading to no risks for human beings and the environment.

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الإدارة المُستدامة لآفات الحبوب المخزونة بإستخدام التربة الدياتومية ضد سوسة الأرز

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تعتبر التربة الدياتومية (DE) هي مصدر طبيعي، صديقة للبيئة، آمنة على الإنسان والأعداء الطبيعية. بالإضافة إلى ذلك، فإن الإفراط في استخدام المبيدات الحشرية الكيميائية يؤدي إلى ظهور صفة المقاومة بالآفات الحشرية وكذلك متبقيات المبيدات بالحبوب المعاملة. كما تشكل آفة سوسة الأرز *Sitophilus oryzae* L. النسبة الأكبر في إصابة الحبوب المخزونة لبعض المحاصيل الإستراتيجية لدى جمهورية مصر العربية مثل القمح، الأرز، والذرة. تهدف الدراسة الحالية إلى استخدام التربة الدياتومية DE ودراسة تأثيرها على كلاً من: (أ) مكافحة سوسة الأرز كوسيلة فيزيائية لمكافحة آفات حبوب القمح المخزونة وفي نفس الوقت تكون صديقة للبيئة دون أي أضرار، و(ب) عملية إنبات بذور القمح المعامل بتركيزات مختلفة التربة الدياتومية Treated wheat seed germination. حيث تم معاملة حبوب القمح بجرعات مختلفة من التربة الدياتومية وهي (٠,٢٥ ، ٠,٥ ، ١ ، ٣ ، ٥ ، ٧ ، ٩ ، ١١ ، و ١٣ ملليجرام) بالإضافة إلي تجربة المقارنة (الكنترول وهي غير مُعاملة بالتربة الدياتومية، DE) لدراسة تأثيرها على الحشرات الكاملة لسوسة الأرز وحساب النسبة المئوية للحشرات الميتة. أوضحت النتائج إلى وصول معدل وفيات الحشرات الكاملة Adult mortalities بنسبة ١٠٠٪ كانت بالجرعة ١٣ مجم DE / ١٠٠ جرام من البذور خلال سبعة أيام من تعرض الحشرات الكاملة للتربة الدياتومية على درجة حرارة المعمل وذلك بمقارنتها بباقي التركيزات والتي أعطت نسب أقل تتناسب بصورة طردية مع تركيز الجرعة المُستخدمة، في حين أعطت الحبوب غير معاملة بالتربة الدياتومية نسبة تقارب الصفر. حيث سجلت نتائج التجربة المعملية أعلى نسبة لموت الحشرة في حالة تعرض حبوب القمح إلى التركيزات المختارة من DE لمدة سبعة أيام، وعلى هذا؛ فقد تم استخدام هذه الحبوب (المعاملة حتى اليوم السابع) في دراسة تأثير التربة الدياتومية على اختبار نسبة إنبات هذه البذور Seed Germination. وأشارت النتائج إلى زيادة نسبة إنبات بذور القمح والتي وصلت إلى ٩٩% عند معاملة بذور القمح بالتركيزات العالية من التربة الدياتومية (١١ و ١٣ مجم DE/١٠٠ جم بذور قمح) بالمقارنة بالبذور غير المعاملة والتي سجلت فقط ٥٣%، أي أن معاملة بذور الحبوب المخزونة بالتربة الدياتومية لتفادي الإصابة بسوسة الأرز لا يؤثر على نسبة الإنبات للبذور المعاملة بل تزيد من كفاءة الإنبات. وهذا للأسباب التالية: (١) معاملة بذور القمح بالتربة الدياتومية أدى إلى موت حشرة سوسة الأرز من بيئة تخزين الحبوب وبالتالي الحفاظ على جنين البذرة من التآكل وبالتالي سرعة الإنبات وهذا يتوقف على التركيز المستخدم من DE، (٢) التربة الدياتومية تعتبر مصدر لأغلب العناصر المغذية والتي تعتبر ضرورية لإنبات بذور القمح، أدى ذلك إلى تحسين كفاءة عملية الإنبات، وهذا اتضح من خلال النتائج المتحصل عليها. خُلصت الدراسة الحالية إلى أنه يمكن استخدام DE بشكل فعال كوسيلة بديلة للمبيدات الحشرية الكيميائية في مكافحة سوسة الأرز بالمخازن، فهي فعالة جداً ضد العديد من آفات الحبوب المخزونة وليس لها متبقيات سامة على الحبوب المعاملة بها، فهي وسيلة فيزيائية لمقاومة آفات المخازن بشكل مستدام وآمن على البيئة وصحة الإنسان.