IMPACT OF DIATOMACEOUS EARTH AGAINST GRANARY WEEVIL (*SITOPHILUS GRANARIUS* L.)

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Abstract

The granary weevil is notorious for causing huge economic losses during storage in various parts of the world. The repeated use of chemical insecticides leads to contamination of seeds with toxic residues, which poses serious concerns to man. The present research work was carried out to find out the non-chemical control tactics for the management of granary weevils using diatomaceous earth under controlled laboratory conditions. The data were recorded on lethal, sub-lethal and repellent impacts of diatomaceous earth against the tested insect pests. The diatomaceous earth was used at fixed doses of 200, 300, 400, 500 and 600 ppm per 50 grams of grains, respectively. Results indicated an inversely proportional trend between different doses of diatomaceous earth and survival rate of the weevils i.e., by increasing the dose, the rate of survival decreased and maximum mortality was observed at the highest dose of DE at 21 days after the application of chickpea grains. A gradual increase in the mortality of weevils was observed by increasing the exposure to DE treated grains. The rate of repellency also increased by increasing the dose and exposure duration. The maximum mean percent repellency of 82.5% was observed after 72 h exposure period. The same trend was observed in case of F_1 adult emergence, emergence of weevil adults, infestation, weight loss, and adult life span. A decrease in F_1 progeny emergence was observed by increasing the dose rates of DE. The minimum progeny emergence, infestation and weight loss was observed in chickpea grains treated with maximum dose of diatomaceous earth. This indicates that the effectiveness of diatomaceous Earth was greatly affected by the selected doses of DE as well as exposure time against *S. granarius*. Cogent findings of the study were that at the dose of 600 ppm, reduction in progeny emergence of *S. granarius* can be achieved while increasing the dose rate can help in inhibiting the infestation. Hence suggested that diatomaceous earth can be used for the safer management of granary weevil.

Keywords: stored grains, diatomaceous earth, lethal effects, sub-lethal effects, repellent effects

1. INTRODUCTION

Chickpea is one of the most primitive legumes cultivated throughout the world. It is one of the important pulse crops commonly grown for its grain/seed to get protein throughout the world. The production of pulses in Pakistan was 0.52 million tons from 2.491 million acres (Boye et al*.,* 2010). Chickpea is grown in semi-desert districts of Thal, Khushab, Bhakkar, Jhang, Layyah, Mianwali and Bahawalpur. It was reported that the production of chickpea was 868 thousand tones on 956.4 thousand hectares with average of 794 kg/ha (Anonymous, 2018). Chickpea is cultivated both in Asia and Europe from ancient times (Abbo et al*.,* 2003). Insect pests of stored grain cause approximately 10-25% losses by infesting stored grain and their by-products worldwide (Magan and Aldred, 2007). These losses include direct damage by feeding resulting in weight loss along with severe reduction in nutrients and seed viability, lower percentage of seed germination, reduced grade and lowering the market value because of webbing, insect cadavers and accumulation of waste (Hill, 1990; Batta, 2018).

The granary weevil, *Sitophilus granarius* is is notorious for causing huge economic losses of stored grain in various parts of the world that can eliminate the whole grain seed (Athanassiou et al., 2007; Batta, 2018). It is a key pest that is able to easily infest sound and undamaged kernels. This species is an internal feeder as female lays its eggs inside the kernel where complete development of immature takes place resulting in severe infestation (Athanassiou et al., 2007). All the growth stages of *S. granarius* are found within the chambers and tunnels bored in the seed and therefore, not normally seen. As they belong to the family Curculionidae, they have elbowed antennae and the characteristic rostrum (Poinar et al*.,* 2009).

They are evenly polished reddish-brown to shiny black or chestnut-brown in color. The body is thinly covered with short and stout yellow hairs (Krcmar and hackenberger, 2011). Except that *S. granarius* cannot fly, the behavior and biology of this species is alike tropical species *Sitophilus zeamais* and *Sitophilus oryzae* (Wakefield et al., 2005). Average life of adults is for 7-8 months. Usually around 150 eggs are laid by females and throughout their lives, they lay up to 300 eggs (Loreto and Isidoro, 2019). Larvae feed on the kernels inside the grains, leaving behind the hulls only. Severe damage may decrease stored grain to a mass of frass and hulls. It is a severe insect pest of barley and wheat grains. It also causes damage to maize, rye, rice and other cereal grains. Sometimes, it infests chickpeas, dried beans, groundnuts, birdseed, ornamental dried corn, chestnuts, acorns, sunflower seeds and pasta products (Mason et al*.,* 2012).

The chemical insecticides have been widely used for the control of stored product insect pests, resulting in various serious problems such as contamination of food products with insecticide residues and insecticide resistance (Abdel-Raheem et al., 2015). Almost 10-30% grains are damaged worldwide every year due to stored grain insect pests (Singh et al., 2009). These limitations have forced scientists to assess alternative control strategies including insect growth regulators, inert dusts, biological control and botanicals (Moore et al., 2000). Use of DE (diatomaceous earth) is one of the most promising substitutes to chemical insecticides (Nikpay, 2006; Shah and Khan, 2014). DE is an inert dust derivative of amorphous sediment and consists of fossilized shells of unicellular algae having low density and its color varies from white to dark grey. It contains approximately 80% silicon dioxide and the remaining part is composed of organic matter, clay minerals, magnesium carbonate, quartz and calcium (Korunic 1997; Stathers et al., 2004; Vayias and Stephou, 2009).

These are directly used for the protection of stored grains in the same way as residual insecticides. Diatomaceous earths have some indisputable benefits compared to chemical insecticides, provided that they have low toxicity to mammals (Athanassiou et al., 2007; Zeni et al., 2021) and environment leaves no hazardous residues in treated grains. The effectiveness of diatomaceous earth has been documented by in various studies against an extensive range of stored grain insect pests (Subramanyam and Roesli, 2000; Athanassiou et al., 2007; Bhalla et al., 2008; Shah and Khan, 2014). DEs affect larvae and adults by adhering to their body as they crawl inside or on the treated grain (Kavallieratos *et al*., 2007; Rojht et al*.,* 2010; Shams et al., 2011). In this study, we aimed to determine the optimal dosage of diatomaceous earth for effective control of granary weevils, considering both lethal and sub-lethal effects as well as to assess its potential as a repellent for long-term weevil management.

2. MATERIALS AND METHODS

2.1 Collection and Culture of Granary Weevil

Mother granary weevil culture was acquired from the Entomology section of ARI (Agriculture Research Institute), Dera Ismail Khan and laboratory conditions were maintained at 65 ± 5% RH and 27 ± 2°C in 12:12 hour of (Light: Dark) day length. Mix population of 200 male and female granary weevil were added to 500 grams of chickpea in plastic jars of 1-liter capacity for multiplication following the methodology proposed by Isah et al., (2012). The jars were kept in an incubator under controlled temperature for ten days to lay eggs, parent insects were removed from jars after 10 days by sieving grains. Infested chickpea grains were kept uninterrupted for additional 20 days and newly emerged weevils were collected and maintained as per their age in different jars separately. Insects of same age were used for each experiment.

2.1.1 Diatomaceous earth

Diatomaceous earth was obtained from China. The diatomaceous earth was used at different doses in combination with food (chickpea).

2.2. Repellent effects

The studies were conducted under laboratory conditions to figure out the repellent potential of diatomaceous earth against weevil adults. The experiment was laid out in a completely randomized design having four treatments and five replications. The DE was used at four different concentrations of 200,400,500 and 600 ppm/50 grams of food. For this purpose, petri dishes having 30 cm diameter and a height of 3 cm were used. The petri dishes were divided into two equal parts by placing a thin cardboard wall in the center of each petri dish. The weighed amount of diatomaceous earth was mixed with fifty grams of chickpea grains and transferred into one part of the petri dish. The untreated chickpea grains were shifted into other part of the petri dishes (control). Ten newly emerged adult insects were then released at the center of each petri dish. The petri dish of each treatment was examined after every four hours for 48 hours and the number of insects settled on treated or untreated chickpea grains were counted and percentages were calculated by using the formula:

$$PR = [(\frac{Nc-Nt}{Nc-Nt}] \times 100$$

Where Nc is the number of weevil adults settled on untreated grains; Nt is the number of weevil adults settled on treated grains

2.3 Lethal effects

For this bioassay, treatments comprising of six different concentrations of 200, 300, 400, 500 and 600 ppm w/w, respectively, having five different repeats including untreated check were used. Fifty grams of sterilized chickpea grains were treated with Diatomaceous earth and kept in transparent plastic jars. In order to evenly distribute DE on chickpea, the grains were stirred for five minutes by magnetic stirrer at the speed of 50 rpm. Twenty newly emerged weevil adults (ten pairs) were then introduced into each jar with the help of soft brush and the jars were covered with mesh cloth. The mortality data were recorded after 1, 2, 3, 7, 14 and 21 days of the introduction of weevil adults in the treated grains.

2.4 Sub-lethal effects

Five sub-lethal doses of DE based on experiment mortality effects having five different repeats including untreated check, were selected. Ten pairs of newly emerged adult weevils, starved for 24-h, were released in jars having pre-treated grains. The jars were covered with perforated cloth and placed in an environmental chamber for seven days. On seventh day, all adults were removed, and chickpea grains were monitored for various biological parameters of succeeding generation of granary weevil as described in 3.7.1. Data recoded was subjected to statistical analysis.

2.5 Statistical analysis

During the experiments, the data recorded was analyzed statistically by using appropriate analysis of variance technique and subsequently means were separated using LSD test using 5%. Probability level. By using computer software STATISTIX (version 8.1) all the statistical analysis was done.

3. RESULTS

3.1 Repellent effects

The data presented in Fig. 1 clearly indicate that DE tested at four different doses had a significant effect on the behaviour of granary weevil. The DE possessed repellent qualities against granary weevil. At 24 hours after treatment, maximum repellency of 41.33% of adult weevils was recorded when chick pea grains were treated with maximum dose (600ppm) of DE having significant variation from all the other tested doses of DE. It was followed by 45% repellency observed on grains treated with 500ppm dose of DE. Among the tested doses, the minimum 27.33% repellency was observed on grains treated with minimum (200ppm) dose of DE.

At 48 hours after the treatment of chick pea grains with DE, the maximum repellency of 66.42% was observed on grains treated with maximum (600ppm) dose of DE having significant difference from all the other tested doses of DE. The minimum repellency of 49.18% was observed on grains treated with minimum (200ppm) dose of DE.

When the data was recorded at 72 hours after the treatment, the DE at maximum dose of 600ppm caused maximum repellency 92.11% of adult granary weevil which was statistically significant from all the tested doses of DE. The minimum repellency 58.17% of adult weevils was observed on grains treated with minimum concentration of DE.

At 168 hours after the treatment of chick pea grains with DE, the maximum repellency of 94.11% was observed on grains treated with maximum concentration (600ppm) of DE having significant difference from all the other tested concentrations of DE. The minimum repellency of 64.44% was observed on grains treated with minimum concentration (200ppm) of DE.

3.2 Mortality effects

The data recorded on the mortality of granary weevil revealed that the efficacy of the DE increased by increasing the concentration of DE and also with exposure period (Table-1). After 24 hours, the maximum (48.80%) mortality of granary weevil was recorded in grains treated with maximum (600ppm) concentration of DE having significant variation from other treatments. The least (20.20%) mortality of weevil adults was observed on grains treated with 200 ppm concentration of DE. After 48 hours, the maximum mortality was noted when DE was tested at higher concentrations of 600 ppm and 500ppm while minimum mortality of 31.00% was recorded on grains treated with minimum concentration of DE.

The DE at 600ppm concentration caused maximum (62.00%) mortality of granary weevil at 72 hours after the treatment which was found statically different from all the other tested contractions of DE while 200 ppm was found least effective causing 34.20% mortality of granary weevil. At 1-week after exposure period, the DE at higher concentrations of 600, 500 and 400 ppm caused more than 50% mortality of granary weevil registering 69.60, 63.20 and 54.20% mortality having significant variation from each other while minimum mortality of 42.60% was documented on grains treated with lowest (200ppm) concentration of DE. The maximum (76.40%) mortality of weevil adults was recorded on grains treated with maximum concentration of DE at 2-weeks exposure period.

In contrast to this, the minimum mortality of 52.20% was recorded on grains treated with minimum (200 ppm) concentration of DE. At 3-weeks after the treatment of chickpea grains with DE at various concentrations, a slight increase in the mortality of granary weevil was recorded. The maximum concentration of DE being most effective caused maximum (82.00%) mortality of granary weevil followed by 74.80 and 70.20% mortality recorded on grains treated with 500 and 400 ppm concentration of DE having significant variation between each other. The lowest concentration (200 ppm) being least effective caused minimum mortality of 53.40%.

Regarding pooled mortality of granary weevil caused by various concentrations of DE, all the selected concentrations were found statistically different from each other (Table-1). The higher concentrations of 600 and 500ppm were found most effective and caused more than 50% mortality of granary weevil having significant variation between each other. The lower concentrations of 400, 300 and 200 ppm could not cause more than 50% mortality of granary weevil. The minimum concentration of 200ppm was found least effective and caused 37.62% pooled mortality of granary weevil (Table-1).

3.3 Sub-lethal effects

3.3.1 Days to adult emergence

The diatomaceous earth at all the evaluated concentrations had significant ($P<0.05$) effect on the developmental duration of granary weevil as related to control (Table-2). Among the tested concentrations, the maximum concentration of 550ppm was found most effective and maximum (20.69) days to emergence of weevil adults were documented in this treatment which differed significantly from all the other tested concentrations of diatomaceous earth. It was followed by 18.41 days developmental duration of granary weevil recorded when granary weevils were reared on grains treated with 450ppm diatomaceous earth. It differed non-significantly from 17.59 days developmental duration recorded on grains treated with 350ppm diatomaceous earth treated grains. The diatomaceous earth used at 250 and 150ppm also had significant effect on the developmental duration of granary weevil. Overall, the minimum developmental duration of 11.70 days was documented when granary weevils were reared on untreated grains.

3.3.2 Emergence of new progenies

The data regarding the impact of diatomaceous earth indicated that the minimum number of 24.44 emergence of weevil adults was noted from chickpea grains treated with maximum concentration of 550ppm of diatomaceous earth which was statistically significant from all the other tested concentrations of diatomaceous earth (Table-2). It was followed by 29.50, 32.56, 35.69 and 38.55 weevils emerged from grains treated with 450, 350, 250 and 150ppm concentration of diatomaceous earth. Overall; significantly maximum number of 49.78 weevils emerged from untreated chickpea grains.

3.3.3 Percent infestation

The diatomaceous earth used at various concentrations significantly inhibited the grain damage caused by granary weevil, the diatomaceous earth treated grains resulted into minimum number of damaged grains compared to untreated grains (Table-2). Among the different concentrations, the maximum concentration of 550ppm was found most effective in reducing the number of infested grains and resulted into 4.36% infested grains having significant variation from the rest of the tested concentrations. It was followed by 7.65% infested grains when weevils were cultured on grains treated with 450ppm treated grains which was statistically similar to 8.74% infested grains observed in 350ppm treated grains. Among the treatments, the maximum number of 11.48% infested grains were recorded on minimum concentration of 150ppm having significant variation from all the tested concentrations of diatomaceous earth. Overall; maximum number of 39.84% infested grains were noted when weevils were reared on untreated grains.

3.3.4 Percent weight loss

The grain weight loss was observed statistically different when granary weevils were cultured on chickpea grains treated with various concentrations of diatomaceous earth (Table-2). Among the treatments, the effect of diatomaceous earth at maximum concentration of 550ppm was found most pronounced in preventing weight loss caused by granary weevil followed by all the other tested concentrations. The minimum 3.16% weight loss was recorded in 550ppm treated grains. It was followed by 4.91% weight loss recorded at 450ppm treated grains having non-significant variation from 6.03% weight loss recorded in 350ppm treated grains. Among the treatments, the maximum weight loss of 9.15% was recorded in grains treated with minimum (150ppm) concentration of diatomaceous earth. Overall, the maximum (32.27%) weight loss was noted in untreated chickpea grains.

3.3.5 Sex ratio

The effect of Diatomaceous earth was found non-significant at all evaluated doses as related to untreated grains regarding the sex ratio of granary weevil. However; it was evident from the recorded data that the fewer male progenies emerged from all treatments compared to female adult weevils (Table-3). Diatomaceous earth is a natural insecticide that has potential for controlling different stored product pests like *S. granarius.* Several studies have investigated effectiveness of Diatomaceous earth at different exposure time and doses. It has substantial impact on overall population dynamics of different stored product pests including mortality and sex ratio.

3.3.6 Adult longevity

The application of diatomaceous earth significantly affected the adult life span of granary weevil cultured at chickpea grains (Table -3). The minimum adult life span of 81.44 days was noted on chickpea grains treated with 250ppm having significant difference from rest of the treatments. It was followed by 89.62, 95.54 and 99.49 days adult longevity of granary weevil cultured at 450, 350 and 250ppm treated grains, respectively. Among the treatments, the maximum adult life span of 103.68 days was documented when weevils were cultured on chickpea grains treated with 150ppm concentration of DE. Overall, the maximum (110.91 days) adult life span was noted when weevils were cultured on untreated grains.

3.3.7 Pre-oviposition period

An inverse relationship was observed between the pre-oviposition period and concentrations of diatomaceous earth (Table-4). The pre-oviposition duration decreased by increasing the concentration of the diatomaceous earth. The maximum pre-oviposition duration of 21.33 days was observed when the adult weevils were cultured on the untreated chick pea grains having non-significant variation from 20.33 diatomaceous earth. The minimum pre-oviposition duration of 13.66 days was documented when the adult weevils were cultured at the maximum (600ppm) concentration of the diatomaceous earth having significant variation from all the other concentrations of the diatomaceous earth.

3.3.8. Oviposition period

The treatment of chick pea grains with different concentrations of diatomaceous earth also significantly affected the oviposition duration of female adults (Table-4). The maximum oviposition duration of 86.00 days was noted when the weevils were cultured on untreated chick pea grains having significant difference from all the concentrations of diatomaceous earth. Among the different concentrations of diatomaceous earth, the minimum concentration (200ppm) was found least effective resulting in maximum oviposition duration of 71.00 days which was statistically similar to 69.00 days oviposition duration recorded at 300ppm concentration. The maximum (600ppm) concentration of diatomaceous earth was found most effective and resulted in 66.00 days oviposition duration having non-significant duration from 500 and 400ppm concentrations, respectively.

3.3.9. Post-oviposition period

The post-oviposition duration was found significantly different at all the concentrations of the diatomaceous earth compared to untreated control (Table-4). The maximum post-oviposition duration of 28.00 days was observed when female adults were cultured on untreated chick pea grains having significant difference from all the other treatments. The minimum post-oviposition duration of 19.33 days was observed when the female adults were cultured at the maximum (600ppm) concentration of diatomaceous earth having non-significance difference from 500, 400 and 300ppm concentrations, respectively, treated chick pea grains.

4. DISCUSSION

The present study revealed that the mortality of the weevil adults not only increased by increasing the doses of DE but also with exposure periods. These results are supported by the findings of El-Aziz and El-Ghany (2018) they tested different doses of DE against *S. granarius* on whole wheat grain and reported increase in adult mortality percentage with increase in tested concentrations during different exposure intervals. These results are also in agreement with those of Sousa *et al*., (2013), who reported that the effectiveness of DE to *S. zeamais* increased with increasing doses of the insecticide and with the temperature of the environment.

The findings of El-Aziz and El-Ghany (2018) also supplement our results. They documented that at 14 days after the application of modifications of diatomaceous earth on wheat grains the maximum mortality of granary weevil reached to 98%. The higher mortality of granary weevil observed is due to the fact that they used diatomaceous earth in modified form. Similar results were also reported by Ertürk et al. (2017). They reported that the mortality of

S. oryzae increased by increasing the concentration as well as exposure period of diatomaceous earth.

The diatomaceous earth tested at 1000 ppm resulted into complete mortality of adult weevils at 14 days after the application. DE also possessed repellent qualities and showed a dose-dependent repellent effect against granary weevil. Higher doses of diatomaceous earth carried higher repellent effects which ultimately caused reduction in infestation rate. Similar findings were also reported by El-Aziz and El-Ghany (2018). They tested diatomaceous earth in modified form i.e., hydroxides of different metals including Sodium, Aluminum and Calcium. Among the modified forms of metals, the Al-DE and Ca-DE were found to have maximum repellent activities against granary weevil on wheat grains leading to reduced feeding of adult weevils and reduced emergence of new progeny.

The results revealed that sub-lethal doses of DE can cause disruption in reproductive potential of granary weevil, aid in long term population control and prolonged development duration of test insects. Similar results were reported by Demissie et al*.* (2008) they concluded that the diatomaceous earth caused the mortality and significantly reduced the progeny emergence of maize weevil. The diatomaceous earth used at all the tested concentrations inhibited the progeny emergence of granary weevil compared with the control. Similar results were reported by Ferezli and Beris (2005) who reported that in case of lesser grain borer maximum doses resulted in minimum adult emergence with increase in exposure time.

Kavallieratos et al*.* (2007) reported that enhanced and natural diatomaeceous earths decreased the progeny emergence of *Tribolium confusum* when the concentration was increased 500 to 1000 ppm as the toxic effects increased on the tested larvae. The findings of Salim et al*.* (2020) also corroborate our results. They reported that the application of diatomaceous earth at 1500mg/kg resulted in 21.00 adults from treated wheat grains after 45 days of the application of wheat grains with diatomaceous earth. The results reported by El-Aziz and El-Ghany (2018) are also in accordance with the present findings. The findings indicate significance differences between the concentrations of diatomaceous earth application and progeny emergence of granary weevil from wheat grains. These results are similar to the reports of Bodroža-Solarov et al*.* (2012). They reported that the application of diatomaceous earth at 0.75 g/kg on wheat grains significantly reduced the rate of infestation caused by *S. oryzae*.

Similar results, regarding the efficacy of the diatomaceous earth against stored grain insect pests were also reported by Ertürk et al. (2017). They reported that the efficacy of the diatomaceous earth against *S. oryzae* increased by increasing the concentration of the diatomaceous earth. Similarly, sub-lethal doses of diatomaceous earth have been shown to minimize the percent loss of chickpea grains caused by granary weevil. Our results are in complete conformity with the findings of Salim et al. (2020). The reported that the application of diatomaceous earth reduces the weight loss caused by granary weevil and no weight loss of wheat grains was noted at the maximum (2000 mg/Kg) concentration. Several studies have investigated effectiveness of Diatomaceous earth at different exposure time and doses.

It has substantial impact on overall population dynamics of different stored product pests including mortality and sex ratio. The use of diatomaceous earth had no significant on the sex ratio of granary weevil. The findings of Toledo et al. (2016) supplement our results. They reported that mortality of weevils exposed to diatomaceous earth can directly influence the sex ratio if exposure time and effect of certain doses affect the survival rate of one sex more than other. The findings suggest that high doses of Diatomaceous earth significantly reduce survival rate of weevils and if the sex ratio of initial population is relatively balanced.

Then in overall survival, a substantial reduction due to high diatomaceous earth doses could indirectly affected the sex ratio of surviving weevils. While adult life span of granary weevil decreased by increasing the concentration of diatomaceous earth. The efficacy of diatomaceous earth against the adults of granary weevil is due to the fact that on contact it is attached to the body of insects and cause dehydration and ultimately cause mortality. Erturk et al. (2020) reported that diatomaceous earth was found highly effective against the adults of *S. oryzae* used at $2g/m^2$ concentration. Aisvarya et al. (2021) found amorphous formulation of diatomaceous earth used at 2 and 4 g/m2 more effective against adults of granary weevil compared to late larval stages.

5. CONCLUSIONS

Our findings highlighted the pivotal role of diatomaceous earth in the management of granary weevil under storage conditions. The use of diatomaceous earth not only caused significant mortality of granny weevil but also significantly inhibited the emergence of weevil and inhibited the losses caused by weevil. In light of these results, it can be concluded that use of diatomaceous earth as a major component of IPM for the management of granary weevil under storage conditions will lead to significantly reduce the losses caused by granary weevil.

Conflict of interest:

The authors declare no conflict of interest

Author contribution:

AB conducted the experiments and MMR conducted statistical analysis and contributed in writing the article.

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Table 1: Percent mortality of granary weevil in chickpea grains treated with DE under laboratory conditions.

Treatments	Percent mortality after						
	1 day	2 days	3 days	1 week	2 weeks	3weeks	Pooled Mortality
200 ppm	20.20 ± 0.53 e	31.00 ± 1.38 e	34.20 ±0.79 e	42.60 ± 1.19 e	52.20 ± 1.01 e	53.40 ± 1.18 e	37.62 ± 0.67 e
300 ppm	26.20 ± 0.86 d	36.40 ± 1.30 d	41.60 ±1.86 d	47.60 ± 1.29 d	60.00 ± 1.09 d	61.00 ± 1.28 d	43.21± 1.07 d
400 ppm	33.20 ±1.07 c	42.80 ± 1.23 c	46.80 ± 0.89 c	54.20 ± 1.18 c	63.60 ± 0.86 c	70.20 ± 1.24 c	48.56± 0.75 c
500 ppm	41.60 ± 1.53 b	50.40 ± 2.06 b	53.20 ± 0.80 b	63.20 ± 0.79 b	72.00 ± 1.03 b	74.80 ± 0.81 b	54.64±0.90 b
600 ppm	48.80 ± 0.86 a	53.60 ± 0.70 a	62.00 ± 1.22 a	69.60 ± 1.29 a	76.40 ± 0.47 a	82.00 ± 1.23 a	59.68± 1.24 a
Control	0.20 ± 0.00 f	0.60 ± 0.00 f	1.60 ± 2.73 f	2.40 ± 2.73 f	3.00 ± 2.73 f	3.60 ± 2.73 f	3.38 ± 2.73 f
$LSD_{0.05}$	1.83	1.75	1.61	1.60	1.66	1.72	0.77

Means in a column sharing similar letter are significantly similar.

Table 2: Effect of diatomaceous earth on duration to adult emergence, total adult emergence, infestation and weight loss (%) caused by granary weevil cultured on chickpea grains.

Concentration (ppm)	Days to adult emergence (days)	Total adults emerged	Percent infestation	Weight loss
50	14.51 ±0.78 d	38.55±0.70b	11.48 ±0.83 b	9.15 ±1.22 b
100	16.32±0.51 c	35.69±0.12c	9.52 ±0.70 c	7.25 ±1.51 c
150	17.59±0.12 b	32.56±0.83d	8.74 ±0.54cd	6.03±0.97cd
200	18.41±0.89 a	29.50±0.72e	7.65 ±0.65 d	4.91 ±0.76 d
250	20.69±0.56 a	24.44±0.65f	4.36 ±1.14 e	3.16 ±0.64 e
Control	11.70± 1.12e	49.78±1.16a	39.84 ±0.89a	32.27±1.14a
$LSD_{0.05}$	0.86	1.81	1.75	1.50

Means in a column sharing similar letter are significantly similar.

Table 3: Effect of diatomaceous earth on adult life span and sex ratio of granary weevil cultured on chickpea grains.

Diatomaceous earth (ppm)	Adult longevity		Adult Sex ratio (M/50F)
	Male	Female	
50	103.68 ± 0.87 b	114.85 ± 2.65 b	43.86 ± 1.67 ^{NS}
100	99.49 ± 0.63 c	109.11 ± 2.32 c	43.48 ± 1.78
150	95.54 ± 1.01 d	105.75 ± 3.11 cd	44.60 ± 1.87
200	89.62 ± 0.67e	102.41 ± 2.33 de	43.83 ± 0.84
250	81.44 ± 0.53f	99.41 ± 1.75 e	43.19 ± 0.37
Control	110.91 ± 0.76 a	134.12 ± 2.88 a	44.61± 0.39
$LSD_{0.05}$	1.95	4.26	3.08

Means in a column sharing similar letter are significantly similar.

Table 4: Effect of different doses of diatomaceous earth on oviposition periods of *Sitophilus granarius*

Concentrations of Diatomaceous earth	Pre-oviposition period	Oviposition period	Post-oviposition period
200ppm	20.33 ± 1.23a	71.00 ± 0.78b	23.00 ± 0.62b
300 ppm	18.00 ± 1.56b	69.00 ± 0.59bc	22.00 ± 0.54bc
400ppm	16.33 ± 0.89c	68.00 ± 1.69cd	21.00 ± 1.91cd
500ppm	15.33 ± 0.54c	67.00 ± 0.48cd	20.00 ± 1.45d
600ppm	13.66 ± 1.84d	66.00 ± 1.20d	19.33 ± 2.01d
Control	21.33 ± 1.91a	86.00 ± 1.71a	28.00 ± 1.82a
LSD Value	1.18	2.17	1.67

Means in a column sharing similar letter are significantly similar.

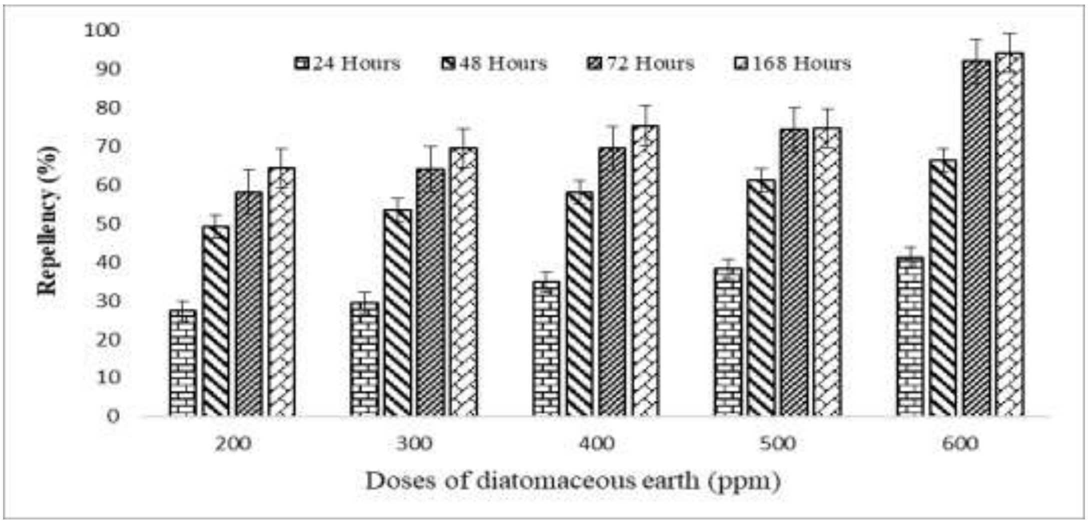

Fig 1: Repellent effect of different doses of Diatomaceous earth on granary weevil.