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Efficacy of Diatomaceous Earth and Insect Growth Regulators against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae)

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Abstract

Among all stored grain insect pests, *Tribolium castaneum* causes huge economic losses. The current investigation was designed to evaluate the toxic and growth regulatory effects of diatomaceous earth (DE) and insect growth regulators (IGRs) alone and in combination against *T. castaneum*. Different concentrations of DE (200, 400 and 600 ppm) and IGRs (0.02, 0.04, and 0.06 ppm) were tested against *T. castaneum*. Maximum mortalities of 79.2%, 98.2% and 38.1% were recorded in case of DE, lufenuron and tebufenozide, respectively, at their highest dose rates. The combined treatment of lufenuron + DE showed maximum mortality of 98.2% at the highest dose rate (0.06 + 600 ppm). It was also observed that the highest doses of lufenuron, tebufenozide, DE and lufenuron + DE showed a significant reduction in larval, pupal and adult emergence of *T. castaneum* compare to control. Minimum mean pupation of 19 was observed at 600 ppm in case of DE, while for lufenuron, tebufenozide and combined treatment (lufenuron + DE), minimum mean populations of 13, 20 and 11.3 were seen at their highest dose rates, respectively. Minimum progeny production recorded in case of lufenuron + DE was 170 over 435 of control. The lufenuron and DE were found most suitable against *T. castaneum*, not only alone but also combined. Overall, the results of the present work clearly indicate that the combined use of DE and IGRs is highly effective against stored grain insect pests.

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Introduction

Among the stored grain insect pests, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) is a serious pest of processed commodities. It causes both qualitative as well as quantitative losses during storage [1, 2]. In storage, up to 10% world's cereal production is lost because of insect infestation every year [3]. In Pakistan, about 10-20% of storage losses are caused by insect pest infestation [4]. Moreover, *Tribolium* spp. secretes carcinogenic chemicals on stored commodity, which are hazardous [5]. During the severe attack of *T. castaneum*, the flour color changes and gives a bitter taste which is not suitable for humane health [6].

The diatomaceous earth (DE) is composed of fossilized remains of unicellular algae (diatoms) deposited in Eocene or Miocene periods. According to an estimate, there are about 250 genera and 8000 species of diatoms, which may find in freshwater (ponds, lakes, bogs, rivers, streams, etc.) as well as in marine water. The diatoms get a deposit in different layers, their thickness may vary from few centimeters to several hundred meters but the thickest deposit is of 300 meters found in California, USA [7]. The DE has potential as an alternative control measure of insect pests that is safe for human beings and does not break down quickly [8, 9]. A variety of DE has been used effectively against stored grain insect pests and mite species [10, 11]. DE acts upon insects badly, causes abrasion in epicuticular wax layer and insect death occur due to excessive water loss [7].

Insect growth regulators (IGRs) are a class of bio-rational compounds that disrupt the normal development of insects. The important bio-rational alternative is the use of IGRs, as a sustainable control measure of stored grain insect pests [12]. The use of IGRs significantly affects the reproductive process of insects [13]. By inhibiting the biosynthesis of chitin, they pose mortality effects in stored grain insect pests [14]. Application of IGRs at immature stages inhibits the normal adult emergence or cause sterile adult emergence [15]. These compounds appear to fulfill the requirements for third-generation pesticides, environmentally benign and safer grain protectants because of their selectivity of action. Compared with the conventional insecticides, IGRs do not exhibit quick knock-down in insects or cause mortality, but the long-term exposure to these compounds largely stops the population growth, as a result of the effects mentioned in both the parents and progeny [16].

We can reduce stored grain losses by using non-chemical methods. Chemical methods pose many environmental hazards. Indiscriminate use of insecticides and fumigants to control stored grain insect pests create a problem of insecticide resistance [17, 18]. Their indiscriminate use also poses serious health effects on human beings [19, 20]. In order to conflict the resistance issue in stored grain insect pests, we should move towards other control methods, which are socially suitable, ecologically consistent and economically practicable [21]. Keeping in view the above information, the current study was planned to investigate the possible potential of DE and IGRs for the management of *T. castaneum*.

Materials and Methods

Insect rearing

The insect *T. castaneum* was collected from grain market and godown of Punjab Food Department, Faisalabad, Pakistan. The culture of *T. castaneum* was reared in an incubator on wheat flour at 30°C±2 and 65±5% R.H. The wheat flour was sterilized at 70°C for 15 minutes and then put in glass jars of 250 g capacity. Fifty adults were released on the culture (wheat flour) in the jars. The mouth of the jars was tightly covered with muslin cloth using a rubber band to prevent the escape of beetles. After three days, these beetles were sieved out from culture. The wheat grains having freshly laid eggs were put into same jars which were kept in a cooled incubator at optimum growth conditions (30°C±2 and 65±5% R.H) to get homogeneous population which was further used in different bioassays.

Wheat grains crushing

Untreated clean with very little dockage and infestation free hard wheat grains were taken from the market for bioassay. The moisture contents of the grains prior to the experiment were 11% measured by Dickey John's moisture meter. The grains were sterilized at 70°C in the electric oven; later, the grains were crushed using a mortar and pestle mill.

Diatomaceous earth (DE) formulation

The DEs formulation (Concern) contained 92% SiO_2, 3% Al_2O_3, 1% Fe_2O_3 and 1% Na_2O with an average particle size between 8-12 mm was imported from Wood Stream™ Corporation, USA.

The dose rates of DE used in the bioassay were 200, 400 and 600 ppm.

Insect growth regulators

Two synthetic insect growth regulators (lufenuron and tebufenozide) were used in bioassay studies at a dose rate of 0.02, 0.04 and 0.06 ppm. Lufenuron (Match) was purchased from Syngenta, Pakistan, while tebufenozide (Confirm) was purchased from Rohm and Haas Corporation, Spring House, PA, USA.

Efficacy of DE against *T. castaneum*

The impact of DE against *T. castaneum* was assessed using sterilized crushed wheat grains. Different concentrations (200 ppm, 400 ppm and 600 ppm) of DE along with an untreated control were applied to 30g of broken wheat grains into plastic vials, respectively. The DE is a marine white dust so it was applied directly in powdered form. These vials were shaken manually for 5 minutes to achieve the equal distribution of DE particles in the grain mass. Twenty adults were released into each plastic vial, covered with muslin cloth using a rubber band and then placed into the incubator at 30±2 °C and 65±5% R.H. The data regarding mortality, and larval, pupal and adult emergence were noticed after 7, 14, 21, 28 and 35 days of treatment application. The progeny production in treated and untreated broken grains was observed after 60 days.

Efficacy of insect growth regulators against *T. castaneum*

The impact of IGRs (lufenuron and tebufenozide) was assessed against *T. castaneum* using sterilized crushed wheat grains. Different concentrations (0.02 ppm, 0.04 ppm and 0.06 ppm) of both IGRs were prepared in 30 ml water separately and sprayed over 30g crushed wheat grains using a small handheld spray gun except control treatment (no IGR). The mixture of IGR and wheat grains was mixed for ten minutes in rotating flasks. After mixing well, the mixture was placed under sunlight for drying and then shifted into plastic vials. Twenty adults were released into each plastic vial, covered with muslin cloth using a rubber band and then placed into the incubator at 30±2 °C and 65±5% R.H. The data regarding mortality, and larval, pupal and adult emergence were noticed after 7, 14, 21, 28 and 35 days of treatment application. The progeny production in treated and untreated broken grains was observed after 60 days.

Combine effect of IGRs and DE against *T. castaneum*

In this experiment, DE and the most effective IGR (lufenuron) from the above experiments were selected to check the combined effect of both on the mortality of *T. castaneum*. The lufenuron and DE at the concentrations of 0.02 + 200, 0.04 + 400 and 0.06 + 600 in ppm, respectively, were applied to the weighed amount of crushed wheat grains in plastic vials. In the case of the combined treatments, first of all, grains were treated with lufenuron as described above and after drying the treated grains, the DEs dust was applied and mixed well. There was also an untreated control for IGR and DE treatments separately. Twenty adults were released in each plastic vial containing the treated diet. Then these vials were placed into the incubator at 30±2 °C and 65±5% R.H. The data regarding mortality, and larval, pupal and adult emergence were noticed after 7, 14, 21, 28 and 35 days of treatment application. The progeny production in treated and untreated broken grains was observed after 60 days.

Statistical analysis

All experiments were conducted by following the completely randomized design (CRD) and each treatment was repeated three times along with a control. Corrected mortality was computed from observed mortality data using Abbott's formula (Abbott, 1925). The data were analyzed statistically using Statistix, Analytical Software, Tallahassee, FL. The means of significant treatments were compared using Tuckey's HSD test.

Results

The results indicated that as the concentration of DE, lufenuron and tebufenozide was increased, the mortality of *T. castaneum* was also increased. Maximum mean mortality of 79.2% occurred at 600 ppm in case of DE (Table 1), while 98.2% and 38.1% were the mortalities found in case of lufenuron and tebufenozide, respectively, at the dose rate of 0.06 ppm (Table 2, Table 3). The results revealed that the increase in dose rates of DE and IGRs have a significant effect on the mortality of *T. castaneum*. The maximum mortality was found in case of lufenuron, so lufenuron was used in further studies in a separate experiment by combining it with DE. In order to check the combined efficacy of lufenuron + DE, three combinations were tested as described above. Maximum mean mortality of 98.2% was recorded at the highest dose rate

Table 1 Comparison of mortality of *Tribolium castaneum* at different concentrations of diatomaceous earth at different time intervals for five weeks.

Concentrations (ppm)	Time intervals				
	7 days	14 days	21 days	28 days	35 days
200	6.66 ±1.66 j	26.66 ± 1.66 gh	35.00 ± 0.00 efg	40.27 ± 1.70 def	58.33 ± 3.00 bc
400	15.00 ± 2.88 ij	31.66 ± 1.66 fgh	38.33 ± 1.66 ef	45.39 ± 1.70 de	68.75 ± 3.00 ab
600	21.66 ± 1.66 hi	36.66 ± 1.66 efg	43.33 ± 1.66 de	50.51 ± 1.70 cd	79.16 ± 3.00 a

Means± S.E sharing similar letter are not significantly different at $P<0.05$.

Table 2 Comparison of mortality of *T. castaneum* at different concentrations of lufenuron at different time intervals for five weeks.

Concentrations (ppm)	Time intervals				
	7 days	14 days	21 days	28 days	35 days
0.02	6.66 ± 1.66 k	23.33 ± 1.66 hi	43.49 ± 2.96 ef	67.01 ± 1.73 c	89.24 ± 0.00 ab
0.04	11.67 ± 1.66 k	31.66 ± 1.66 gh	53.77 ± 2.96 de	79.16 ± 3.00 b	96.41 ± 1.79 a
0.06	16.66 ± 1.66 ij	35.00 ± 2.88 fg	60.61 ± 1.71 cd	91.31 ± 1.73 a	98.20 ± 1.79 a

Means± S.E sharing similar letter are not significantly different at $p<0.05$.

Table 3 Comparison of mortality of *Tribolium castaneum* at different concentrations of tebufenozide at different time intervals for five weeks.

Concentrations (ppm)	Time intervals				
	7 days	14 days	21 days	28 days	35 days
0.02	3.33 ± 1.66 g	10.00 ± 1.66 efg	14.43 ± 0.00 cdef	15.25 ± 1.69 cdef	22.68 ± 2.97 bc
0.04	6.66 ± 1.66 fg	13.33 ± 1.66 def	16.11 ± 1.67 cde	18.64 ± 0.00 cde	27.83 ± 2.97 b
0.06	10.00 ± 0.00 efg	16.66 ± 1.66 cde	19.46 ± 0.00 bcd	22.03 ± 1.69 bcd	38.14 ± 2.97 a

Means± S.E sharing similar letter are not significantly different at $P<0.05$.

Table 4 Comparison of mortality of *Tribolium castaneum* at different combined concentrations of lufenuron and diatomaceous earth at different time intervals for five weeks.

Concentrations (ppm)	Time intervals				
	7 days	14 days	21 days	28 days	35 days
0.02 + 200	15.00 ± 2.88 k	31.66 ± 1.66 hi	63.33 ± 1.66 f	81.09 ± 1.71 cd	92.93 ± 1.76 ab
0.04 + 400	21.66 ± 1.66 ij	41.66 ± 1.66 gh	70.00 ± 2.88 ef	86.25 ± 1.71 bc	98.23 ± 1.76 a
0.06 + 600	26.66 ± 1.66 i	51.66 ± 1.66 g	75.00 ± 2.88 de	91.40 ± 1.71 abc	98.23 ± 1.76 b

Means± S.E sharing similar letter are not significantly different at $P<0.05$.

(0.06 + 600 in ppm). These results showed that the mortality of *T. castaneum* was increased with the increase in the combined dose rate of lufenuron and DE (Table 4).

The data regarding larval emergence, pupal emergence and adult emergence of *T. castaneum* was also recorded for F_1 generation during mortality intervals. Results revealed that increased dose rate of DE and IGRs cause significant reduction in larval emergence. Minimum mean larval emergence at 600 ppm concentration of DE was 119.3 (Table 5), while at 0.06 ppm concentrations of lufenuron and tebufenozide, mean larval emergence was 53.3 and 111.7, respectively (Table 6, Table 7). These results revealed that increasing dose of DE and IGRs reduced the larval emergence, pupal emergence and adult emergence of *T. castaneum*. The larval emergence for DE and tebufenozide was observed after 7 days, while for lufenuron, larval emergence was observed after 14 days, indicated that lufenuron not only delayed the larval emergence but also reduced it significantly. On the other hand, time for pupal emergence and adult emergence was not different among DE and IGRs. The results of the combined use of lufenuron and DE showed that at their highest dose (0.06 + 600 ppm), minimum larval emergence of 30, minimum pupal emergence of 11.3 and minimum adult emergence of 8.7 of *T. castaneum* was observed (Table 8). The larval emergence for the combined treatment of lufenuron and DE was observed after 14 days, pupal emergence was observed after 21 days while the adult emergence was found after 28 days (Table 8). These results vary compared to the alone treatments of DE and IGRs. The combined treatment of lufenuron and DE not only further delayed the

Table 5 Effect of different concentrations of diatomaceous earth on larval, pupal and adult emergence of *Tribolium castaneum* at different time intervals for five weeks.

Time interval (days)	Concentration (ppm)	Larval emergence	Pupal emergence	Adult emergence
	200	-	-	-
	400	-	-	-
7	600	-	-	-
	control	-	-	-
	200	145.00 ± 2.88 e	-	-
	400	133.33 ± 1.66 ef	-	-
14	600	119.33 ± 2.96 f	-	-
	control	175.00 ± 2.88 d	-	-
	200	276.66 ± 6.66 b	33.33 ± 1.66 d	-
	400	242.66 ± 7.88 b	24.66 ± 0.88 e	-
21	600	220.00 ± 2.88 c	19.00 ± 0.57 e	-
	control	296.66 ± 7.66 a	45.33 ± 1.20 c	-
	200	-	98.33 ± 4.40 b	27.66 ± 1.45 f
	400	-	90.33 ± 2.40 b	24.00 ± 0.57 f
28	600	-	96.00 ± 3.21 b	19.00 ± 0.57 g
	control	-	131.33 ± 2.18 a	45.33 ± 1.20 e
	200	-	-	97.33 ± 1.20 b
	400	-	-	89.33 ± 1.45 c
35	600	-	-	85.00 ± 0.57 d
	control	-	-	129.66 ± 2.02 a

Means± S.E sharing similar letter are not significantly different at $P<0.05$.

Table 6 Effect of different concentrations of lufenuron on larval, pupal and adult emergence of *Tribolium castaneum* at different time intervals for five weeks.

Time interval (days)	Concentration (ppm)	Larval emergence	Pupal emergence	Adult emergence
	0.02	-	-	-
	0.04	-	-	-
7	0.06	-	-	-
	control	-	-	-
	0.02	-	-	-
	0.04	-	-	-
14	0.06	-	-	-
	control	191.66 ± 4.40 a	65.00 ± 2.88 b	-
	0.02	80.00 ± 2.88 e	16.33 ± 0.88 d	-
	0.04	65.00 ± 2.88 f	13.66 ± 0.33 d	-
21	0.06	53.33 ± 1.66 f	13.00 ± 0.57 d	-
	control	200.00 ± 5.77 a	60.00 ± 2.88 b	-
	0.02	155.00 ± 2.88 b	32.66 ± 1.76 c	13.33 ± 0.88 de
	0.04	135.00 ± 2.88 c	27.33 ± 0.66 c	10.00 ± 0.57 e
28	0.06	121.66 ± 1.66 d	26.00 ± 1.15 c	7.33 ± 0.33 ef
	control	195.00 ± 2.88 a	120.00 ± 5.77 a	60.00 ± 2.88 b
	0.02	-	-	28.00 ± 1.15 c
	0.04	-	-	23.66 ± 1.45 c
35	0.06	-	-	20.66 ± 1.45 cd
	control	-	-	120.00 ± 5.77 a

Means± S.E sharing similar letter are not significantly different at $P<0.05$.

Table 7 Effect of different concentrations of tebufenozide on larval, pupal and adult emergence of *Tribolium castaneum* at different time intervals for five weeks.

Time interval (days)	Concentration (ppm)	Larval emergence	Pupal emergence	Adult emergence
	0.02	-	-	-
	0.04	-	-	-
7	0.06	-	-	-
	control	-	-	-
	0.02	125.00 ± 2.88 d	-	-
	0.04	111.66 ± 1.66 de	-	-
14	0.06	98.33 ± 4.40 e	-	-
	control	196.66 ± 12.01 c	-	-
	0.02	250.00 ± 5.77 b	26.66 ± 1.66 e	-
	0.04	223.33 ± 3.33 b	21.66 ± 1.66 e	-
21	0.06	196.66 ± 8.81 c	20.00 ± 2.88 e	-
	control	276.66 ± 6.67 c	50.00 ± 2.88 d	-
	0.02	-	125.00 ± 2.88 b	24.66 ± 1.66 d
	0.04	-	111.66 ± 1.66 b	20.33 ± 1.33 d
28	0.06	-	98.33 ± 4.40 c	18.00 ± 2.30 d
	control	-	196.66 ± 5.40 a	55.00 ± 2.88 c
	0.02	-	-	88.33 ± 5.04 a
	0.04	-	-	70.33 ± 2.90 b
35	0.06	-	-	55.00 ± 2.90 c
	control	-	-	96.66 ± 4.40 a

Means sharing similar letter are not significantly different at $P<0.05$.

larval emergence, pupal emergence and adult emergence of *T. castaneum* but also showed a higher reduction of all parameters compared to their alone application. These results further verify the significance of using the combined treatment of DE and IGR compared to their single-use.

The data regarding progeny production was taken after 60 days. The result showed that progeny production of *T. castaneum* was observed minimum at the highest dose rate of DE and IGRs. Minimum progeny production of 195 and 220 in case of lufenuron and tebufenozide was observed at 0.06 ppm, respectively. While in the case of DE, minimum progeny production of 225 was found at 600 ppm dose rate. The combined application of lufenuron and DE further reduced the progeny production of *T. castaneum* and minimum progeny production was found at the highest dose (0.06 + 600 ppm), respectively (Table 9).

Discussion

The diatomaceous earth and two insect growth regulators (lufenuron and tebufenozide) were tested, alone and in combination against *T. castaneum*. Diatomaceous earth is inert dust harvested from sediments at the bottom of oceans, lakes, and rivers around the globe. DE is unique among inert dusts because of its abrasive properties. DE is virtually harmless to humans, mammals and the environment. It is chemical-free, kills mechanically by disrupting insect soft waxy shell structure, punctures their breathing system, chews up their digestive organs and causes death by dehydration [7]. Different insects have different susceptibility to DEs and IGRs. The results of this study revealed that the DE and IGRs have a significant effect on the mortality, larval emergence, pupal emergence, adult emergence and progeny production of *T. castaneum*, while IGRs also have the insecticidal effect and delayed metabolism properties. The IGRs have been reported for a reduction in the oviposition, fecundity and survival of subsequent progeny of insects [14]. Our results are in accordance with the results of Wakil et al. [23] and Arthur [24], who concluded that mortality of all insects increases as the dose rate and exposure time of DE increases. Differences in toxicity of DE were depended on the type of the commodity. DE formulations showed differences in toxicity when applied on different grains. The mortality showed by *Sitophilus oryzae* was more on rice grains as compared to maize treated with DE [25]. Similar results were observed between maize and wheat for *Tribolium confusum*

Table 8 Effect of different concentrations of lufenuron and diatomaceous earth combined application on larval, pupal and adult emergence of *Tribolium castaneum* at different time intervals for five weeks.

Time interval (days)	Concentration (ppm)	Larval emergence	Pupal emergence	Adult emergence
	0.02 + 200	-	-	-
	0.04 + 400	-	-	-
7	0.06 + 600	-	-	-
	control	-	-	-
	0.02 + 200	-	-	-
	0.04 + 400	-	-	-
14	0.06 + 600	-	-	-
	control	188.33 ± 4.40 ab	-	-
	0.02 + 200	36.66 ± 1.66 d	-	-
	0.04 + 400	31.66 ± 1.66 d	-	-
21	0.06 + 600	30.00 ± 10.00 d	-	-
	control	175.00 ± 2.88 b	115.00 ± 2.88 a	-
	0.02 + 200	73.33 ± 3.33 c	13.00 ± 0.57 c	-
	0.04 + 400	63.33 ± 3.33 c	12.00 ± 0.57 c	-
28	0.06 + 600	43.33 ± 3.33 d	11.33 ± 0.88 c	-
	control	191.67 ± 1.66 a	65.00 ± 2.88 b	62.00 ± 3.60 a
	0.02 + 200	-	-	12.33 ± 0.33 b
	0.04 + 400	-	-	10.66 ± 0.33 b
35	0.06 + 600	-	-	8.66 ± 0.88 b
	control	-	-	65.00 ± 2.88 a

Means sharing similar letter are not significantly different at $P<0.05$.

[26]. In another study, DE formulation was effective against stored grain insect pests at the dose rate of 125 ppm and caused 77% mortality of *S. oryzae* after the exposure of 14 days on barley grains [25]. Our study showed that the highest dose of combined treatment of lufenuron + DE has more pronounced effects against *T. castaneum* compared to their single-use. Arthur [24] studied the combined effect of methoprene and DE against *Rhyzopertha dominica* and stated that the survival of the insects was greatly decreased with increasing dose rate. In other studies of stored grain insects, due to the combined use of spinosad and DE, the growth, development and survival of insects was decreased with the increase in dose rate [27]. Application of hydroprene during the larval stage restricted and inhibited the normal development, and larvae could not emerge as adults or emerge as abnormal sterile adults [15]. The lufenuron drastically affected the nymph of the desert locust by inhibiting the growth and development and by prolonging the pupation of locust [28]. In another study, the tebufenozide affected the pupation of codling moth by reducing the larval feeding as well as growth and showed the symptoms of double head capsule [29]. It was found that 0.01 ppm concentration of pyriproxifen completely inhibited the F1 adult emergence of both S and R strains of the red flour beetle and tebufenozide appeared less effective as compared to lufenuron [30], these results were also in accordance with our results where lufenuron showed more pronounced effect compared to tebufenozide. Tebufenozide induced sterility in the male and female codling moths, which produced less F_1 progeny [29], while the lufenuron inhibited the adult emergence when the last-instar nymphs of the desert locust were treated [31]. DEs showed the ability to cause 100% suppression of the progeny in *Sitophilus oryzae* [32]. Methoprene and DE when used in combination, showed 100% suppression of progeny [24]. These results in combination with our results showed the great potential of DE and IGRs in suppressing the insect pests of grains. Thus, our experiment with *T. castaneum* might serve as a good model for evaluating the effect of DEs and IGRs in order to suppress the population of stored grain insect pests. Our results provide very strong evidence that the diatomaceous earth and lufenuron can be used with success in stored grain products.

Conclusions

Our results revealed that lufenuron was more effective against *T. castaneum* as compared to tebufenozide. On the other hand, diatomaceous

Table 9 Effect of different concentrations of diatomaceous earth and insect growth regulators (lufenuron and tebufenozide) and combined application of lufenuron and diatomaceous earth on progeny production of *Tribolium castaneum* after 60 days.

Treatment	Concentration (ppm)	Progeny production
Diatomaceous earth	200	253.33 ± 4.40 b
	400	235.00 ± 2.88 c
	600	225.00 ± 2.88 c
	control	455.00 ± 2.88 a
Lufenuron	0.02	225.00 ± 2.88 b
	0.04	210.00 ± 2.88 c
	0.06	195.00 ± 2.88 d
	control	455.00 ± 2.88 a
Tebufinozide	0.02	250.00 ± 2.88 b
	0.04	235.00 ± 2.88 c
	0.06	220.00 ± 2.88 d
	control	465.00 ± 2.88 a
Lufenuron + diatomaceous earth	0.02 + 200	200.00 ± 2.88 b
	0.04 + 400	185.00 ± 2.88 c
	0.06 + 600	170.00 ± 2.88 d
	control	435.00 ± 2.88 a

Means sharing similar letter are not significantly different at $P<0.05$.

earth showed promising results. Our results also revealed that lufenuron and DE have great potential against stored grain insect pests when using in combination. Keeping in view the results obtained in the present study, it is suggested that we should give more attention to develop commercial formulations of DE and IGR's, which are safe for human health as well as for the environment. The information obtained in the present study would serve as a guideline.

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Conflict of Interest

Authors declare no conflict of interest.

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