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Research Article

Insecticidal Efficacy of Diatomaceous Earth and Botanical Powders against Pulse Beetle, *Callosobruchus analis* F. in Stored Mung Bean (*Vigna radiata* L.)

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Abstract: The pulse beetle is the most damaging insect pest of legumes causing huge economic losses. The experiment was conducted to find out the insecticidal effects of diatomaceous earth (DE) combined with three botanical powders in three different combinations of 25% plant powder with 75% DE, 50% plant powder with 50% DE, and 75% plant powder with 25% DE. The results indicated that the least number of adult beetles settled on grains treated with T_9 (75% GP + 25% DE) and T_3 (75% NP + 25% DE) whereas a maximum number of adult beetles settled in T_4 (25% TP + 75% DE). After 168 hours, all the treatments showed significant mortality (100%) of adult beetles compared to control (43%). All the treatments reduced the number of eggs (3.60 to 6.80 eggs per 20 grains) in comparison to control (17.00). The maximum (28.80) days to adult emergence were documented in T_9 whereas; minimum (21.40) days were recorded in untreated grains. Among all the treatments, T_9: showed minimum emergence (36.40) of adult beetles whereas; the maximum (125.20) adults emerged in control. The lowest grain damage (5.50%) was observed in T_9 as related to the maximum grain damage (28.96%) in the untreated control. The minimum weight loss (3.49%) was recorded in T_9. The maximum weight loss (21.08%) was recorded in untreated grains. The use of diatomaceous earth in combination with garlic powder is recommended for the management of pulse beetle under storage conditions.

Keywords: *C. analis*, Repellency, Insecticidal Efficacy, Biological Effects, Mung Bean.

1. INTRODUCTION

The mung bean (*Vigna radiata* L) is a significant pulse crop among grain legumes grown in Pakistan. It ranks second to Chickpea (*Cicer arietinum*) among the grain legumes in terms of production. Its seeds are very tasty, nourishing, and easily digestible and never cause flatulence than other pulses grown in Pakistan [1]. Approximately one third of the total food production in the world is destroyed by more than 20000 species of pre- and post-harvest insect pests causing more than 100 billion dollars loss annually. The losses caused by insect pests include weight loss, reduced germination potential and reducing the commercial value of the infested grains [2]. The insect pests damage stored grains by consuming grains and contamination by debris of exuviae and cadavers thereby reducing the quality as well as quantity and making the grains unfit for human consumption [3]. The infestation of Bruchids begins in the field before the crop is harvested [4] which is passed to storerooms, leading to higher infestation and damage of stored grains. The suitable environmental conditions including high humidity and temperature facilitates the rapid development of stored grain insect pests. The eggs hatch into larvae which bore into the pulses and start damaging them. Haines [5] reported that *C. analis* is a major pest of the green gram and white soybean.

Losses caused by insect pests both in the field and storage are one of main reasons for pulses production. Approximately 8.5% of total annual production is lost during storage and postharvest handling [6]. Various species of bruchids including *C. chinensis, C. maculates* and *C. analis* have been documented to cause post-harvest damage to stored grain legumes [7]. Among the stored grain pests. the pulse beetle (*Callosobruchus analis* F.) (Coleoptera:

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Bruchidae) is one of the most damaging insect pests infesting mung bean, gram, cowpea, lentil and other pulses and making them unsuitable for human consumption and planting [8, 9]. The larval stage of pulse beetle (*Callosobruchus spp)* inflicts heavy damage as they make holes in grains and consume inner part and cause damage ranging from 32-64%. The damaged grains are unable to sprout and also become inedible for human consumption [10, 11].

Generally, the management of stored grain insect pests is relied on the use of fumigants [12] and also by synthetic insecticides [13, 14], which carry many limitations and ill effects. The indiscriminate use of insecticides may cause serious health hazards as well as the destruction of beneficial insects and lead to increasing costs of application [15-17]. Entomologists throughout the world are seeking efficient, safer, economical and effective methods of pest control in stored grains which can be combined with older practices like sanitation, packaging, better storage facilities and periodical inspection to devise integrated pest management models [18, 19].

Numerous local plant species have been tested in recent years with significant degree of success as protectants against a variety of stored grain insect pests [20, 21]. Insecticidal plants are efficient substitutes for chemical insecticides to trim down pesticide load in the environment [22]. Botanicals have been used in the world for decades to control stored insect pests [23]. Previously, plant aqueous extracts using *Nicotiana tabacum* and *A. indica* caused complete mortality of *C. chinensis* at nine days after treatment of chickpea grains [24].

To substitute the use of synthetic chemicals for nontoxic, natural and effective products against stored grain pests has led to the development of inert dust formulations [25]. Diatomaceous earth is an inert dust, which is derived from amorphous sediments containing fossilized carapaces of unicellular algae. It is a white to dark gray light weight material with low density. It is composed of 80-93% silicon dioxide and the remaining content is comprised of clay minerals, calcium and magnesium carbonate, quartz and organic matter [25, 26]. Shah and Khan [27] reported that diatomaceous earth is a sound option for pest control in grain storage. Diatomaceous earth is abrasive and slightly absorptive, its particles adhere to the insect's cuticle and remove the lipid monolayer, causing the insect to desiccate [25, 28].

Diatomaceous earth has the potential as a protector of grains, because of its safety, efficacy, lower prices and no effect on the final quality of grains [29]. Diatomaceous earths (DEs) are one of the best alternatives to contact insecticides. These dusts can be applied directly to the grain without using any equipment and are nontoxic to mammals [25, 28]. Diatomaceous earths (DEs) can be effectively incorporated into integrated stored grain pest management (ISGPM) program as they possess low mammalian toxicity, and have been found effective against a variety of insect pests [8]. Keeping in view the problems of conventional/ synthetic pesticides, the benefits of botanicals and diatomaceous earths as safe alternative to control pulse beetle and to minimize the losses caused by it during post-harvest storage in Mung bean grains. The present research work was undertaken by using a combination of three indigenous plant powders and diatomaceous earth for the management of pulse beetle.

2. MATERIALS AND METHODS

The experiment was conducted to figure out the insecticidal efficacy of various native plant materials (powders) and diatomaceous earth against pulse beetle (*Callosobruchus annalis* F.) on mung bean in the Post Graduate Laboratory of the Department of Entomology, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa (KPK), Pakistan.

2.1. Preparation of Insect Culture

Mung bean (*Vigna radiate* L.) seeds, muslin cloth, mesh sieve, plastic jars, funnel etc. were used to prepare the culture of pulse beetle. The infested grains were collected from the local grain market for further multiplication after the identification of *C. analis*. Mung bean grains of locally available variety Dera mung were purchased from the grain market. The seeds were sieved and cleaned to remove the undesired materials. To eliminate the traces of insects, the grains were sterilized. Five hundred grams of disinfested mung bean grains having 12-14% moisture content (mc) in each plastic jar were used to establish the culture of pulse beetle. The moisture content of the seeds was measured by using OSAW digital moisture meter before starting the experiments. The jars having infested seeds of mung bean enclosed with muslin fabric were retained in an incubator (Versatile Environment test Chamber, Sanyo Japan, Model-MLR-350 H) at a controlled temperature of 27 ± 3 °C, 65 ± 5% R.H. and a photoperiod of 12:12 hours (Light: Dark) till the emergence of adult beetles following standard method described by Zafar *et al*. [30]. Healthy adults emerged from the container were shifted to the other plastic jars (having 500-gram mung bean seeds) for oviposition purpose. The mouths of the jars were closed with muslin fabric and tightened with elastic bands to avoid escape of pulse beetle and to allow air in and out of the jars. After 168 hours, the pulse beetles were removed from the jars with the help of mesh sieve and introduced into other jars to multiply the insect culture. The jars having infested mung bean seeds were retained undisturbed for ten days. The newly emerged subsequent generations of pulse beetle were utilized for the investigations.

2.2. Plant Materials and Diatomaceous Earth

The plant materials including neem, *Azadirachta indica* (seeds), turmeric, *Curcuma longa* (Rhizomes) and Garlic, *Allium sativam* (bulbs) were obtained from the field, local market as well as local growers. The plant materials were shade dried and used to prepare powders for experiments and maintained under constant environmental conditions until used. Diatomaceous earth imported from China was utilized in combination with various plant powders.

2.3. Preparation of Plant Powders

The plant materials used in the study were dried in shade. The dried plant materials were milled separately into very fine powder with the help of an electric grinder and sieved using 2mm mesh sieve to get fine powders and stored in air tight bottles.

2.4. Experimental Procedure

2.4.1. Settling response

An experiment was conducted to investigate the impact of the aforementioned native plant materials (powders) and diatomaceous earth on the settling response of pulse beetle on mung bean. The settling response of the *C. analis* was investigated using 30 × 30 cm^2 circular plastic boxes. For the investigations, there were ten treatments having five repeats. For the experiment, newly emerged adult beetles were collected. The beetles were kept starved for an hour before the start of the trial. A group of 50 newly emerged adult beetles were selected and were released in the middle of the plastic boxes to find out the effect of selected treatments on the settling response of beetles. The data was recorded after 24, 48 and 72 h of the release of the adult beetles and was converted to a percent settling response. While recording the data on the settling response of adult beetles, those beetles that did not respond, i.e., they did not settle on the treated grains and settled on different parts of the arena or remained unmoved were also recorded.

2.4.2. Insecticidal and biological effects

The experiment was conducted to study the insecticidal effects of diatomaceous earth (DE) combined with three selected botanical powders. The plant powders were mixed with the diatomaceous earth in three different combinations consisting of 25% Plant powder with 75% DE, 50% Plant powder with 50% DE and 75% Plant powder with 25% DE. All the treatments were used at 500 PPM. The studies were carried out in an incubator set at 27 ± 3°C and 65 ± 5% relative humidity. There were ten treatments having five replications. In every treatment, 50 grams of sanitized mung bean seeds were kept in transparent plastic jars which were thoroughly treated with a combination of DE and Plant powders. Jars for each dose were kept undisturbed for 30 minutes to allow the dust particles to settle down. The diatomaceous earth concentrations were prepared by following the standard procedure described by Fields *et al*. [31].
After the treatment of mung bean grains five pairs of newly emerged pulse beetle adults for each treatment were introduced in each jar and then the jars were closed tightly with cotton cloth to inhibit the movement of beetles. At 168 hours after the treatment of mung bean grains, the parent insects were removed and the number of eggs laid on 20 grains were noted and the mean was calculated. The jars were checked daily for recording data on the number of days to adult appearance. The number of adults emerged were counted daily and continued up to 40 days and later on were added to determine the total number of adult pulse beetles that emerged and then the average was calculated.

Mortality data was recorded after 24, 48, 72 and 168 hours, respectively, of the release of beetles. The dead adult beetles were collected and removed after each observation. The sublethal effects of the selected treatments were confirmed by recording data on the number of eggs per 20 grains, days to F_1 adult emergence, overall emergence of adult progeny, infestation (%), percentage weight loss, sex percentage (male and female ratio) and life span of adult beetles. The percent mortality was calculated by following formula as used by Ahmed *et al*. [32] and weight loss of grains were calculated by following formula as used by Salim *et al*. [33].

$$\% \; Mortality = \frac{No.of \; dead \; weevils}{Total \; No.of \; weevils \; released} \times 100$$

$$\% \; weight \; loss = \frac{weight \; of \; control \; grains - weight \; of \; treated \; grains}{weight \; of \; control \; grains} \times 100$$

2.5. Statistical Analysis

The data recorded were statistically analyzed using computer software Statistix Ver. 8.1 at P < 0.05 using one-way analysis of variance technique.

3. RESULTS

3.1. Settling Response

The data indicated in Fig. 1 show varying degree of repellent effect of selected treatments against pulse beetle on mung bean. The data regarding the settling response of pulse beetle show that after 24 hours the least number of adult pulse beetle settled on the mung bean grains treated with T_9 (75% GP + 25% DE), T_3 (75% NP + 25% DE) and T_6 (75% TP + 25% DE), whereas; maximum number of adult beetles settled on T_4 consisting of 25% TP + 75% DE, T_1 consisting of 25% NP + 75% DE and T_7 consisting of 25% GP + 75% DE, respectively. At 48 and 72 hours after the treatment an almost similar settling response of pulse beetle was noted (Fig. 1). Overall; T_3 and T_9 were found most-effective treatments resulting in minimum settling response whereas; T_4, T_1 and T_7 were found least effective treatments having minimum effect on the settling response of adult pulse beetle.

3.2. Mortality of Pulse Beetle after 24 Hours

Mortality of adult pulse beetle recorded after 24 hours of the application of diatomaceous earth and plant powders was found significantly different (P < 0.05) (Table 1) in all the treatments as compared to mortality (lowest) observed in the control. However, among all the nine treatments 75% GP (Garlic powder) + 25% DE and 75% TP + 25% DE showed the maximum mean mortality (27.80% and 26% respectively) of adult pulse beetle having significant variation from the rest of the treatments. The effectiveness of the treatments after turmeric powder was followed by 50% GP (Garlic powder) + 50% DE (25.20%) and 50% TP + 50% DE (24.60%). The minimum mortality of adult beetles was recorded in 25% TP (Turmeric powder) + 75% DE (22%). No mortality of the pulse beetle was recorded in the untreated control.

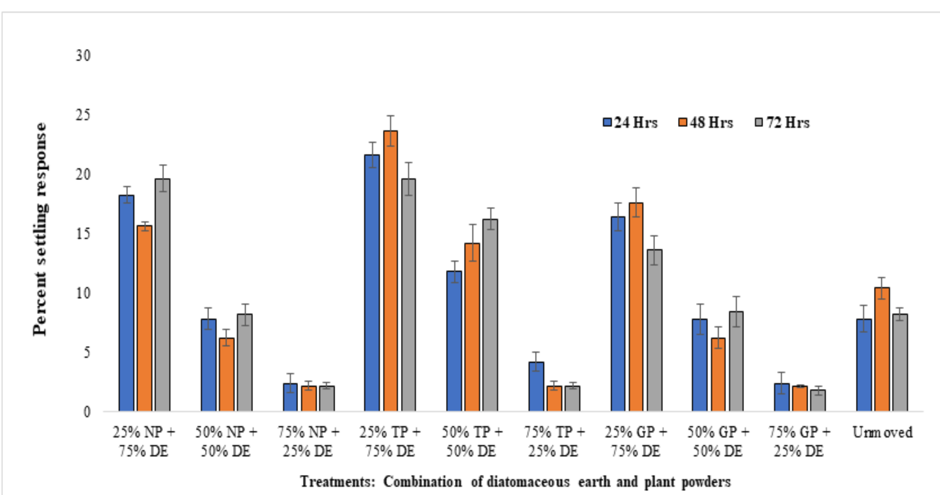

Fig. 1. Impact of plant powders and diatomaceous earth on the settling response of *C. analis* on mung bean grains under laboratory conditions.

3.3. Cumulative Mortality of Pulse Beetle after 48 Hours

Cumulative mortality of adult pulse beetle noted after 48 hours of the application of three plant powders in combination with diatomaceous earth (DE) was found significantly different ($P < 0.05$) in all treatments compared to the control. However, among all the treatments 75% GP (garlic powder) + 25% DE showed maximum mean mortality (69.60%) of pulse beetle adults being statistically different from all other treatments. It was followed by 50% GP + 50% DE and 75% TP + 25% DE showing 61.80 and 61% mortality of adult beetles having no significant variation from each other (Table:1). All the remaining six treatments showed significant mortality of (47.80% to 50.60%) of adult beetles having no significant variation from each other. The minimum mortality (2.40%) of adult pulse beetle was recorded in the control treatments (Table 1).

3.4. Cumulative Mortality of Pulse Beetle after 72 Hours

Collective mortality of pulse beetle recorded after 72 hours of the application of treatments was found significantly different ($P < 0.05$) in all treatments as compared to control where minimum mortality was observed (Table 1). However, among all the treatments, T_9 (75% garlic powder + 25% diatomaceous earth) caused the maximum mortality having non-significant difference from T_8, T_7, T_6 and T_5, having significant variation from the rest of the treatments. The control treatments were found least effective having minimum mortality (5.40%) of pulse beetle. All the treatments after 72 hours were found very effective in controlling the pulse beetle as compared to untreated control.

3.5. Collective Mortality of Pulse Beetle after 168 Hours

Combined mortality of pulse beetle noted after seven days of the application of three plant powders in combination with diatomaceous earth (DE) was found significantly different ($P < 0.05$) in all the treatments as compared to control where minimum mortality was recorded. All the treatments showed highest mortality (100%) of pulse beetle adults being statistically similar with each other having significant variation from untreated control having minimum mortality (13.80%) of pulse beetle at seven days after the exposure period (Table 1). It was observed that the rate of mortality increased with the increase of exposure period at all concentrations/ combinations of plant powders and DE.

3.6. Number of Eggs per 20 Grains

The recorded data revealed that a significantly higher number of eggs were observed in untreated grains compared to plant powders plus diatomaceous earth treated mung bean grains ($P < 0.05$). All the combinations of botanical powders and diatomaceous earth significantly inhibited oviposition by pulse beetle. The minimum number of eggs (3.60) were noted on mung bean grains treated with 75% GP + 25% DE having significant variation from all other treatments. It was followed by 50% GP + 50% DE recording 4.40 eggs. Overall,

Table 1. Percent mortality of pulse beetle at different concentrations of plant powders and diatomaceous earth after 24 h, 48 h, 72 hours and 168 hours exposure period.

Treatments	24-hours	48-hours	72-hours	7-days
25% NP + 75% DE	22.80 ± 1.11 cd	48.00 ± 0.43 c	91.60 ± 3.17 d	100.00 a
50% NP + 50% DE	23.00 ± 1.23 bcd	49.80 ± 1.27 c	92.80 ± 1.34 cd	100.00 a
75% NP + 25% DE	24.20 ± 0.45 bcd	50.60 ± 1.39 c	95.40 ± 1.34 bc	100.00 a
25% TP + 75% DE	22.00 ± 0.76 d	47.80 ± 1.11 c	92.20 ±1.37 cd	100.00 a
50% TP + 50% DE	24.60 ± 1.29 bcd	49.20 ± 1.26 c	97.20 ± 2.11 ab	100.00 a
75% TP + 25% DE	26.00 ± 2.11 ab	61.00 ± 2.27 b	98.80 ± 1.29 a	100.00 a
25% GP + 75% DE	23.00 ± 1.76 bcd	49.40 ± 2.34 c	96.40 ± 2.16 ab	100.00 a
50% GP + 50% DE	25.20 ± 1.19 abc	61.80 ± 3.56 b	98.80 ± 2.33 a	100.00 a
75% GP + 25% DE	27.80 ± 1.32 a	69.60 ± 2.45 a	99.40 ± 1.67 a	100.00 a
Control	0.00e	2.40 ± 1.11 d	5.40 ± 1.15 e	13.80 ± 1.45 b
$LSD_{0.05}$	3.11	3.51	3.25	0.99

Mean values having different letter(s) are significant at $P < 0.05$

the maximum number of eggs (17.00 eggs per 20 grains) were recorded in control treatments (Table 2).

3.7. Days to F_1 Adult Emergence

The application of three plant powders combined with diatomaceous earth had a significant effect ($P < 0.05$) on the number of days to adult emergence of pulse beetle compared to the untreated control. The maximum (28.80) days to adult emergence were documented in T_9 having non-significant variation from 50% GP + 50% DE, 75% NP + 25% DE, 75% TP + 25% DE, 25% GP + 75% DE and 50% TP + 50% DE. The minimum duration to adult emergence was recorded in untreated grains (21.40 days) being statistically different from all the other tested treatments (Table 2).

3.8. Total F_1 Adult Emergence

Collective emergence of F_1 adult beetles from mung bean grains recorded after the application of three plant powders in combination with diatomaceous earth (DE) was found significantly different ($P < 0.05$) in all treatments compared to control where maximum adult emergence was noted (Table 2). However, among all the treatments T_9: 75% GP (garlic powder) plus 25% DE (diatomaceous earth) showed minimum emergence of adult beetles (36.40 mean) having non-significant difference from T_8: 50% GP + 50% DE, T_7: 25% GP + 75% DE, T_6: 75% TP (turmeric powder) plus 25% DE (40.60, 41.20 and 44.80 mean respectively). The maximum mean number of adults emerged (125.20 mean) were noted from untreated mung bean grains.

3.9. Percent Infestation of Mung Bean Grains

At 40 days after the treatment of mung bean grains, the infested mung bean grains in different treatments were found significantly less as compared to untreated control (Table 3). The data revealed that all the treatments performed better in reducing the damage of grains compared to untreated control that sustained significant ($P < 0.05$) seed damage due to infestation and feeding by *C. analis*. The maximum grain damage (28.96%) was observed in untreated control and the lowest grain damage ranging from 5.50 to 9.09% was recorded in all the treatments of plant powders plus diatomaceous earth being significant to untreated control. Among the treatments, the lowest grain damage (5.50%) was observed in T_9 consisting of 75% GP (garlic powder) + 25% DE followed by T_6: 75% TP + 25% DE and T_7: 25% GP + 75% DE (6.42% and 6.59% respectively) being statistically at par with each other. All the remaining treatments were also effective in reducing the percent grain damage as compared to control.

3.10. Weight Loss of Mung Bean Grains

The use of botanical powders in combination with diatomaceous earth significantly reduced the weight loss of mung bean grains caused by *C. analis* compared to untreated control (Table 3). Among the treatments, the minimum weight loss of 3.49% was recorded in T_9: 75% GP (garlic powder) + 25% DE having non-significant variation from T_8: 50% GP + 50% DE, T_6: 75% TP + 25% DE and T_7: 25% GP + 75% DE. However, all the treatments

Table 2. Number of eggs per 20 grains, days to F_1 adult emergence and Total F_1 adult emergence of pulse beetle on mung bean grains.

Treatments	No. of eggs/20 grains	No. of days to F_1 adult emergence	Total F_1 adult emergence
25% NP + 75% DE	6.80 ± 0.12 b	24.80 ± 1.12 b	61.00 ± 1.23 b
50% NP + 50% DE	6.40 ± 0.15 bc	25.20 ± 1.13 b	51.20 ± 0.36 cd
75% NP + 25% DE	5.40 ± 0. 17 bc	28.00 ± 0.77 ab	51.00 ± 0.19 cd
25% TP + 75% DE	6.20 ± 0.19 bc	25.00 ± 0.47 b	55.20 ±1.34 bc
50% TP + 50% DE	5.60 ± 0.11 bc	25.80 ± 0.39 ab	51.60 ± 1.23 cd
75% TP + 25% DE	5.80 ± 0.22 bc	27.80 ± 0. 44 ab	44.80 ± 1.45 de
25% GP + 75% DE	5.20 ± 0. 17 bc	27.00 ± 0.39 ab	40.60 ± 1.29 ef
50% GP + 50% DE	4.40 ± 0.19 bc	28.00 ± 1.23 ab	41.20 ± 2.16 ef
75% GP + 25% DE	3.60 ± 0.11 c	28.80 ± 1. 37 a	36.40 ± 1.39 f
Control	17.00 ± 1.11 a	21.40 ± 1.23 c	138.20 ± 3.23 a
$LSD_{0.05}$	2.98	3.30	8.25

Mean values having different letter(s) are significant at $P < 0.05$

were found significantly effective in reducing the percent weight loss of grains compared to untreated control where maximum weight loss (21.08%) of mung bean grains was recorded.

3.11. Sex Ratio

The sex ratio of adult *C. analis* did not differ significantly ($P < 0.05$). The mean sex ratios (44.60 to 45.80% males) of emerged adult pulse beetles showed that the number of males were less in all the treatments as compared to female beetles. However, non-significant results were observed among all the treatments of plant powders plus diatomaceous earth and control (Table 3).

3.12. Adult Longevity

The adult longevity of newly emerged beetles in all the treatments was found statistically significant compared to the control ($P < 0.05$). All the plant powders plus diatomaceous earth treatments had a significant effect on the life span (6.80 to 9.40 days) of adult pulse beetle (Table 3). The minimum adult life span of 6.80 days was recorded in T_9 (6.80%) having non-significant variation from T_3, T_6, T_4, T_5, T_8 and T_7. The maximum adult longevity of 12.00 days was recorded in T_{10} (control).

4. DISCUSSION

There have been certain studies on the efficacy of plant powders and diatomaceous earth (DE) against stored grain pests. However, there is a dearth of available information on the usage of plant powders and diatomaceous earth (DE) in combined form against *C. analis*. The results of our research showed that binary mixes of botanical powders and diatomaceous earth have insecticidal potential against *C. analis*. All the treatments caused high mortality of adult beetles from 24 to 96 hours after treatment. However, adult mortality rapidly increased after 48 hours contact period. Similarly, all the tested treatments had significant effect on the settling response of pulse beetle. It is evident that among the tested treatments, the least number of adult pulse beetle settled on the mung bean grains treated with 75% GP + 25% DE, 75% NP + 25% DE and 75% TP + 25% DE, whereas, the maximum number of adult beetles settled on untreated mung bean grains.

The reason for the better efficacy of plant powders plus diatomaceous earth (DE) could be ascribed to the existence of various constituents in plant powders and DE that synergized with each other and enhanced the efficiency of applied mixtures. The findings of our research are similar to former research work which revealed that stored grain insect pests including *C. analis* can be managed by using plant powders in combination with diatomaceous earth. Paponja *et al*. [34] tested diatomaceous earth (DE Silico Sec) enhanced with plant products (bay leaves dust, corn oil and essential oil lavender) and silica gel against *Tribolium castaneum, Sitophilus oryzae* and *Rhyzopertha dominica*) in stored barley and wheat. Results indicated that botanicals enhanced the activity of diatomaceous earth, SilicoSec and showed great mortality and inhibited the emergence of new progenies of tested insect pest species. Similarly, Athanassiou *et al*. [35] tested the insecticidal

Table 3. Percent infestation, percent weight loss, sex ratio and life span of adult pulse beetle on mung bean grains.

Treatments	Percent infestation	Percent weight loss	Sex ratio N.S.	Life span of adult beetles
25% NP + 75% DE	9.09 ± 0.21 b	6.12 ± 0.13 b	45.80 ± 1.44	9.40 ± 0.28 b
50% NP + 50% DE	8.92 ± 0.32 b	5.49 ± 0.07 bc	44.80 ± 1.65	9.00 ± 0.38 b
75% NP + 25% DE	7.24 ± 0.11 bcd	4.89 ± 0.11 bcde	45.00 ± 2.11	7.40 ± 0.31 bc
25% TP + 75% DE	8.52 ± 0.36 bc	5.13 ± o.13 bcd	44.80 ± 1.54	8.80 ± 0.11 bc
50% TP + 50% DE	7.37 ± 0.12 bcd	4.69 ± 0.18 bcde	45.00 ± 1.87	8.80 ± 0.13 bc
75% TP + 25% DE	6.42 ± 0.38 cd	4.11 ± 0.09 cde	44.80 ± 1.76	8.00 ± 0.15 bc
25% GP + 75% DE	6.59 ± 0.33 cd	4.39 ± 0.13 cde	45.00 ± 1.23	8.80 ± 0.14 bc
50% GP + 50% DE	6.95 ± 0.17 d	3.86 ± 0.11 de	45.20 ± 1.76	8.60 ± 0.17 bc
75% GP + 25% DE	5.50 ± 0.19 d	3.49 ± 0.16 e	44.60 ± 1.77	6.80 ± 0.41 c
Control	38.96 ± 1.23 a	27.08 ± 1.33 a	45.60 ± 2.22	12.00 ± 0.23 a
$LSD_{0.05}$	2.15	1.49	1.78	2.08

Mean values having different letter(s) are significant at $P < 0.05$

activity of bitter barkomycin (BBM) prepared from the roots of the *Celastrus angulatus*, alone or as a mixture with diatomaceous earth against adults of the rusty grain beetle, *Cryptolestes ferrugineus*, *S. zeamais* and *T. castaneum*. A combination of BBM and DE at all the tested concentrations was found very effective in reducing the infestation of all three stored grain insect pests within 14 days and in decreasing the progeny production of the tested insect pests. These results are in conformity with the previous research findings [36-38].

Plant powders in combination with diatomaceous earth (DE) significantly reduced F_1 adult emergence in all the treatments compared to untreated control. The suppression of F_1 adult emergence may be due to less oviposition or toxic effects of treatments on eggs laid. This is in accordance with Paponja *et al*. [34] who reported a significant reduction of *C. analis* adults in mung bean grains treated with plant powders combined with diatomaceous earth (DE). The present research also corroborates with the findings of Ofuya *et al*. [39], they reported that the mixtures of *Piper guinese* seed powder and diatomaceous earth (DE) significantly reduced the oviposition and F_1 adult emergence of pulse beetle on stored cowpea. From our findings it was observed that grains treated with plant powders and diatomaceous earth (DE) showed reduced F_1 adult emergence, however, complete suppression of F_1 adult emergence was not recorded, which may be due to the potential of female adult beetles to lay eggs in unfavorable conditions. This is in agreement with Athanassiou [40], who stated that progenies of rice weevil, emerged even in those treatments of stored wheat which were treated with a combination of betacyfluthrin and *diatomaceous earth* (DE) where 100% mortality of adult rice weevils was recorded. The life duration of newly emerged adult pulse beetles in all the treatments were found statistically significant compared to control. All the plant powders plus diatomaceous earth (DE) treatments had a significant effect on the life span (6.80 to 9.40 days) of adult pulse beetle. Our results are similar to Yankanchi and Lendi [41]. They tested various plant powders against pulse beetle and found them effective in reducing the longevity and oviposition by *C. chinensis*.

5. CONCLUSIONS

The combined use of diatomaceous earth along with garlic and turmeric powders possessed repellent and insecticidal properties against pulse beetle in stored mung bean. The minimum number of beetles settled on treated grains. The maximum mortality and minimum progeny emergence of the beetle adults was documented on mung bean grains treated with the aforementioned products. Based on the results it can be concluded that combination of diatomaceous earth and plant powders (garlic and turmeric) are highly effective for the management of pulse beetle (*C. analis*) in stored mung bean. However, further investigations are needed to assess the use of garlic and turmeric powders under field and conventional storage conditions. The use of DE in combination with garlic and turmeric powders would be a good alternative to synthetic chemicals. This study will help to the development of natural pesticides as a vital part of pest management strategies.

6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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