



Effect of *Beauveria bassiana* (Bals.) with botanical extracts against *Trogoderma granarium* (Everts.) under laboratory conditions)

Muhammad Ashir^{1*}, Mohsin Mazhar¹, Javed Hassan², Muhammad Wasif²

¹Department of Entomology, FA&E, The Islamia University of Bahawalpur, 63100, Bahawalpur, Pakistan

²Faculty of Agricultural Sciences and Technology, University of Layyah, 31200, Layyah, Pakistan

*Corresponding Author's email address: ashirkhattak47@gmail.com

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Abstract

Worldwide, stored grain products are severely harmed by the khapra beetle, *Trogoderma granarium* (Bals.). It results in significant losses for wheat, *Triticum aestivum* (Linn.). The goal of the current experiment was to determine how well three plant extracts moringa, lupin, and lemon grass and fungus *Beauveria bassiana* (Bals.) worked against *T. granarium* larvae. Fungal formulation was formulated at 0.3×10^8 , 0.6×10^8 , and 0.9×10^8 conidia kg^{-1} of crushed wheat grains. In a lab conditions with $30 \pm 2^\circ\text{C}$ and $65 \pm 5\%$ relative humidity (r.h.), it was also combined with each plant extract. Combination dosages of the plant extracts and the fungal conidial formulation caused the greatest amount of larval mortality when compared to their solo treatments. Combination treatment of *B. bassiana* (0.9×10^8 conidia kg^{-1}) with lemon grass extract resulted in highest larval death rate (71.22%). Furthermore, highest concentration of *B. bassiana* (0.9×10^8 conidia kg^{-1}) alone caused a higher percentage of *T. granarium* larval death (57.63%) compared to the extracts from lupin and moringa plants (37.36 and 43.94%, respectively). When *B. bassiana* was applied separately from the plant extracts, the insect larvae showed a much higher maximal rate of mycosis and sporulation. In treatment, lowest concentration of *B. bassiana* (0.3×10^8 conidia kg^{-1}) was only utilized, resulting in the observation of mycosis (53.33%) and sporulation ($140 \text{ conidia kg}^{-1}$). Thus, it was determined that the combined usage of fungus and plant extract might be beneficial for *T. granarium* integrated pest control program.

1. Introduction

Agriculture is mostly responsible for providing a sufficient and nutrient-rich food supply for world's population. According to estimates from FAO, smallholder farmers produce over 80% of food consumed globally (FAO, 2020). In order to meet the nutritional demands of a growing global population, sustainable agricultural methods are crucial, especially in poorer nations where food insecurity is rife. Recent data indicates that Pakistan's GDP is mostly derived from agriculture, which also employs over 40% of its people resources (World Bank, 2021). Grain storage plays a vital role in agricultural production, providing food and money for millions of people globally. Worldwide, stored rice, wheat, oats, and other cereals are known to be heavily

parasitized by *Trogoderma granarium* (Coleoptera: Dermestidae) (Lowe et al., 2000; Shoaib et al., 2007).

T. granarium larvae may endure for up to three years without nourishment and can thrive on stored grains with the least amount of moisture. Millions of metric tons of stored grain are lost annually in Pakistan due to khapra beetle infestations, resulting in severe financial consequences for merchants, farmers, and the country's economy as a whole (Ahmedani et al., 2007). According to recent research, Pakistan's total grain output can suffer post-harvest losses from the khapra beetle by 15% to 35%, which is a significant blow to both agricultural productivity and economic growth (Government of Pakistan, 2022). Problem of managing pests in agriculture industry has historically

Corresponding Author: Muhammad Ashir

Email: ashirkhattak47@gmail.com

been mostly dependent on application of chemical pesticides. These insecticides have been successful in eliminating pests, but they also have a number of negative consequences on non-target creatures, environment, and human health. A rising number of people are realizing how important it is to investigate alternate methods of managing pests, such using plant extracts.

Although chemical pesticides are effective in the short term, there are serious health concerns associated with them. Long-term pesticide exposure has been connected to a number of harmful health outcomes, such as neurological conditions, respiratory issues, and certain cancers (Mostafalou and Abdollahi, 2017). To make matters worse, chemical insecticides can harm the ecosystem. Aquatic habitats can be harmed and water supplies contaminated by pesticide runoff from agricultural areas (Simon-Delso et al., 2015). It is vital to create long-term, efficient pest management plans for stored grains in light of these difficulties. Bio-based remedies, including combining entomopathogenic fungus and native plant extracts. Plant extracts, on the other hand, provide a more ecologically friendly substitute for pest control. Compounds originating from plants frequently have insecticidal qualities and can successfully manage pest populations while reducing the unfavorable effects of conventional pesticides. Furthermore, plant extracts are less harmful to the environment and human health since they are biodegradable (Isman, 2008).

Plant extracts are effective substitutes for pesticides, according to several research. For instance, pyrethrum (*Chrysanthemum cinerariifolium*), garlic (*Allium sativum*), and neem (*Azadirachta indica*) extracts have demonstrated potential in managing a variety of agricultural pests (Regnault-Roger et al., 2012; Pavela, 2016). Farmers may decrease environmental contamination, increase ecosystem health, and lessen their reliance on chemical pesticides by utilizing the natural pest-controlling capabilities of plants (Isman, 2006). It has been shown that these substances possess insecticidal qualities by interfering with the metabolism of the insect and upsetting essential physiological functions (Nakkeeran et al., 2018). Flavonoids are secondary metabolites found in moringa leaves and seeds that have been shown to have both insecticidal and antioxidant properties. It has been claimed that some alkaloids found in moringa, such as moringine and moringinine, have insecticidal effects (Abdallah et al., 2018). These substances may have harmful effects on insect nervous systems or interfere with cellular processes, which would result in insect death. Numerous studies have shown that moringa extract is effective against stored grain (Chattopadhyay et al., 2019).

Pests, including khapra beetle, studies have demonstrated that when used as grain protectants or fumigants, moringa leaf powder and seed extract can

demonstrate the ability to resist and diminish the population of stored grain pests, including *Trogoderma granarium* (Dhingra and Nandal, 2019). Furthermore, because of its insecticidal qualities, moringa extract is a good option for integrated pest management plans. In these plans, it may be used in conjunction with other biocontrol agents or cultural techniques to maximize the effectiveness of pest control while reducing the negative effects on the environment. They have demonstrated effectiveness against a variety of insect pests, including stored grain pests like khapra beetle, and is frequently employed in insect repellent compositions (Chauhan et al., 2018). Additionally, it serves as a strong repellent, keeping pests away from surfaces that have been treated (Choo et al., 2018). Lemongrass essential oil contains geraniol, a terpene alcohol with insecticidal and antifeedant qualities. Insect death results from geraniol's disruption of metabolic pathways and cellular membranes. Moreover, it discourages pests from feeding, minimizing harm to grains and other commodities that are kept (Tak et al., 2016).

Fungus *Beauveria bassiana* is a member of the Ascomycetes class. Its potential as a biological control agent against a variety of insect pests, such as the infamous khapra beetle (*Trogoderma granarium*), which is a pest of stored grains, is well known. An integrated strategy that blends plant extracts with biological control agents like *Beauveria bassiana* offers a viable method for managing infestations while reducing the negative effects associated with chemical pesticides in the context of the khapra beetle (*Trogoderma granarium*). This method helps maintain the resilience and sustainability of agricultural systems in addition to providing efficient insect management. To discover toxic effect of plant extracts and *B. bassiana* for the management of *T. granarium* and to examine the mycosis and sporulation of fungus applied on target insects.

2. Materials and Methods

Current study was carried out during year 2022-2023 at the Department of Entomology, The Islamia University Bahawalpur, and Punjab, Pakistan.

2.1 Collection and rearing of test insects

Trogoderma granarium populations were gathered from grain markets in Pakistan's Punjab province's two districts, Bahawalpur and Layyah. This culture was brought into the lab and raised in 1.0 L glass jars (11×6 cm) with 500 g of sterilized wheat grains and a fine muslin cloth covering them. Culture was raised for at least the third generation at a temperature of 30±2°C and a relative humidity of 65±5%. To create a uniform population, just emerging adults were moved into other jars.

2.3 Source of bio insecticides

Department of Plant Pathology provided bio insecticides, which included the formulation of *Beauveria bassiana*, an

entomopathogenic fungus that contains 1×10^8 conidia kg^{-1} . The Islamia University of Bahawalpur, Punjab, Pakistan's Cholistan Institute of Desert Studies (CIDS) provided the moringa, lemon grass, and lentil leaves that were harvested.

2.4 Preparation of plant extracts

After being cleaned with water, the plant leaves were placed in the shade to dry. An electrical grinder was used to crush the plant material into a powder. The following process was outlined by (Sagheer et al., 2013). Extracts were made using a rotatory shaker (IRMECO, OS 10) by immersing 50 g of powder in 250 ml of ethanol in conical flasks. Before being used, the solvents from the crude extracts were kept in a refrigerator at 4°C after being evaporated using a rotary evaporator.

2.5 Bioassay to assess the toxic effect of plant extracts and *Beauveria bassiana* against *Trogoderma granarium*

Using Whatman filter sheets, the mortality of *Trogoderma granarium* larvae was assessed. Before the bioassay began, filter sheets were treated with a concentration of 5% plant extracts and let to dry. Filter sheets that had been processed were put into petri dishes. For each treatment, a single petri dish with the untreated food was maintained as a control. A total of thirty third-instar *T. granarium* larvae were introduced into each petri dish that contained whole and crushed wheat grains and had perforated covers. For every treatment, three replications were employed. Data on larval mortality was collected at 7, 14, and 21 days.

Three rates of application of *B. bassiana* formulation against *T. granarium* were used: 0.3×10^8 , 0.6×10^8 , and 0.9×10^8 conidia kg^{-1} of wheat grains. Target insect pests were fed the sterilized food that had been treated with entomopathogenic fungus at each dosage rate. For each dosage rate, samples weighing 50 g of treated product were put into three different, sterile, little plastic jars (replicates). As a control, three jars containing untreated food were made. After 7, 14, and 21 days, data on larval mortality were recorded.

2.6 Effect of plant extracts and *Beauveria Bassiana* against *Trogoderma granarium*

Plant extracts' growth-inhibiting properties were assessed in little plastic jars. Wheat and broken grains were treated with plant extracts, which were subsequently allowed to dry. Each plastic jar contained thirty *T. granarium* larvae in their third instar. After regular intervals until the full emergence of adults, data about pupal and adult inhibitions were recorded. Three rates of application were used for the *B. bassiana* formulation: 0.3×10^8 , 0.6×10^8 , and 0.9×10^8 conidia kg^{-1} of each diet. For each of these two test insects, thirty larvae in their third instar were put into different plastic jars. For *T. granarium*, 50g of treated whole and crushed wheat

grains were utilised in each plastic container. After regular intervals, data on inhibitions in pupae and adults were recorded

2.7 Combined effect of effective plant extract and *Beauveria bassiana* against *Trogoderma granarium*

There were 0.3×10^8 , 0.6×10^8 , and 0.9×10^8 kg^{-1} *B. bassiana* (Racer TM) conidia for every kilogram of crushed and whole wheat grains. Three 50g batches of the meal treated with fungal conidia were placed in separate small plastic jars and sprayed with 5% of the potential plant extract. The prepared grains were placed in little plastic containers. The thirty-third-instar larvae of each of the two insect pests were given treated food in little plastic jars. Three replications were produced. Data on mortality and growth inhibition were documented at regular intervals.

2.8 Mycosis and sporulation

T. granarium cadavers were taken out of the experimental units that had been treated with fungus, placed on a Petri plate that had been cleaned, and then stored in tiny vials at 4°C . Subsequently, all of the corpses underwent two to three minutes of superficial decontamination with a 0.05% sodium hypochlorite solution, followed by two to three minutes of distilled water washing. Following that, cadavers were placed on Potato Dextrose Agar (PDA) Petri dishes and cultured for seven days at $26 \pm 1^\circ\text{C}$ and $75 \pm 5\%$ relative humidity. Under a microscope, insect cadaver's dislocation of the external fungal growth was observed. Mycosed insect cadavers from each replication were combined with 20 mm of distilled water, a drop of Tween-80, and blended for ten minutes to verify sporulation. Under a microscope, the hemocytometer was used to count the total number of conidia/ml (Riasat et al., 2011)

2.9 Statistical analysis

After the completion of all bioassays, Abbott's formula (Abbot, 1925) was used to compute corrected mortality of the recorded data. Tuckey-HSD test was used to evaluate important treatment findings after statistical analysis of data on percentage corrected larval mortality, other treatments,

$$\% \text{ Pupae or Adult inhibition} = 100 * (1 - \frac{t}{c})$$

and their combinations was conducted using STATISTICA 8.1. Percentage of inhibitions in pups and adults was computed as follows:

Where "t" is the number of pupae or adults in treated wheat grains and "c" is number of pupae or adults present in control.

3. Results

3.1 Mortality rates of *T. granarium*

Table 1. *T. granarium* mortality rates on days 7, 14, and 21 following the application of *L. albus* (10%) and *B. Bassiana* concentration 0.3, 0.6 & 0.9. The Tukey- (HSD) test at 5% and p value ≤ 0.05 indicates that the results are significant.

Treatments	Means Mortality (Corrected)		
	Days 7	Days 14	Days 21
<i>L. albus</i> (10%)	28.77±3.13 A	6.75±1.62 B	6.75±1.62 B
0.3	8.50±1.76 B	16.93±1.55 AB	54.21±2.99 A
0.6	8.33±4.40 B	18.68±1.86 AB	57.63±4.33 A
0.9	13.59±1.81 B	27.36±7.91 A	62.63±3.73 A
F Value	10.4	4.02	60.7
P Value	≤0.05	≤0.05	≤0.05

Table 1. *T. granarium* mortality rates on days 7, 14, and 21 following the application of *C. citratus* (10%) and *B. Bassiana* concentration 0.3, 0.6 & 0.9. The Tukey- (HSD) test at 5% and p value ≤ 0.05 indicates that the results are significant.

Treatments	Means Mortality (Corrected)		
	Days 7	Days 14	Days 21
<i>C. citratus</i> (10%)	57.63±1.44 A	50.78±4.65 A	8.33±4.40 B
0.3	8.50±1.76 B	16.93±1.55 B	54.21±2.99 A
0.6	8.33±4.40 B	18.68±1.86 B	57.63±4.32 A
0.9	13.59±1.81 B	27.36± 7.91 B	62.63±3.73 A
F Value	81.6	10.8	14.4
P Value	≤0.05	≤0.05	≤0.05

Table 2. *T. granarium* mortality rates on days 7, 14, and 21 following the application of *M. oleifera* (10%) and *B. Bassiana* concentration 0.3, 0.6 & 0.9. The Tukey- (HSD) test at 5% and p value ≤ 0.05 indicates that the results are significant.

Treatments	Means Mortality (Corrected)		
	Days 7	Days 14	Days 21
<i>M. oleifera</i> 10%	35.52±4.75 A	37.28±4.33 A	10.26±3.11 B
0.3	8.50±1.76 B	16.93±1.55 A	54.21±2.99 A
0.6	8.33±4.40 B	18.68±1.86 A	57.63±4.33 A
0.9	13.59±1.81 B	27.36±7.91 A	62.63±3.73 A
F Value	13.8	3.99	45.6
P Value	≤0.05	≤0.05	≤0.05

The goal of the current study was to determine the toxicity of *Beauveria bassiana*, *Lupinus albus* L., *Cymbopogon citratus* and *Moringa oleifera* (Lam.) at different exposure times and concentrations 7, 14, and 21 hours, respectively. Bioassays for growth inhibition and mortality were carried out in a lab setting. Analysis was also done on the combined impact of *B. bassiana* and superior plant extract.

Table 4.1 shows that after 21 days of exposure, a substantially higher percentage of larvae (62.63%) of *T. granarium* were discovered dead with the highest fungal dose (0.9×10^8 conidia kg⁻¹) of wheat grains. After 7, 14, and 21 days, relatively low larval mortalities of 28.77 percent, 6.75 percent, and 6.75 percent were noted in the lupin treatment. Larval mortality was generally greater in the three fungal dosage rates (0.3×10^8 , 0.6×10^8 , and 0.9×10^8

conidia kg⁻¹) than in the lupin plant extract at all exposure times. This difference was particularly noticeable at the highest dose rate of *B. bassiana*.

Table 4.2 reveals that after 7, 14 and 21 days of exposure of lemon grass treatment, 57.63, 50.78, and 8.33% were found dead respectively. *T. granarium* larvae of the highest fungal dosage (0.9×10^8 conidia kg⁻¹) of wheat grains were much more likely to be dead (62.63%) than those of other two doses. After 21 days, comparatively low larval mortalities of 8.33% were noted in the lemon grass treatment. Explanation is that environmental variables and sunlight cause plant extracts to denature over time. Larval mortality in the three fungal dosage rates (0.3×10^8 , 0.6×10^8 , and 0.9×10^8 conidia kg⁻¹) was generally greater than in the plant extract at all exposure times, with a significant difference observed at the highest dose rate of *B. bassiana*.

According to the mean mortality results in Table (4.3), moringa exposure increased mortality to a maximum of 35.52% in *T. granarium* following a 7-day exposure period. However, after 14 and 21 days, respectively, relatively low larval mortalities of 37.28 and 10.26 percent were noted. Larval mortality was typically greater in the three fungal dosage rates (0.3×10^8 , 0.6×10^8 , and 0.9×10^8 conidia kg⁻¹) than in plant extract at all exposure times. It was discovered that exposure time affected the mortality response. As time goes on, fungal doses increase mortality, whereas plant extracts lower incidence of death.

The mycosis in the cadavers of *T. granarium* larvae in their third instar was impacted by the applied therapies. When the insect larvae were subjected to individual treatments of *B. bassiana*, a notably higher rate of mycosis was seen than when the plant extracts were applied in combination. The treatments with the greatest concentration of *B. bassiana* (0.9×10^8 , 0.6×10^8 , and 0.3×10^8 conidia kg⁻¹) were found to have the highest mycosis (18%, 17%, and 16 %). The combined treatments with concentrations of *B. bassiana* (0.9×10^8 , 0.6×10^8 , and 0.3×10^8 conidia kg⁻¹) showed the lowest mycosis.

When *B. bassiana* and the plant extracts were applied together, *T. granarium* showed a significant reduction in pupation compared to when they were applied separately. This finding pertains to the suppression of pupae. The treatment with the highest concentration of *B. bassiana* (0.9×10^8 conidia kg⁻¹) and lemon grass had the lowest pupation (9.71). While the treatment with the lowest separate fungal concentration (0.3×10^8 conidia kg⁻¹) produced the greatest pupation of *T. granarium* larvae (52.87), the treatments with the lowest larval mortality typically produced the highest pupation.

Regarding adult inhibition, *T. granarium* subjected to combination applications of *B. bassiana* + plant extracts showed a notable reduction in adult appearance compared to their separate usage. The treatment with the highest

Table 4. *Trogoderma granarium* mycosis following application of various treatments of botanical extract and *Beauveria bassiana* 0.3×10⁸, 0.6×10⁸ and 0.9×10⁸ conidia kg⁻¹. The Tukey- (HSD) test at 5% and p value ≤ 0.05 indicates that the results are significant.

Treatments	Mycosis	Treatments	Mycosis
0.3	16±1.15 AB	<i>M. oleifera</i> +0.3	11±1.15 BCDE
0.6	17±1.15 AB	<i>M. oleifera</i> +0.6	7±1.15 DE
0.9	18±1.15 A	<i>M. oleifera</i> +0.9	8±1.15 CDE
<i>L. albus</i> +0.3	15±1.15 AB	<i>C. citratus</i> +0.3	7±1.15 DE
<i>L. albus</i> +0.6	14±1.15 ABC	<i>C. citratus</i> +0.6	6±1.15 E
<i>L. albus</i> +0.9	13±1.15 ABCD	<i>C. citratus</i> +0.9	5±1.15 E
F Value	12		
P Value	0.00		

Table 5. *Trogoderma granarium* sporulation following application of various treatments of botanical extract and *Beauveria bassiana* 0.3×10⁸, 0.6×10⁸ and 0.9×10⁸ conidia kg⁻¹. The Tukey- (HSD) test at 5% and p value ≤ 0.05 indicates that the results are significant.

Treatments	Sporulation	Treatments	Sporulation
0.3	160±1.15 A	<i>M. oleifera</i> +0.3	60±1.15 G
0.6	150±1.15 B	<i>M. oleifera</i> +0.6	40±1.15 H
0.9	140±1.15 C	<i>M. oleifera</i> +0.9	30±1.15 I
<i>L. albus</i> +0.3	120±1.15 D	<i>C. citratus</i> +0.3	25±1.15 IJ
<i>L. albus</i> +0.6	100±1.15 E	<i>C. citratus</i> +0.6	22±1.15 JK
<i>L. albus</i> +0.9	80±1.15 F	<i>C. citratus</i> +0.9	18±1.15 K
F Value	12		
P Value	0.00		

concentration of *B. bassiana* (0.9×10⁸ conidia kg⁻¹) and lemon grass had the lowest adult emergence (4.89%). Generally, the treatments with the lowest larval mortality had the highest adult inhibition. However, the treatment with the lowest separate fungal concentration (0.3×10⁸ conidia kg⁻¹) had the highest adult inhibition of *T. granarium* larvae (44.20%).

4. Discussion

The findings of this investigation show that, in comparison to the individual administration of each treatment, the combination of *Beauveria bassiana* and several plant extracts considerably raises larval mortality in *T. granarium*. In particular, the application of *B. bassiana* at (0.9×10⁸ conidia/ml) in conjunction with extract from the lemon grass plant resulted in the greatest larval death rate (71.32%). On the other hand, 57.63% was the maximum mortality recorded when *B. bassiana* was used alone at the same dosage. This suggests that *B. bassiana* and lemon grass extract work in concert to increase overall toxicity against *T. granarium* larvae. This synergistic impact is consistent with other study that shown the ability of botanical extracts to increase the effectiveness of entomopathogenic fungi.

Table 6. The emergence of pupae of *Trogoderma granarium* following the administration of various therapies. The Tukey- (HSD) test at 5 % and p < 0.05 indicates significant difference.

Treatments	Pupa	Treatments	Pupa
<i>L. albus</i>	53.61±2.30 A	<i>L. albus</i> +0.9	29.48±3.01 BCDE
<i>M. oleifera</i>	33.40±1.07 BCD	<i>M. oleifera</i> +0.3	25.83±1.24 CDE
<i>C. citratus</i>	29.48±3.01 BCDE	<i>M. oleifera</i> +0.6	31.23±3.98 BCDE
0.3	44.43±2.77 AB	<i>M. oleifera</i> +0.9	25.66±4.15 DEF
0.6	42.47±2.53 ABC	<i>C. citratus</i> +0.3	13.69 ±3.04 EF
0.9	34.84±5.73 BCD	<i>C. citratus</i> +0.6	14.53±4.50 EF
<i>L. albus</i> +0.3	38.76±1.96 ABCD	<i>C. citratus</i> +0.9	9.07±3.35 F
<i>L. albus</i> +0.6	35.25±2.11 BCD		
F Value	13.4		
P Value	0.00		

Table 7. The emergence of adult of *Trogoderma granarium* following the administration of various therapies. The Tukey- (HSD) test at 5 % and p value < 0.05 indicates significant difference.

Treatments	Adult	Treatments	Adult
<i>L. albus</i>	44.42± 2.79 A	<i>L. albus</i> +0.9	24.12±1.96 CDE
<i>M. oleifera</i>	31.33±4.43 ABC	<i>M. oleifera</i> +0.3	21.85±5.72 BCD
<i>C. citratus</i>	27.72±2.91 ABCD	<i>M. oleifera</i> +0.6	27.73±2.82 ABCD
0.3	38.66±4.38 AB	<i>M. oleifera</i> +0.9	19.99±7.06 ABCD
0.6	37.00±1.04 AB	<i>C. citratus</i> +0.3	18.56 ±3.79 BCD
0.9	29.57±4.72 ABC	<i>C. citratus</i> +0.6	12.68±4.44 CD
<i>L. albus</i> +0.3	33.40± 33.07AB	<i>C. citratus</i> +0.9	9.07±3.35 D
<i>L. albus</i> +0.6	29.68±2.03 ABC	-	-
F Value	6.20		
P Value	0.00		

To increase an insect's susceptibility to fungal infections, for example, botanical extracts may enhance fungal adherence and penetration or interfere with the insect's immunological response (Shah and Pell, 2003; Roy and Cottrell, 2008). The observed increased mortality with combined treatments implies that combining *B. bassiana* with botanical extracts may be a more successful pest management approach.

Remarkably, when larvae were treated with *B. bassiana* alone as opposed to combination treatments with plant extracts, the rate of mycosis in cadavers was substantially greater. *B. bassiana* concentrations of (0.9×10⁸, 0.6×10⁸, and 0.3×10⁸ conidia kg⁻¹) showed the greatest mycosis rates (60, 56.68, and 53.33%), respectively. For the same concentrations, the mycosis rates with combination therapies decreased to as low as 23, 20, and 16%. Similarly, maximum counts of 160, 150, and 140 for the relevant concentrations were observed in larvae treated with *B. bassiana* alone, but in combination treatments the corresponding numbers were 25, 22, and 18.

These findings imply that whereas plant extracts increase early larval mortality, they could also prevent fungal development and sporulation in the future. Plant extracts' antifungal qualities, which allow some plant chemicals to impede growth of fungi, may be the cause of

this inhibitory effect (Isman, 2006; Pavela, 2016). Adult emergence of *T. granarium* was significantly reduced by the combined treatments of *B. bassiana* and plant extracts. When *B. bassiana* (0.9×10^8 conidia kg^{-1}) was coupled with lemon grass extract, lowest adult emergence rate (4.89%) was seen. This combination reduced amount of adults that could reproduce by upsetting pest's life cycle and increasing the death rate of larvae.

On the other hand, the treatment with lowest individual concentration of *B. bassiana* (0.3×10^8 conidia kg^{-1}) had greatest adult inhibition rate (44.20%) among all treatments, suggesting that lower fungal concentrations might still influence adult emergence, albeit less successfully than when paired with other treatments. These results highlight potential of integrated pest management approaches that aim to achieve complete control of insect populations by utilising both botanical extracts and biopesticides. This study concludes by highlighting the possible advantages of using plant extracts along with entomopathogenic fungi in pest management. More efficient *T. granarium* management strategies may result from combined treatments' significant increase in larval mortality and decrease in adult emergence.

5. Conclusion

Study's conclusions offer insightful information for creating integrated pest management (IPM) plans. Combining *B. bassiana* with plant extracts lemon grass in particular can dramatically increase *T. granarium* larval mortality and decrease adult emergence, providing a more efficient and ecologically friendly means of pest management. This study recommended that, *T. granarium* effectively controlled with *B. bassiana*. The results also show that, in contrast to synthetic pesticides, bio-extracts are sustainable and only slightly detrimental to environment. This demonstrates their potential for use in future pest management plans and in reducing reliance on extremely hazardous chemical pesticides.

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7. Conflict of Interest

The authors declare no conflict of interest.

8. Authors' Contribution

MA conducted bioassay in the laboratory

MI data collecting and provided guidelines on bioassay setting

MM performed statistical analysis and prepared data tables

JH completed write up and finalized the MS

HT Proof read the document

MSH Prepared tables and figures

MW help in collecting and rearing population

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