



Research Article

EFFICACY OF DIATOMACEOUS EARTH AND METARHIZIUM ANISOPLIAE (METSCHNIKOFF) SOROKIN AGAINST TRIBOLIUM CASTANEUM, RHYZOPERTHA DOMINICA AND SITOPHILLUS GRANARIUS

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Abstract

The effectiveness of the entomopathogenic fungus *Metarhizium anisopliae* and Diatomaceous earth on the adults of stored grain insect's species i.e. *Tribolium castaneum*, *Rhyzopertha dominica*, *Sitophilus granarius* were tested at the laboratory of Regional agricultural research institute Bahawalpur. The tests were performed either alone or in conjunction with Grain guard (natural). A dosage rate of 1.7×10^4 was used for the fungal formulations, while 50 and 100 ppm of Grain Guard (Natural) were administered. The experiment was conducted at a temperature of $30 \pm 1^\circ\text{C}$ and relative humidity of $65 \pm 5\%$. In all treatments, mortality rate of insects was observed following exposure at intervals of 7, 14, and 21 days. After maximum exposure time, at a dosage rate of 100 ppm, *T. castaneum*, *S. granarius*, and *R. dominica* all reached maximum mortality rates of 70.49, 74.62, and 77.21, respectively, when treated with Grain Guard Natural. The corresponding mortality rates for *T. castaneum*, *S. granarius*, and *R. dominica* at lower doses of fungal spores were 26.35, 28.36, and 29.61, respectively. When the fungal formulations and Grain Guard Natural were used together at the maximum dosage rate of $100 \text{ ppm} + 1.7 \times 10^4$, 87.15 percent mortality was noted for *T. castaneum*, 92.35% for *S. granarius*, and 95.14% for *R. dominica*. For *R. dominica*, *S. granarius*, and *T. castaneum*, the proportion of mycotic insects was 81.86, 78.62, and 76.12 at a dosage rate of 1.7×10^4 , respectively.

Keywords: *Mycosis, Integrated Pest management, bio-insecticide, environmental sustainable, cereals.*

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1. INTRODUCTION

The emergence of entomopathogenic fungi, as a highly researched and potentially useful biocontrol tool for reducing populations of commercially significant insect pests is creating positive approaches in IPM (Coates *et al.*, 2002; Kaur and Padmaja, 2008). Entomopathogenic fungus are group of microorganisms which infect and often kills insects and arthropods. They are typically nonpathogenic to plants and pose no toxicity

to humans and animals (Skinner *et al.*, 2014). *Metarhizium anisopliae* (Metschnikoff) Sorokin and *Beauveria bassiana* (Balsomo) Vuillemin are two of the most important species of these fungi because they have been used and evaluated extensively in pest management strategies for both stored grain and field crops (Silva *et al.*, 2025; Rehner and Buckley, 2005; Akbar *et al.*, 2004; Dal-Bello *et al.*, 2001; Moino *et al.*, 1998). According to several studies, including those conducted



by Akbar *et al.*, 2004, Wakefield *et al.*, 2002, Stathers, 2002, Padin *et al.*, 2002, Dal-Bello *et al.*, 2001, Lord, (2001), Moore *et al.*, 2000, Rice and Cogburn (1999) *B. bassiana* as an effective pest against many types of stored-product-infesting insects is Vuillemin (Deuteromycotina, Hyphomycetes). Several factors influence the pathogenicity of entomophagous fungi to various insects and is also influenced by abiotic factors such as temperature, relative humidity, and light conditions, as well as host species, host-pathogen interactions, and the duration of fungal exposure (MacLeod *et al.*, 1966).

Entomopathogenic fungi kill host insects by penetrating through their cuticles and entering their bodies through the body cavity (Ma *et al.*, 2024). Once inside, the fungus produces hyphal bodies that break down the insect's internal tissues (Zibae *et al.*, 2025). In addition to beauvericin, bassianolide, oosporein, and other similar substances, fungi also produce a number of other compounds that aid in the transmission of their poisonous effects on insect biological systems (Seethapathy, 2025). The *Isaria fumosoroseus* clade, which includes the *Paecilomyces fumosoroseus*, is a powerful natural enemy of whiteflies (Granados-Echegoyen *et al.*, 2025), and has been found to have an epizootic effect on *Bemisia* and *Trialeurodes* spp. in both in vitro and in vivo (Carruthers *et al.*, 1993; Faria and Wraight, 2001). Our research looked at the efficacy of diatomaceous earth and the entomophagous fungus *Isaria fumosoroseus* against the aforementioned insect pests.

It is a very nice strategy to employ DEs in conjunction with fungi. The application of many environmentally friendly management methods is the foundation of IMP in stored items. Entomophagous fungus and DEs both affect the cuticles of insects (Wakil *et al.*, 2025). Lord (2001), Akbar *et al.*, 2004 and Vassilakos *et al.*, 2006 all propose using them together to lower the application rate.

According to Akbar *et al.*, 2004, a synergistic effect was observed against red flour beetle larvae when *B. bassiana* (Balsamo) Vuillemin was integrated with the DE formulation Protect-It. This discovery suggests the feasibility of an integrated strategy employing mixtures of mycoinsecticides. DE Protect-It enhanced the insecticidal effectiveness of *B. bassiana* on *Rhyzopertha dominica* larvae, a diminutive grain borer, according to Lord's (2001) first report.

The abundance of research into the causes of this synergism and the variables influencing the efficacy of the fungal/DE combination led to this discovery. Both Akbar *et al.*, 2004 and Athanassiou, 2004 confirmed this synergistic impact against red flour beetle larvae and adult *Sitophilus oryzae*, a rice weevil, and *Tribolium confusum*, a confused flour beetle, respectively. Nevertheless, each of these experiments only looked at one temperature level, so we still don't know enough about how temperature affects a *B. bassiana* and DE combination. Given that DEs and entomopathogenic fungi both originate in nature and are not very hazardous to mammals (Wakil *et al.*, 2025; Saw *et al.*, 2025; Korunic, 1998), It appears that a combination of the two chemicals could provide some benefit as a long-term protector, as they both remain on the grain. In addition, they are administered using technology that is similar to traditional pesticide and can be easily removed from treated grain (Subramanyam and Roesli, 2000).

By keeping in view the above mentioned literature and benefits of non-toxic and environmental friendly insect control strategies, this research aims to determine the impact of DE and Entomopathogenic fungi for controlling insects of stored grains. Moreover, optimization of concentration of both bio-control agents will be done.

2. MATERIALS AND METHODS

2.1. Test insects

In 2024, a colony was created in the Integrated Pest Management laboratory, at Regional Research Institute using specimens obtained from District Faisalabad of the Lesser grain borer (*Rhyzopertha dominica*), Grainary weevil (*S. granarius*), and red floor beetle (*Tribolium castaneum*). Raised in darkness at 28 °C with 65 ± 5% relative humidity, the adults of *T. castaneum* were given wheat flour enriched with 5% brewery yeast by weight (Shayesteh and Ziaee, 2007). The experimental *R. dominica* *S. granarius* strain was cultured on whole wheat under conditions of 30 ± 1 °C and 60% relative humidity (Erika *et al.*, 2007). Using a heated three-inch iron pipe, we sliced the tops of each plastic rearing jar half lengthwise to make a circle. The openings of the jars were covered with iron sieves of a size of sixty. It had two purposes: first, to ensure that the raising insects had enough air circulation, and second, to prevent the insects from escaping the jars to the greatest extent possible. The sieves were affixed to the jar caps using adhesive. Red floor beetles, Lesser grain borer, and granary weevil adults, ranging in age from 7 to 21 days, were utilized to ensure a homogeneous lab population.

The red floor beetle, lesser grain borer, and granary weevil samples that were infested were screened to eliminate any adult and larvae using a camel hairbrush. Afterwards, distinct culture jars were used to place each group under the aforementioned conditions for the following 14 days. The pure laboratory culture was obtained by repeating this technique four times, each time sifting the culture. In order to achieve a homogeneous laboratory population, the same method was repeated six times. The bioassay was conducted using the filtered adult insects of each pest after that time period.

2.2. Grains

The hard wheat grains used in the bioassay were purchased from the market and were untreated, clean, and infestation-free. The grains had a moisture content of 11% as detected by Dickey John's moisture meter before the experiment. To achieve moisture equilibrium, the grains were left at 25 °C and 75% R.H. for a duration of 7 days. After 7 days, the moisture contents were recorded at 13.8 ± 0.4 % using Dickey John's moisture meter.

2.3. DE formulation

Experiments utilized Grain Guard Natural, a DE formulation consisting of pyrethrum, PBO, and soap. The DE sample was kept at room temperature in the lab for around three weeks prior to the start of the studies.

2.4. Fungal formulations

Making a conidial suspension in order to study mortality reactions Mole cricket cadavers were used to gather fungal isolates. The specimens were first washed with a 5% sodium hypochlorite solution, rinsed with distilled water two or three times, and then cultivated on potato dextrose agar (PDA) media. To prepare the conidia suspension, surface cultures aged 2 to 3 weeks were scraped and transferred into universal bottles containing 10 ml of sterile distilled water, 0.05% Triton X-100, and 3 mm glass beads. Following the filtration of the mixtures using muslin cloth, they were mixed using a Vortex for 5 minutes to ensure homogeneity. A haemocytometer was used to get different concentrations by successive

2.5. Grain treatment

Grain lots weighing 1 kg were used for each treatment. Different amounts of fungus and DE, or DE alone, were added to each bunch. To make sure the dust was well distributed throughout the grain mass, each batch was put into glass jars and shook by hand for around five minutes. As a control, we used one untreated grain lot for everyone treated grain. Incubators were maintained at 26 °C

and 65% relative humidity for the duration of the experiment.

2.6. Bioassays

The bioassay was conducted in containers at a temperature of 30 ± 1 °C and relative humidity of $65 \pm 5\%$. The grains were exposed to either fungus or DE alone, or both treatments combined. For this bioassay, we extracted nine samples, 50 grams of grains each, from each container. For aeration and to prevent the insect's escape, each specimen was positioned within a little cylindrical glass vial. The vials were 20 cm tall and 10 cm in diameter. At the top, there was a 1.5 cm diameter hole covered with a 60-mesh size. In each vial, sixty adults of the respective bug species were introduced. After that, the vials were put in an incubator under those circumstances.

Following Greenspan's (1977) recommendation, a saturated salt solution of NaCl was used to maintain the desired relative humidity in the incubators. Following exposure intervals of 7, 14, and 21 days in both treated and untreated grain, the counts of living and deceased individuals in each vial were recorded. Every kind of bug went through the same process. The exposed adults were categorized as either living or dead. However, for each replication of mycosis and sporulation, different cadavers were transferred to centrifuge vials and preserved at 4°C. Therefore, the total mortality rate noted throughout the experiment was caused by the utilizing fungus in the second bioassay, DE alone, and fungus in combination with DE.

2.7. Mycosis

The cadavers were first cleaned in distilled water two or three times, then immersed in water containing 0.5% sodium hypochlorite for a few seconds. After that, they were grown on PDA media and incubated at 25 °C. Using a stereo microscope, the mycotic insects were identified after 7 days.

2.8. Sporulation

The next step was to rinse the mycotic insects with water containing twin 80, 3% for two to three minutes per replication, ensuring that all of the spores were removed from the insects' bodies. Using a hemocytometer, we measured the number of spores in 1 milliliter of water extracted from the solution.

2.9. Statistical analysis

Using statistix 8.1 (Analysis software, 1998), we performed a one-way analysis of variance (ANOVA) on the combined mortality and progeny emergence data, and we used tukey's honestly significant difference (HSD) to separate the means for significance.

3. RESULTS

3.1. Mortality Rate of insects

Compared to the fungal formulation of the entomophagous fungi, the natural Grain Guard caused a high rate of insect mortality even at half the dosing rate. At 50 ppm, *R. dominica* mortality was 12.218 for Grain guard natural, at 100 ppm it was 28.372, and for fungi it was 9.6164. Also, for *S. granarius*, the concentrations at 50 ppm were 10.551, 100 ppm were 24.144, and 8.7689 for fungal conidia. At 50 ppm, 8.88 for *T. castaneum*, 20.34 for 100 ppm Grain Guard Natural, and 6.79 percent for fungal conidiospores. Across all intervals, the same pattern emerged. In both cases, the mortality rate was higher. In the case of 100ppm+ 1.7×10^8 , a higher mortality rate was noted for *R. dominica* (41.071), *S. granarius* (41.093), and *T. castaneum* (39.65) in the first interval. The greatest mortality rates for *R. dominica* (95.18), *S. granarius* (92.354), and *T. castaneum* (87.15) were found in Table 2, Table 1, and Table 3, respectively. *R. dominica* (44.5), *S. granarius* (48.4), and *T. castaneum* (52.4) had F values of 44.5 for the first interval and 209, 191, and 143 for the maximum interval, respectively indicating that mortality was substantial across all treatments.

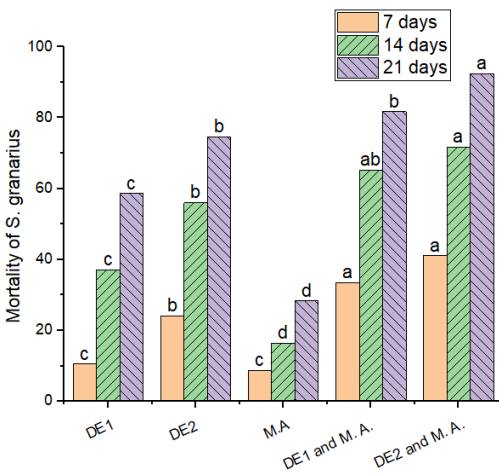


Fig 1: Mortality of *S. granarius* at intervals of 7, 14 and 21 days of exposure

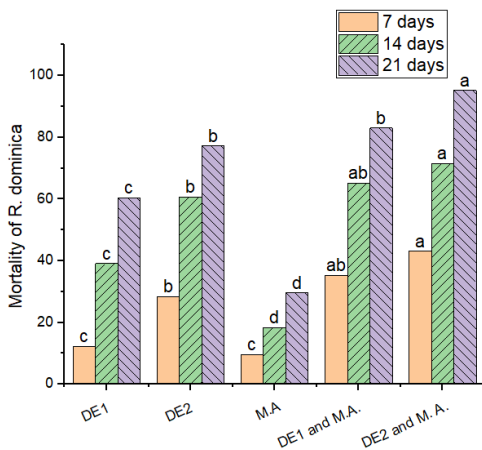


Fig 2: Mortality of *R. dominica* at intervals of 7, 14 and 21 days of exposure

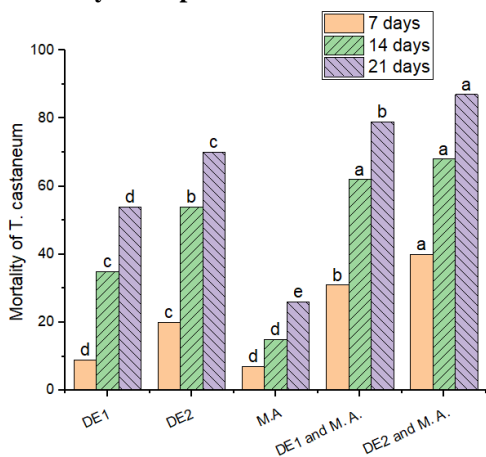


Fig 3: Mortality of *T. castaneum* at intervals of 7, 14 and 21 days of exposure

3.2. Mycosis rate

As a whole, *R. dominica* were less likely to succumb to mycosis. In cases where the dose of fungus was 1.7×10^4 , a higher prevalence of mycosis was seen. Mycosis cases involving the values for *Rhyzo*, *Tribolium*, and *S. granarius* exhibited values of 81.86, 78.62, and 76.12, respectively. The combination of fungus and DE effectively reduced mycosis; however, the 50 ppm + 1.7×10^4 dose rate of fungus demonstrated greater efficacy compared to the 100 ppm + 1.7×10^4 dose rate. The F values recorded for *Rhyzo*, *Tribolium*, and *S. granarius* were 17, 13, and 21, respectively, indicating that mycosis was significant across all treatments.

3.3. Sporulation

At a treatment rate of 1.7×10^6 fungal spores, the most spore formation was noted in the case of *psocids*. *Psocid*, *Crypto*, *Rhyzo*, and *Tribolium* all produced spores at concentrations of 178.33, 169, 162.44, and 157.89 spores/ml, respectively. There were 156.44, 150.11, 147.89, and 146.78 spores/ml for 1.7×10^8 spores produced simultaneously. The combination's spore output was lower than the minimum fungal dosage rate. The results showed that sporulation was substantial across the board, with *Crypto*, *Psocid*, *Rhyzo*, and *Tribolium* having F values of 14.3, 10.4, 13.1 and 14.2 correspondingly.

4. DISCUSSION

Metarhizium anisopliae (Metschnikoff) Sorokin and DE were demonstrated to be effective against *T. Causataneum*, *R. dominica*, and *S. granarius* in the study. Additionally, our data indicates that the insecticidal activity of Grain Guard natural was boosted by *Metarhizium anisopliae*. Our results are in accordance with previous studies that shows that DE and *B. bassiana* can work together to reduce the population of stored product beetle species (Gidari *et al.*, 2025; Lord, 2001; Akbar *et al.*, 2004).

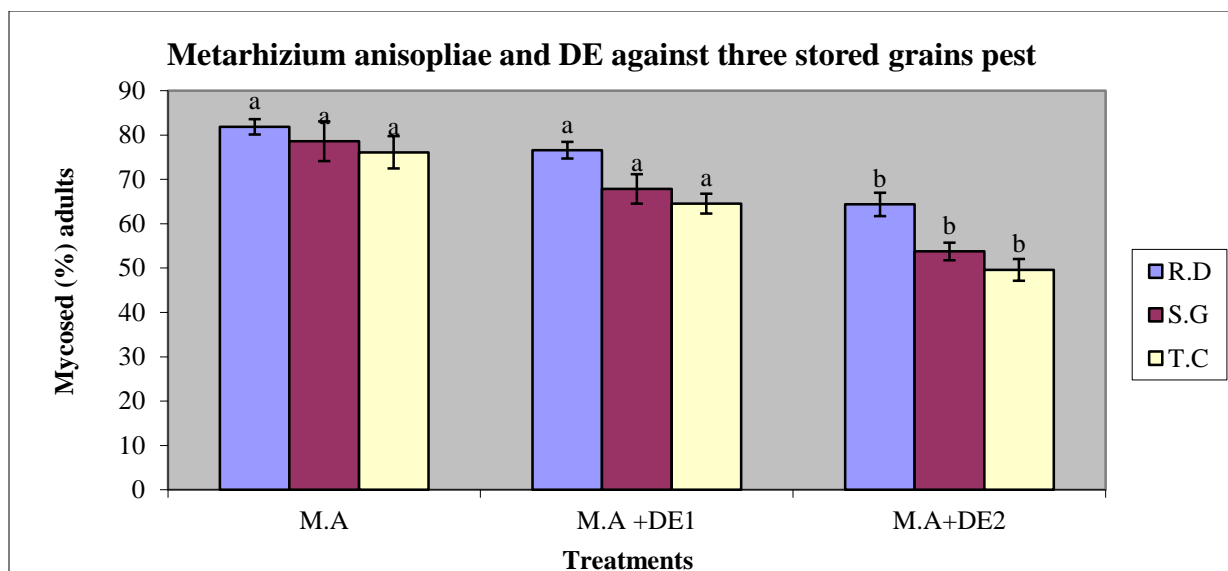


Fig 4: *Metarhizium anisopliae* and DE against three stored grains pest

Table 1. Mortality of *S. granarius* after 7, 14 and 21-d of exposure to *M. anisopliae* and Grain-Guard natural.

Treatments	Doses	Interval		
		7 days	14 days	21 days
DE	50ppm	10.551±2.35c	37.04±2.48c	58.62±1.68c
DE	100ppm	24.144±1.96b	56.01±1.83b	74.627±2.08b
M.A	1.7×10 ⁴	8.7689±1.88c	16.39±1.99d	28.363±1.91d
DE1 and M. A.		33.420±1.97a	65.150±2.07ab	81.74±1.54b
DE2 and M. A.		41.093±1.95a	71.66±1.94a	92.354±1.80a
D.F		4,58	4,58	4,58
F Value		48.4	116	191
P Value		0.000	0.000	0.000

Table 2. Mortality of *R. dominica* after 7, 14 and 21-d of exposure to *M. anisopliae* and Grain-Guard natural.

Treatments	Doses	Interval		
		7 days	14 days	21 days
DE	50ppm	12.218±2.31c	39.07±2.35c	60.408±2.01c
DE	100ppm	28.372±2.47b	60.606±2.02b	77.213±2.07b
M.A	1.7×10 ⁴	9.6164±2.05c	18.334±2.21d	29.613±1.71d
DE1 and M.A.		35.256±2.00ab	65.150±2.07ab	82.99±1.55b
DE2 and M. A.		43.071±1.97a	71.498±2.06a	95.18±1.42a
D.F		4,58	4,58	4,58
F value		44.5	105	209
P value		.0000	0.000	0.000

Table 3. Mortality of *T. castaneum* after 7, 14 and 21-d of exposure to *M. anisopliae* and Grain-Guard natural.

Treatments	Doses	Interval		
		7 days	14 days	21 days
DE	50ppm	8.88±1.66d	35.10±2.50c	53.52±1.96d
DE	100ppm	20.34±2.16c	53.62±1.57b	70.49±2.42c
M.A	1.7×10 ⁴	6.79±2.01d	14.69±2.01d	26.35±2.05e
DE1 and M. A.		31.40±2.09b	61.64±1.92a	78.75±1.44b
DE2 and M. A.		39.65±1.75a	67.62±1.80a	87.15±2.11a
D.F		4,58	4,58	4,58
F Value		52.4	122	143
P Value		0.000	0.000	0.000

A study conducted by Lord (2001) was the first to document the use of the Protect-It DE formulation as a pesticide against *Oryzaephilus surinamensis* (L.) and *Rhyzopertha dominica* (F.) two species of beetles belonging to the Bostrychidae and Silvanidae families, respectively. In their study on *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), Akbar *et al.*, 2004 likewise found similar results.

This research is the first to investigate the possibility of using *Metarhizium anisopliae* in conjunction with DE. Batta (2004) demonstrated that an enhanced effect was also present in this example using *M. anisopliae* in conjunction with dust that contained many inert components, including charcoal and oven ash. According to his hypothesis, these substances have a desiccant function, and their inclusion enhanced the fungus's efficacy against *S. oryzae*. The fungal formulation might benefit from the DE's inclusion. According to Lord (2001), DE has the potential to dissolve the epicuticular lipid layers that allow the fungal conidia to grow and gain easier access to the insect's body. Additionally, when the fungus was sprayed with DE, Akbar *et al.*, 2004 found that the degree of adhesion of *B. bassiana* conidia to the cuticle of *T. castaneum* larvae was significantly increased.

This may provide light on why *B. bassiana* and DE work so well together. Despite a considerable synergism against *R. dominica*, Lord (2001) could not observe any substantial increase in conidial attachment for this species. *Metarhizium flavoviride*, Gams, and Rozsypal (Deuteromycotina: Hyphomycetes) have been found to be more conidially viable when exposed to inert materials such clays or silicas (Horaczek and Viernstein, 2004; Moore and Higgins, 1997; Moore *et al.*, 1996). In order to make fungal formulations more stable and prolong their storage life, desiccant dusts are being employed to dry conidia to 4-5% relative humidity (Hedgecock *et al.*, 1995; Moore and Higgins, 1997). The impact of these extracts on the insecticidal properties of fungi remains inadequately assessed, despite an increasing necessity to address the stability of entomopathogenic fungal formulations in commercial production (Moore *et al.*, 2000). We found that the combination of fungus and DE increased mortality rates relative to either agent alone, especially when given in conjunction with 200 ppm Silico-Sec and a high dosing rate of fungal spores. We found that several clays improved conidial viability, contrary to what Moore and Higgins (1997) said happened when *M. flavoviride* conidia were germinating. As the concentration of fungal conidia in DE formulation grew, the

mortality rate of adults also rose. The mortality rate rose in direct correlation with the dosage rate of fungal conidia. Based on this information, it seems that the DE efficacy is enhanced by fungal conidia only when the conidial concentration is higher than. Because we used sound grains in our experiment instead of wheat flour, the DE particles either did not bind to the insect's cuticle or were removed from their bodies, leading to a significant fatality rate.

Flour may reduce fungal efficacy for the same reasons. Both Padin *et al.*, 2002 and Rice and Cogburn, 1999 have verified that different types of stored commodities affect the effectiveness of *B. bassiana*. DE's effectiveness might be diminished if its particles absorb atmospheric moisture (Stathers *et al.*, 2004). But Akbar *et al.*, 2004 also found no significant variations regarding using DE Protect-It to ward off M. P. Michalaki, 2006 in conjunction with our findings are in agreement with them. The fact that mycotic insects were more prevalent in the presence of modest doses of fungi rather than high doses lends credence to the idea that a combination of several environmentally friendly control approaches should form the basis of any integrated pest management program for stored items. The current study shows that stored commodities can benefit greatly from a combination of *Metarhizium anisopliae* and DE, two highly promising alternatives to this method.

5. REFERENCES

Akbar, W., J. C. Lord, J. R. Nechols and R. W. Howard, 2004. Diatomaceous earth increases the efficacy of *Beauveria bassiana* against *Tribolium castaneum* larvae and increases conidia attachment. J. Econ. Entomol., 97(2): 273-280.

Athanassiou, C. G., Papagregoriou, A. S., and Buchelos, C. T., 2004. Insecticidal and residual eVect of three pyrethroids against *Sitophilus*

oryzae (L.) (Coleoptera: Curculionidae) on stored wheat. J. Stored Prod. Res., 40: 289–297.

- Batta, Y. A., 2003. Production and testing of novel formulations of entomopathogenic fungus *Metarhizium anisopliae* (Metch.) Sorokin (Deuteromycotina: Hyphomycetes). Crop Prot., 22(2): 415-422.
- Batta, Y.A., 2004. Control of the rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) with various formulations of *Metarhizium anisopliae*. Crop Prot., 23: 103–108.
- Carruthers, R.I., Wraight, S.P. and Jones, W.A. (1993) An overview of biological control of the sweetpotato whitefly, *Bemisia tabaci*. *Proceedings of the Beltwide Cotton Conference*, = Vol. 2. National Cotton Council, Memphis, TN, USA, pp. 680–685.
- Coates B. S., Hellmich R. L., and Lewis L. C., (2002). Allelic variation of a *Beauveria bassiana* (Ascomycotina: Hyphocreales) minisatellite is independent of host range and geographic origin. *Genome.*, 45 :125-132.
- Dal-Bello, G., Padin, S., Lopez-Lastra, C. and Fabrizio, M., 2001. Laboratory evaluation of chemical-biological control of the rice weevil (*Sitophilus oryzae* L.) in stored grains. J. Stored Prod. Res. 37, 77–81. Ebeling, W., 1971. Sorptive dusts for pest control. *Ann. Rev. Entomol.* 16,
- Faria, M. and Wraight, S.P. (2001) Biological control of *Bemisia tabaci* with fungi. *Crop Protection.*, 20: 767–778.
- Gidari, D. L. S., Boukouvala, M. C., Filintas, C. S., Skourti, A., and Kavallieratos, N. G. (2025). Combining Natural and Microbial Insecticides with Diatomaceous Earth for Effective

- Management of *Prostephanus truncatus*. *Insects*, 16(11), 1162.
- Granados-Echegoyen, C. A., Calderón-Cortés, N., Vásquez-López, A., de Gives, P. M., Reyes-Estebanez, M., Sarmiento-López, L. G., and Sánchez-Hernández, C. (2025). Pest Control Strategies Using Secondary Metabolites of Entomopathogenic Fungi. In *The Role of Entomopathogenic Fungi in Agriculture* (pp. 267-297). CRC Press.
- Hawksworth, D. L., P. M. Kirk., B. C. Sutton., and D. N. Pegler. 1995. *Ainsworth and Bisby's dictionary of the fungi*. CAB International, Wallingford, UK.
- Hedgecock, S., Moore, D., Higgins, P. M., Prior, C., 1995. Influence of moisture content on temperature tolerance and storage on *Metarhizium flavoviride* conidia in an oil formulation. *Biocontrol Sci. Technol.*, 5: 371–377.
- Horaczek, A., Viernstein, H., 2004. Comparison of three commonly used drying technologies with respect to activity and longevity of aerial conidia of *Beauveria brongniartii* and *Metarhizium anisopliae*. *Biol. Control.*, 31: 65–71.
- Kaur G and Padmaja V (2008). Evaluation of *Beauveria bassiana* isolates for virulence against *Spodoptera litura* (Fab.) (Lepidoptera; Noctuidae) and their characterization by RAPD-PCR, *African journal of Microbiology Res.*, 2: 299-307.
- Korunic, Z., 1998. Diatomaceous earths, a group of natural insecticides. *J. Stored Prod. Res.*, 34: 87–97.
- Lord, J. C., 2001. Desiccant dust synergizes the effect of *Beauveria bassiana* (Hyphomycetes: Moniliales) on stored-grain beetles. *J. Econ Entomol.*, 94: 367–372.
- Ma, M., Luo, J., Li, C., Eleftherianos, I., Zhang, W., and Xu, L. (2024). A life-and-death struggle: interaction of insects with entomopathogenic fungi across various infection stages. *Frontiers in immunology*, 14, 1329843.
- MacLeod, D. M., C. MacBain, and R. S. Sooper, 1966. The influence of environmental conditions on epizootics caused by entomopathogenic fungi. *Revue Roumaine de Biologie-Botanique.*, 11(1):125-134.
- Moino J, A., S. B. Alves and R. M. Pereira, 1998. Efficacy of *Beauveria bassiana* (Balsamo) Vuillemin isolates for control of stored grain pests. *J. Appl. Entomol.*, 122: 301-305.
- Moore, D., Douro-Kpindou, O. K., Jenkins, N. E., Lomer, C. J., 1996. Effects of moisture content and temperature on storage of *Metarhizium flavoviride* conidia. *Biocontrol Sci. Technol.*, 6: 51–61.
- Moore, D., Higgins, P. M., 1997. Viability of stored conidia of *Metarhizium flavoviride* Gams and Rozsypal, produced under different culture regimes and stored with clays. *Biocontrol Sci. Technol.*, 7: 335–343.
- Moore, D., Lord, J. C. and Smith, S. M., 2000. Pathogens. In: Subramanyam, Bh., Hagstrum, D. W. (Eds.), *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, Dordrecht, pp. 193–227.
- Moore, D., Lord, J. C. and Smith, S. M., 2000. Pathogens. In: Subramanyam, Bh., Hagstrum, D.W. (Eds.), *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, Dordrecht, pp. 193–227. of temperature on the insecticidal effect of *Beauveria bassiana* in

- combination with diatomaceous earth against *Rhizopertha dominica* and *Sitophilus oryzae* on stored wheat. *Biol. Control.*, 38: 270–281.
- Padin, S., Dal-Bello, G., Fabrizio, M., 2002. Grain loss caused by *Tribolium castaneum*, *Sitophilus oryzae*, and *Acanthoscelides obtectus* in stored durum wheat and beans treated with *Beauveria bassiana*. *J. Stored Prod. Res.*, 38: 69–74.
- Rehner, S. A., and Buckley, E. (2005). A *Beauveria* phylogeny inferred from nuclear ITS and EF1- α sequences: evidence for cryptic diversification and links to *Cordyceps* teleomorphs. *Mycologia*, 97(1), 84–98.
- Rice, W. C., Cogburn, R. R., 1999. Activity of the entomopathogenic fungus *Beauveria bassiana* (Deuteromycota: Hyphomycetes) against three coleopteran pests of stored grains. *J. Econ. Entomol.*, 92: 691–694.
- Saw, G., Sarkar, S., Dhar, D. W., and Das, S. (2025). Diatoms as Insect Control Agents. In *Diatoms and Sustainable Agriculture* (pp. 141-158). CRC Press.
- Seethapathy, P. (2025). Mass Production of *Beauveria bassiana*. In *The Role of Entomopathogenic Fungi in Agriculture* (pp. 298-320). CRC Press.
- Silva, C. S., Monteiro, P. H. R., del Pilar Rodriguez-Rodriguez, M., de Oliveira, I. T., da Silva, R. S., Leite, G. L. D., and Soares, M. A. (2025). Sustainable Pest Management: Compatibility of *Metarhizium anisopliae* with Botanical and Chemical Insecticides.
- Skinner, M., Parker, B. L., and Kim, J. S. (2014). Role of entomopathogenic fungi in integrated pest management. *Integrated pest management*, 169-191.
- Stathers, T., 2002. Entomopathogenic fungi in grain storage any lessons for Europe from elsewhere? In: Zdarkova, E., Lukas, J., Hubert, J. (Eds.), *Proceedings of the 2nd meeting of WG 4 of COST Action 842*, Prague, pp. 100–109.
- Subramanyam, Bh., Roesli, R., 2000. Inert dusts. In: Subramanyam, Bh., Hagstrum, D.W. (Eds.), *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, Dordrecht, pp. 321–380.
- Vassilakos, T. N., Athanassiou, C. G., Kavallieratos, N. G. and Vayias, B. J., 2006. Influence of temperature on the insecticidal effect of *Beauveria bassiana* in combination with diatomaceous earth against *Rhizopertha dominica* and *Sitophilus oryzae* on stored wheat. *Bio. Control.*, 38: 270–281.
- Wakefield, M., Cox, P. D., Wildey, K. B., Price, N. R., Moore, D. and Bell, B. A., 2002. The use of entomopathogenic fungi for stored product insect and mite control further progress in the ‘‘Mycopest project’’. In: Zdarkova, E., Lukas, J., Hubert, J. (Eds.), *Proceedings of the 2nd meeting of WG 4 of COST Action 842*, Prague, pp. 110–115.
- Wakil, W., Boukouvala, M. C., Kavallieratos, N. G., Gidari, D. L. S., Skourti, A., and Riasat, T. (2025). Advances in stored-product pest management: Combined effects of diatomaceous earths with botanicals, insecticides, entomopathogenic/plant pathogenic fungi, and silica gel. *Sustainability*, 17(8), 3316.
- Zibae, A., Malagoli, D., and Dubovskiy, I. (2025). Entomopathogenic Fungi in

Insects: From Physiological Effects
to Applications. Academic Press.