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Effect of Entomopathogens on Angoumois Grain Moth and Seed Viability

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Abstract— *The laboratory experiment on the effect of entomopathogens on the Angoumois grain moth, Sitotroga cerealella* Olivier revealed that the significantly highest percent adult mortal*ity (72.33%) of S. cerealella was recorded in deltamethrin at 0.04 mL/kg after 72 hours of treatment. In case of entomopathogens, the treatment of M. anisopliae 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth @ 20 + 5 g/kg was found to be the next effective treatment having 65.80% adult mortality. The significantly lowest percent adult mortality (38.33%) of S. cerealella was recorded in Metarhizium anisopliae 1.15 WP (1.0 × 10^8 CFU/g) at 10 g/kg after 72 hours of treatment. In case of adult emergence, the significantly lowest adult emergence (2.00) was recorded in deltamethrin at 0.04 mL/kg. The significantly highest seed germination (91.33%) was recorded in treatment of B. bassiana 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg and M. anisopliae 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (91.00%). The significantly lowest seed moisture content (8.24%) was recorded in B. bassiana 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg and it was statistically at par with M. anisopliae 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (8.41%).*

Keywords— Beauveria bassiana, Metarhizium anisopliae, Diatomaceous earth, Sitotroga cerealella, Stored grain pest, Sorghum, Biological control, Seed viability, Entomopathogenic fungi.

I. INTRODUCTION

Sorghum is a significant cereal crop that is widely cultivated in tropical and subtropical climates worldwide. It is essential for industrial applications, fodder and food security. Among all the biotic factors, insect pests are considered the most important and cause huge losses in the cereal grains (30%–40%) (Kumar, 2017). The Angoumois grain moth is a serious primary pest of stored grain in many parts of the world especially on stored wheat and rice (Boshra, 2007). The control of stored-grain insect pests using chemical insecticides and fumigants (methyl bromide and phosphine) is an essential tool for preventing or minimizing insect damage to stored grain. However, the use of synthetic insecticides in stored grain protection resulted in potential hazards for mammals (Mostafalou and Abdollahi, 2013), can be harmful to the natural enemies and insects develop resistance to them (Prakash et al., 1993; Salem et al., 2007). These problems had necessitated the development of new classes of safer insect control agents that would be biodegradable, cheap, readily available and non-toxic to consumers and environmentally friendly. Biological control of stored-product insect pests involves the use of hymenopteran parasitoids, predatory insects and mites as well as insect pathogens such as entomopathogenic fungi, bacteria, viruses, protozoa and nematodes (Moore et al., 2000; Flinn and Scholler, 2012). Among insect pathogens, entomopathogenic fungi represent a promising alternative to chemical insecticides and conventional pesticides. The conidia of these fungi attach to the insect cuticle, germinate and penetrate the integument, ultimately leading to the death of the host. Entomopathogenic fungi are naturally occurring, environmentally safe and exhibit low toxicity to mammals (Cox and Wilking, 1996). The use of diatomaceous earth offers another promising alternative to conventional insecticides. Its particles abrade and inactivate the epicuticular lipids of the insect cuticle leading to internal water loss and eventually death by desiccation (Ebeling, 1971; Korunic, 1998; Mewis and Ulrichs, 2001).

II. MATERIALS AND METHODS

The experiment was carried out under ambient storage condition at Biocontrol Laboratory, Department of Entomology, N. M. College of Agriculture, NAU, Navsari during 2025-2026. The experiment was laid out in completely randomized design with ten treatments including untreated control and three replications. The seeds of sorghum cv. GJ-102 were used for this experiment. To evaluate the different entomopathogens against Angoumois grain moth, *S. cerealella*, 500 g of freshly harvested sorghum seeds with a high percentage of germination and low moisture content (<10%) were taken for each treatment. Each entomopathogen was applied at a respective dose to a previously sterilized bulk of 500 g sorghum seed. Each treatment was mixed thoroughly with sorghum seed by shaking it manually for 5 min in a jar and water used as a carrier for the uniform smearing of insecticide on seeds. The required quantity of deltamethrin was diluted in 2 mL water to treat 500 g of seed for proper coating. After drying in shade, treated seeds were packed in air tight glass jar and kept in a room under ambient temperature, while untreated seeds were taken as control.

Three samples of treated sorghum seed, each of 100 g (one sample for one replication) were drawn from each bulk of treatment. The samples were filled in a plastic jar (25 × 30 cm) individually. Ten pairs of freshly emerged (0-24 hrs old) adults were released in each plastic jar. Then after, the respective containers were tightly closed with the perforated lid and stored in laboratory at room temperature under hygienic conditions. The total number of eggs laid by the Angoumois grain moth, number of adult emergence and percent weight loss were recorded after 15 days and then after 30, 60, 90 and 120 days by drawing a sample of about 100 seeds randomly from each treatment.

TABLE 1
DETAILS OF TREATMENTS

S. No.	Treatment	Dose per kg of seed
1	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	10 g
2	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	20 g
3	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	10 g
4	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	20 g
5	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g
6	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g
7	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g
8	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g
9	Deltamethrin 2.8 EC	0.04 mL
10	Untreated control	–

2.1 Seed Germination

The germination test was carried out on germination papers. A total of 100 seeds from each treatment were randomly selected and spread on circularly cut moist germination paper at uniform distance in Petri plate. The Petri plate covered with the lid carrying the moist filter paper. Little quantity of distilled water was sprinkled on filter paper once a day to keep it moist. The numbers of germinated seeds were counted after 7 days of incubation and percent germination was worked out by counting number of sprouted and non-sprouted seeds.

$$\text{Germination (\%)} = \frac{\text{No. of seed germination}}{\text{Total numbers of seed}} \times 100 \tag{1}$$

2.2 Seed Moisture

First of all, empty metallic crucible was weighed. By taking 100 g of sorghum seeds adjusting with empty metallic crucible. Metallic crucible with sample was placed in oven at 105°C for 24 hrs. The metallic crucible along with sample was weighed and again put it for 2 to 3 hrs till constant weight. After drying, the sample was allowed to cool for some time in oven. Then the metallic crucible was closed and put it in the desiccators for further cooling. After cooling at room temperature, the final weight of metallic crucible with dried sample was noted. This method is given by Bhargava and Raghupathi (1993).

Weight of empty metallic crucible = A

Weight of metallic crucible + sample = B

Weight of sample = (B – A)

Weight of metallic crucible + oven dry sample = C

Weight of moisture content in seed sample = (B – C)

$$\text{Moisture content (\%)} = \frac{(B-C)}{(B-A)} \times 100 \tag{2}$$

2.3 Corrected Mortality

The mortality was recorded at 24 hrs intervals up to 3 days. Besides dead, moribund insects were also considered as dead. The percent mortality of the adults was corrected by using a formula suggested by Abbott (1925).

$$P = \frac{(P' - C)}{(100 - C)} \times 100 \tag{3}$$

Where,

P = Percent corrected mortality

P' = Percent mortality in treatment

C = Percent mortality in control

The zero and percent values were replaced by using formula (1/4n) × 100 and (1 – 1/4n) × 100, respectively suggested by Bartlett (1947).

Where, n = Number of adults per treatment

2.4 Adult Emergence

The mean number of adults that emerged from each replication were recorded after 30, 60, 90 and 120 days of treatment.

2.5 Weight Loss

Emerging adults were removed from a sample after 15, 30, 60, 90 and 120 days and the damaged and healthy seeds were weighted separately with electric balance. The weight loss was calculated as per the methodology suggested by Adams and Schulten (1978).

$$\text{Weight loss (\%)} = \frac{(UNu) - (DNd)}{U(Nd + Nu)} \times 100 \tag{4}$$

Where,

U = Weight of undamaged seeds

Nu = Number of undamaged seeds

D = Weight of damaged seeds

Nd = Number of damaged seeds

(A)

(B)

PLATE 1: Experiment setup for effect of entomopathogens (A) and set of seed treatment for seed germination (B)

III. RESULTS AND DISCUSSION

3.1 Adult Mortality

Data recorded after 72 hrs of treatment revealed that the significantly highest percent adult mortality (72.33%) of *S. cerealella* was recorded in the treatment of deltamethrin at 0.04 mL/kg. The treatment of *M. anisopliae* 1.15 WP (1.0×10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg was found to be the next effective treatment having 65.80% adult mortality followed by *B. bassiana* 1.15 WP (1.0×10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (61.80%). Significantly the lowest adult mortality of *S. cerealella* was found in *M. anisopliae* 1.15 WP (1.0×10^8 CFU/g) at 10 g/kg (38.33%).

TABLE 2
EFFECT OF ENTOMOPATHOGENS ON ADULT MORTALITY OF *S. CEREALELLA* IN STORED SORGHUM

Treat. No.	Treatments	Dose per kg of seed	Corrected (%) adult mortality of *S. cerealella* at different period of storage interval		
			24 hrs	48 hrs	72 hrs
T1	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g)	10 g	28.37gh* (32.17)	34.00gh (35.66)	41.17f (39.91)
T2	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g)	20 g	32.00f (34.44)	38.00f (38.05)	44.50e (41.84)
T3	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g)	10 g	26.37h (30.88)	32.00h (34.44)	38.33g (38.25)
T4	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g)	20 g	30.00fg (33.20)	35.00g (36.27)	42.50ef (40.68)
T5	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	10 + 5 g	40.50d (39.52)	45.50d (42.41)	51.70d (45.97)
T6	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	20 + 5 g	44.50c (41.84)	53.70c (47.12)	61.80c (51.82)
T7	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	10 + 5 g	38.00e (38.05)	42.50e (40.68)	49.50d (44.71)
T8	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	20 + 5 g	47.50b (43.56)	56.70b (48.85)	65.80b (54.21)
T9	Deltamethrin 2.8 EC	0.04 mL	58.70a (50.01)	66.80a (54.81)	72.33a (60.22)
T10	Untreated control	–	0.00i (0.00)	0.00i (0.00)	0.00h (0.00)
	S. Em. ±		0.49	0.45	0.51
	CD at 5%		1.46	1.32	1.52
	CV (%)		2.49	2.05	2.13

Figures in parentheses are arc sine transformed values while those outsides are original values. Treatment means followed by the same letter(s) are not significantly different according to DNMRT at 5% level of significance.

3.2 Adult Emergence

The data on adult emergence of *S. cerealella* after 30, 60, 90 and 120 DAT are presented in Table 3. Recorded data revealed that all the treatments were found significantly superior in adult emergence over untreated control. More or less corresponding trends of results were also observed for 60, 90 and 120 DAT. In case of 120 DAT, significantly lowest adult emergence (2.00) was recorded in deltamethrin at 0.04 mL/kg. The next significantly effective treatment was *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (5.00) and it was statistically at par with *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (6.00). Significantly highest adult emergence (37.00) was found in untreated control.

TABLE 3
EFFECT OF ENTOMOPATHOGENS ON ADULT EMERGENCE OF *S. CEREALELLA* IN STORED SORGHUM

Treat. No.	Treatments	Dose per kg of seed	Average number of adults emerged after indicated days of treatment			
			30 DAT	60 DAT	90 DAT	120 DAT
T1	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	10 g	9.00f* (3.07)	11.00f (3.38)	13.00g (3.67)	16.00f (4.06)
T2	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	20 g	6.00de (2.54)	7.00de (2.73)	9.00f (3.07)	13.33e (3.71)
T3	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	10 g	7.00e (2.73)	8.00e (2.91)	10.00f (3.23)	14.33ef (3.84)
T4	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	20 g	5.00d (2.33)	6.00d (2.54)	7.00e (2.73)	11.00d (3.38)
T5	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g	3.00c (1.85)	4.00c (2.11)	6.00de (2.54)	10.00d (3.23)
T6	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g	1.33b (1.34)	3.00bc (1.87)	4.00c (2.11)	6.00bc (2.54)
T7	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g	2.33c (1.67)	3.67c (2.01)	4.67cd (2.27)	7.00c (2.73)
T8	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g	1.00b (1.22)	2.00ab (1.58)	2.67b (1.77)	5.00b (2.33)
T9	Deltamethrin 2.8 EC	0.04 mL	0.00a (0.70)	1.33a (1.34)	1.67a (1.46)	2.00a (1.58)
T10	Untreated control	–	17.00g (4.18)	25.67g (5.11)	32.67h (5.75)	37.00g (6.12)
	S. Em. ±		0.09	0.1	0.1	0.11
	CD at 5%		0.27	0.3	0.3	0.31
	CV (%)		7.35	6.86	6.07	5.48

DAT: Days After Treatment. Figures in parentheses are square root transformed values while those outsides are original values. Treatment means followed by the same letter(s) are not significantly different according to DNMRT at 5% level of significance.

3.3 Number of Eggs

The data on effect of entomopathogens on oviposition of *S. cerealella* at different periods of storage intervals are presented in Table 4. Results revealed that significant effect of all the treatments on oviposition were found over untreated control. At 120 DAT, the significantly lowest number of eggs (8.33) was recorded in treatment of deltamethrin at 0.04 mL/kg. The next effective treatment in terms of egg laying (14.67) was *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg followed by *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (20.67). Significantly highest number of eggs laid (67.33) was observed in the untreated control.

TABLE 4
EFFECT OF ENTOMOPATHOGENS ON OVIPOSITION OF *S. CEREALELLA* IN STORED SORGHUM

Treat. No.	Treatments	Dose per kg of seed	Mean number of eggs laid by females after indicated days of treatment				
			15 DAT	30 DAT	60 DAT	90 DAT	120 DAT
T1	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g)	10 g	14.00f* (3.80)	22.67h (4.81)	27.00g (5.24)	32.00g (5.70)	40.00h (6.36)
T2	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g)	20 g	5.33d (2.41)	13.33f (3.71)	18.00e (4.30)	24.00f (4.94)	35.00fg (5.95)
T3	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g)	10 g	8.00e (2.91)	18.00g (4.37)	22.00f (4.74)	25.00f (5.04)	37.00g (6.12)
T4	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g)	20 g	4.00c (2.11)	11.00e (3.38)	16.67e (4.14)	22.33ef (4.77)	33.33ef (5.81)
T5	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	10 + 5 g	3.33c (1.95)	8.00d (2.91)	11.67d (3.48)	19.67e (4.48)	31.67e (5.67)
T6	*Beauveria bassiana* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	20 + 5 g	0.00a (0.70)	1.67b (1.46)	8.00c (2.91)	13.67d (3.76)	20.67c (4.60)
T7	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	10 + 5 g	1.00b (1.22)	3.67c (2.03)	9.00c (3.07)	11.00c (3.38)	24.00d (4.94)
T8	*Metarhizium anisopliae* 1.15 WP (1.0×10^8 CFU/g) + Diatomaceous earth	20 + 5 g	0.00a (0.70)	1.33b (1.34)	4.00b (2.11)	6.00b (2.54)	14.67b (3.89)
T9	Deltamethrin 2.8 EC	0.04 mL	0.00a (0.70)	0.00a (0.70)	2.33a (1.67)	3.33a (1.93)	8.33a (2.96)
T10	Untreated control	–	20.33g (4.56)	32.00i (5.70)	43.00h (6.59)	52.33h (7.26)	67.33i (8.23)
	S. Em. ±		0.07	0.09	0.1	0.11	0.08
	CD at 5%		0.2	0.27	0.29	0.33	0.23
	CV (%)		5.64	5.2	4.5	4.48	2.47

DAT: Days After Treatment. Figures in parentheses are square root transformed values while those outsides are original values. Treatment means followed by the same letter(s) are not significantly different according to DNMRT at 5% level of significance.

3.4 Weight Loss

Data on percent weight loss by *S. cerealella* after 15, 30, 60, 90 and 120 DAT are presented in Table 5. In case of 120 DAT, the lowest weight loss (19.80%) was recorded in treatment of deltamethrin at 0.04 mL/kg which was followed by *M. anisopliae* 1.15 WP (1.0×10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (22.30%), *B. bassiana* 1.15 WP (1.0×10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (25.70%) and *M. anisopliae* 1.15 WP (1.0×10^8 CFU/g) + diatomaceous earth at 10 + 5 g/kg (30.20%). Significantly highest weight loss (48.00%) was recorded in untreated control.

The lowest F1 progeny of *S. cerealella* emerged from diatomaceous earth at 1000 mg/kg + *B. bassiana* at 5 g/kg (37.33) followed by diatomaceous earth at 1000 mg/kg + *M. anisopliae* at 5 g/kg (41.67) was reported by Muthukumar et al. (2016) and these results are in close conformity with present study. Yadav (2024) studied the effect of entomopathogen and inert dust on storage insect pest on wheat and found that the significantly higher adult mortality rate of *S. cerealella* was recorded in treatment of deltamethrin at 0.04 mL/kg seed (60.00%) followed by *B. bassiana* at 20 g/kg seed + diatomaceous earth at 5 g/kg seed (50.00%) after 12 months of storage. Rajasri et al. (2012) studied the efficacy of different indigenous inert materials against stored grain pests of rice and concluded that among the different inert materials, indispron P 406 at 2.5 g/kg and diatomaceous earth at 5 g/kg were found effective against *S. cerealella* up to twelve months of storage period. Thus, the present findings are more or less in conformity with the earlier reports.

TABLE 5
EFFECT OF ENTOMOPATHOGENS ON WEIGHT LOSS AGAINST *S. CEREALELLA* IN STORED SORGHUM

Treat. No.	Treatments	Dose per kg of seed	Percent weight loss at different period of storage interval				
			15 DAT	30 DAT	60 DAT	90 DAT	120 DAT
T1	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	10 g	23.37g* (28.90)	27.00g (31.30)	32.00h (34.45)	37.60h (37.81)	41.20h (39.93)
T2	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	20 g	20.17f (26.67)	23.03f (28.67)	26.00f (30.65)	31.17gh (33.93)	36.70gf (37.28)
T3	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	10 g	22.10g (28.03)	25.33g (30.21)	28.17g (32.05)	32.37g (34.67)	38.00g (38.05)
T4	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	20 g	18.70f (25.62)	20.27e (26.75)	24.70f (29.79)	29.50ef (32.89)	35.60ef (36.63)
T5	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g	15.80e (23.42)	17.27d (24.55)	21.70e (27.76)	27.47e (31.60)	33.37e (35.28)
T6	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g	9.83c (18.27)	12.47c (20.67)	16.27c (23.78)	20.60c (26.98)	25.70c (30.45)
T7	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g	13.60d (21.62)	15.83d (23.43)	18.60d (25.54)	23.17d (28.76)	30.20d (33.33)
T8	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g	6.47b (14.72)	10.50b (18.89)	13.50b (21.54)	17.43b (24.66)	22.30b (28.17)
T9	Deltamethrin 2.8 EC	0.04 mL	4.43a (12.12)	6.60a (14.86)	9.43a (17.88)	14.70a (22.53)	19.80a (26.40)
T10	Untreated control	–	28.50h (32.26)	32.00h (34.44)	37.23i (37.60)	42.33i (40.58)	48.00i (43.85)
	S. Em. ±		0.39	0.41	0.34	0.44	0.46
	CD at 5%		1.15	1.21	1.01	1.31	1.37
	CV (%)		2.9	2.79	2.1	2.44	2.3

DAT: Days After Treatment. Figures in parentheses are arc sine transformed values while those outsides are original values. Treatment means followed by the same letter(s) are not significantly different according to DNMRT at 5% level of significance.

3.5 Seed Germination

The initial germination percentage of sorghum seeds before treatment was 98.00% and after completion of study, the seed germination (%) are presented in Table 6. Results revealed that significantly highest seed germination (91.33%) was recorded in treatment of *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg and it was statistically at par with *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (91.00%), deltamethrin at 0.04 mL/kg (90.00%) and *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 10 + 5 g/kg (89.00%). The next effective treatment in terms of seed germination (%) was *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 10 + 5 g/kg (88.00%) which was followed by *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) at 20 g/kg (87.67%), *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) at 20 g/kg (86.00%), *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) at 10 g/kg (85.00%) and *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) at 10 g/kg (84.00%). The significantly lowest germination percentage (80.00%) was recorded in untreated control.

3.6 Seed Moisture

The initial moisture percentage of sorghum seeds before treatment was 7.25% and after completion of study, the seed moisture (%) are presented in Table 6. Significantly lowest seed moisture content (8.24%) was recorded in *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg and it was statistically at par with *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg (8.41%). The next effective treatment in terms of seed moisture (%) was *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 10 + 5 g/kg (8.56%) and it was at par with the treatment of *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + diatomaceous earth at 10 + 5 g/kg (8.67%) and deltamethrin at 0.04 mL/kg (8.90%). The remaining treatments in ascending chronological order based on seed moisture (%) was *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) at 20 g/kg (9.46%) < *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) at 20 g/kg (9.53%) < *B. bassiana* 1.15 WP (1.0 × 10^8 CFU/g) at 10 g/kg (9.66%) < *M. anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) at 10 g/kg (9.70%). Significantly highest seed moisture content (9.87%) was recorded in untreated control.

Rajasri et al. (2012) studied the efficacy of different indigenous inert materials and reported that the germinability of seed maintained for twelve month which is above certification standards (>80%). These results are in close agreement with the findings of Theertha et al. (2023), who reported that the *M. anisopliae* at 20 g/kg seeds + diatomaceous earth at 5 g/kg seeds had the lowest seed moisture content of 9.64% and highest seed germination 82% after nine months of storage. Anuradha and Bera (2025) also reported that the *M. anisopliae* at 20 g/kg seed + diatomaceous earth at 5 g/kg seeds recording 64.67% germination and 8.33% moisture after twelve months of storage. These results are in close conformity with previous findings, where the significantly lowest moisture content (8.20%) was recorded in treatment of *B. bassiana* at 20 g/kg seed and significantly highest germination percentage (68.67%) was recorded in treatment of *B. bassiana* at 10 g/kg seed + diatomaceous earth at 5 g/kg seed, while significantly highest moisture content (9.06%) was found in the untreated control after 12 months of storage (Anonymous, 2025).

TABLE 6
EFFECT OF ENTOMOPATHOGENS ON SEED VIABILITY IN STORED SORGHUM

Treat. No.	Treatments	Dose per kg of seed	Seed germination (%)	Seed moisture (%)
T1	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	10 g	85.00de* (67.22)	9.66c (18.11)
T2	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g)	20 g	87.67bcd (69.46)	9.46c (17.91)
T3	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	10 g	84.00e (66.42)	9.70c (18.15)
T4	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g)	20 g	86.00cde (68.03)	9.53c (17.98)
T5	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g	89.00abc (70.74)	8.56ab (17.00)
T6	*Beauveria bassiana* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g	91.33a (72.98)	8.24a (16.68)
T7	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	10 + 5 g	88.00bcd (69.74)	8.67ab (17.12)
T8	*Metarhizium anisopliae* 1.15 WP (1.0 × 10^8 CFU/g) + Diatomaceous earth	20 + 5 g	91.00a (72.55)	8.41a (16.84)
T9	Deltamethrin 2.8 EC	0.04 mL	90.00ab (71.57)	8.90b (17.36)
T10	Untreated control	–	80.00f (63.45)	9.87c (18.30)
	S. Em. ±		0.86	0.14
	CD at 5%		2.54	0.43
	CV (%)		2.15	1.42

PLATE 2: Germination performance of sorghum seeds after treatment with entomopathogens and diatomaceous earth

IV. CONCLUSION

The study demonstrated that entomopathogenic fungi, particularly in combination with diatomaceous earth, are effective alternatives to chemical insecticides for managing *Sitotroga cerealella* in stored sorghum. The combination treatments of *M. anisopliae* + diatomaceous earth and *B. bassiana* + diatomaceous earth at 20 + 5 g/kg showed significantly higher adult mortality, reduced adult emergence, lower oviposition, minimized weight loss, and maintained better seed viability compared to individual treatments.

Key Findings:

1) The combination of *M. anisopliae* (1.0×10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg was the most effective entomopathogenic treatment, achieving 65.80% adult mortality, 91.00% seed germination, and only 8.41% seed moisture content.
2) *B. bassiana* (1.0×10^8 CFU/g) + diatomaceous earth at 20 + 5 g/kg was the second most effective treatment, with comparable results.
3) Chemical insecticide (deltamethrin) showed the highest adult mortality (72.33%) but also maintained good seed viability (90.00% germination), indicating its effectiveness as a grain protectant.
4) Deltamethrin is effective but raises concerns about residues, resistance development, and environmental impact. Therefore, entomopathogens combined with diatomaceous earth offer a sustainable alternative for stored grain pest management.

Recommendations:

1) **For Farmers:** The combination of *M. anisopliae* or *B. bassiana* with diatomaceous earth at 20 + 5 g/kg can be recommended as an eco-friendly alternative to chemical insecticides for protecting stored sorghum.
2) **For Seed Viability:** These treatments maintain seed germination above 90% and moisture content below 9%, ensuring seed quality for planting.
3) **For Future Research:** Field-level validation, long-term storage studies, and evaluation of these treatments on different sorghum varieties are recommended.

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CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this manuscript.

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