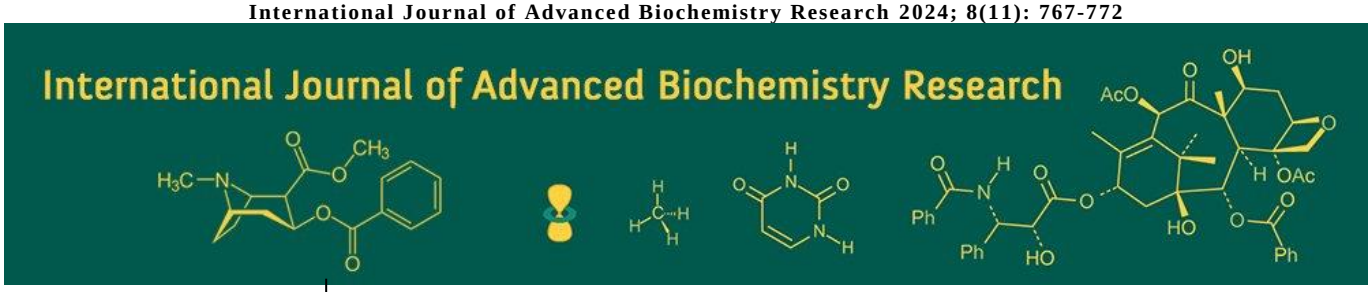

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(11): 767-772
www.biochemjournal.com
Received: 20-09-2024
Accepted: 28-10-2024

Harshada Madali
Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India

Uttam Kumar Behera
Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India

Nirakar Ranasingh
Department of Plant Pathology, College of Agriculture, OUAT, Bhawanipatna, Odisha, India

Manoj Kumar Rout
Department of Plant Pathology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India

Pravasini Behera
Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India

Simly Das
Department of Nematology, College of Agriculture, OUAT, Bhawanipatna, Odisha, India

Chitta Ranjan Satapathy
Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India

Jayaraj Padhi
Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India

Corresponding Author:
Uttam Kumar Behera
Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, Odisha, India

Efficacy of entomopathogens against different life stages of *Spodoptera frugiperda* (J.E. Smith, 1797) (Noctuidae: Lepidoptera) under laboratory conditions

Harshada Madali, Uttam Kumar Behera, Nirakar Ranasingh, Manoj Kumar Rout, Pravasini Behera, Simly Das, Chitta Ranjan Satapathy and Jayaraj Padhi

DOI: https://doi.org/10.33545/26174693.2024.v8.i11j.2953

Abstract
A laboratory experiment was conducted in the Department of Entomology, College of Agriculture, OUAT, Bhubaneswar, during 2021–22 to evaluate the efficacy of various entomopathogens against different life stages of *Spodoptera frugiperda* (J.E. Smith, 1797) (Noctuidae: Lepidoptera), including eggs and second to sixth instar larvae. Topical application of *Metarhizium anisopliae* on eggs resulted in the highest reduction in hatchability (15%), followed by *Beauveria bassiana* and *Metarhizium rileyi* (12.5% each), while *Bacillus thuringiensis* showed no effect. In the leaf dip bioassay for larval instars, the efficacy of entomopathogens decreased with increasing larval age. Among second instars, *B. thuringiensis* exhibited the highest mortality (27.78%) at 120 hours after treatment (HAT), followed by *M. rileyi* (17.5%) and *B. bassiana* (15.56%). Third instar larvae were most affected by *B. thuringiensis* (25% mortality) and *B. bassiana* (15%), while fourth instar larvae showed maximum cumulative mortality with *B. bassiana* (15%) and moderate effectiveness of *B. thuringiensis*, *M. rileyi*, and *M. anisopliae* (12.5% each). Fifth and sixth instars demonstrated reduced susceptibility, with *B. thuringiensis*, *M. rileyi*, and *M. anisopliae* achieving only 10% mortality in the fifth instar and *B. bassiana* showing 5% mortality in the sixth instar.

Key words: *Spodoptera frugiperda*, entomopathogens, larval mortality, egg hatchability, biocontrol

1. Introduction
The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae), is a highly destructive and globally significant polyphagous pest. It has been reported to infest 353 plant species across 76 families (Montezano *et al*., 2018) [17]. Controlling FAW is seriously challenging due to its trans boundary movement, broad host range, short life cycle, quick reproduction, and absence of a diapause phase, all of which contribute to sizable crop damage. Chemical insecticides are commonly employed to manage FAW populations (Tambo *et al*., 2019) [20]. However, their excessive and indiscriminate use has led to the emergence of resistant FAW populations, reducing the long-term efficacy and sustainability of chemical control measures (Day *et al*., 2017) [5]. Moreover, frequent or high-dose applications of chemical insecticides negatively impact beneficial insects, disrupt natural enemy populations, pose risks to human health, and contribute to environmental pollution (Kebede and Shimalis, 2019) [11].

To address these challenges, adopting an Integrated Pest Management (IPM) approach is critical. Bio-intensive alternatives, particularly microbial-based pesticides, have become a cornerstone of sustainable pest management strategies (Souza *et al*., 2019) [19]. These microbial agents include entomopathogenic fungi, nematodes, bacteria, and viruses, all of which have potential in managing FAW. Entomopathogenic fungi (EPFs) such as *Beauveria bassiana* (Balsamo) Vuillemin, *Metarhizium rileyi* (Farlow) Kepler, S.A. Rehner and Humber (formerly classified under *Botrytis*, *Spicaria*, or *Nomuraea*), and *Metarhizium anisopliae* (Metschn.) have demonstrated efficacy against FAW in field conditions, highlighting their potential as biocontrol agents (Faria *et al*., 2015; Wraight *et al*., 2010) [7, 22].

However, the success of these fungi is often influenced by environmental factors (Hoverman *et al*., 2012; Khan and Ahmad, 2015) [9, 12]. Entomopathogenic nematodes from the families Steinernematidae and Heterorhabditidae are also effective against FAW, with the genera *Steinernema* and *Heterorhabditis* being particularly noteworthy. These nematodes form symbiotic relationships with *Xenorhabdus* and *Photorhabdus* bacteria, respectively, which are essential for killing the insect host (Boemare *et al*., 1993; Hominick *et al*., 1996) [4, 8]. Among entomopathogenic bacteria, *Bacillus thuringiensis* Berliner (Bt) plays a pivotal role. This gram-positive bacterium produces crystal proteins (δ-endotoxins) during sporulation, which are highly toxic to FAW. Studies have identified varying susceptibilities of FAW strains to different *Bt* endotoxins, such as Cry1Ac, Cry1Ab, Cry1Ca, and Cry1Ea, with the rice strain of FAW being more susceptible to Cry1Ab than the corn strain (Monnerat *et al*., 2006) [15].

Considering the need for sustainable pest control, microbial-based biopesticides offer an environmentally friendly and effective alternative for managing FAW populations as part of an integrated pest management strategy.

2. Materials and Methods

2.1 Experimental Site and Methodology

The experiment was conducted under optimal laboratory conditions (controlled laboratory conditions (temperature: 25±2 °C, % relative humidity: 70±5%) to evaluate the bio potency of different entomopathogens at their recommended dosages and to assess their efficacy against critical life stages of *Spodoptera frugiperda*. The study followed a Completely Randomized Design (CRD) with four replications, including an untreated control.

2.2 Bioassay studies on FAW eggs

To evaluate the efficacy of entomopathogens against FAW eggs, bioassays were conducted using glass petri plates lined with filter paper. Fresh maize leaves obtained from 30 to 45 days old plants, cut into small pieces, were placed in each plate. Ten numbers of two-day-old eggs were introduced per plate. Biopesticides suspensions were prepared at recommended dosages, and eggs were immersed in the suspensions for one minute. After immersion, the eggs were sieved, placed on blotting paper to remove excess moisture, and then transferred onto the maize leaves. Observations on hatching were recorded, and each treatment was replicated four times.

2.3 Bioassay studies on *Bacillus thuringiensis* against FAW larvae

The leaf dip method was employed to test the efficacy of *Bacillus thuringiensis* against FAW larvae. Maize leaf strips (8 cm × 2 cm) were dipped in the suspension for two minutes, shade-dried, rolled, and placed in multi-cavity trays lined with filter paper. Laboratory-reared larvae (second to sixth instar) were introduced to the trays, with ten larvae per replication. Untreated control trays contained maize leaves treated with distilled water. Larvae were allowed to feed on treated leaves for 48 hours, after which untreated leaves were provided. Observations on larval mortality were recorded every 24 hours.

2.4 Bioassay studies on entomopathogenic fungi against FAW larvae: The efficacy of entomopathogenic fungi (*Beauveria bassiana*, *Metarhizium rileyi*, and *Metarhizium anisopliae*) was tested against all instars of FAW larvae. Larvae were immersed in biopesticide suspensions for 20 seconds and transferred to multi-cavity trays lined with filter paper. Fresh maize leaves were provided as food every 24 hours. Untreated control larvae were treated with distilled water. Observations on mortality due to fungal infection were recorded at every 24 hours.

2.5 Bioassay studies on *Heterorhabditis indica* against FAW larvae

To assess the biopotency of *Heterorhabditis indica*, FAW larvae were placed in multi-cavity trays lined with filter paper. A 1 mL suspension of the entomopathogenic nematode, prepared at the recommended dose, was added to each tray cell. Fresh maize leaves were provided every 24 hours, and observations on larval mortality were recorded daily.

2.6 Statistical analysis

Data on egg and larval mortality were subjected to statistical analysis using a Completely Randomized Design (CRD). Non-normally distributed data were transformed using square root ($\sqrt{x} + 0.5$) transformation before analysis. Corrected mortality rates were calculated using Abbott's formula (Abbott, 1925) [1], and ANOVA was performed for each FAW life stage.

$$\text{Percentage of mortality} = \frac{\text{number of larvae dead}}{\text{number of larvae introduced}} \times 1 \quad \text{.....(1)}$$

$$\text{Corrected percentage of mortality} = \left(1 - \frac{\text{n T after treatment}}{\text{n C after treatment}}\right) \times 100 \quad \text{.....(2)}$$

3. Results and Discussion

3.1 Effect of entomopathogens on FAW eggs

The impact of entomopathogens on the hatchability of two-day-old *Spodoptera frugiperda* (FAW) eggs was evaluated. Eggs that failed to hatch by the third or fourth day were considered infected or dead. The results of the topical application of biopesticides (Table 2) demonstrated that all entomopathogens except *Bacillus thuringiensis* exhibited an effect on egg mortality.

Among the tested treatments, *Metarhizium anisopliae* resulted in the highest reduction in egg hatchability, causing 15.0% mortality, followed by *Metarhizium rileyi* and *Beauveria bassiana*, which each caused 12.5% mortality. The treatment with *Heterorhabditis indica* caused 5.0% mortality, while no effect on egg hatchability was observed in the case of *Bacillus thuringiensis* (0.0%).

The superior efficacy of *M. anisopliae* in reducing egg hatchability aligns with the findings of Akutse *et al*. (2019) [3], which reported that *M. anisopliae* strains performed better than *B. bassiana* in similar studies. However, the observed effectiveness of *M. rileyi* in the present investigation contrasts with the findings of Lezama-Gutierrez *et al*. (1996) [13], who reported no impact of *M. rileyi* on FAW eggs.

Remarkably, no significant effect was recorded for *B. thuringiensis* on egg hatchability, which corroborates the results of Liu and Zhang (1997) [14]. They observed that *B. thuringiensis* did not affect the eclosion of eggs in pests such as *Plutella xylostella* (diamondback moth), *Spodoptera litura*, and *Pieris brassicae*, but caused substantial mortality in the larvae hatched from treated eggs.

3.2 Effect of entomopathogens on mortality of second instar larvae of FAW

The results on the mortality of second instar larvae treated with entomopathogens are presented in Table 3. There were no significant differences in mortality among treatments after 120 hours of treatment (HAT). Initial mortality was observed within 24 hours, with *Bacillus thuringiensis* and *Metarhizium rileyi* causing 5.0% and 2.5% mortality, respectively.

By 120 HAT, *B. thuringiensis* exhibited the highest mortality rate (27.78%), followed by *M. rileyi* (17.50%) and *Beauveria bassiana* (15.56%). Mortality due to *Heterorhabditis indica* was 15.28%. These findings align partially with previous studies, though variations in effectiveness were observed, likely due to differences in fungal strains, concentrations, or geographical origin of the pest population (Espine and Cotes, 2008; Wandee *et al*., 2021) [6, 21].

3.3 Effect of entomopathogens on third instar larvae of FAW

Mortality caused by entomopathogens in third instar larvae showed significant differences among treatments, beginning at 72 HAT and continuing up to 120 HAT (Table 4). The highest mortality was recorded for *B. thuringiensis* (25.0%), followed by *B. bassiana* (15.0%). Both *Metarhizium anisopliae* and *H. indica* caused 12.50% mortality each at 120 HAT. These results align with those of Idrees *et al*. (2021) [10], who reported 10% mortality in third instar larvae treated with *B. bassiana*.

3.4 Effect of entomopathogens on fourth instar larvae of FAW

The results for fourth instar larvae (Table 5) indicated no significant differences in mortality among treatments up to 120 HAT. Mortality began at 24 HAT, with *B. bassiana* causing the highest cumulative mortality (15.0%), followed by *B. thuringiensis*, *M. rileyi*, and *M. anisopliae* (12.50% each). *H. indica* resulted in the lowest mortality (10.0%). These findings align partially with those of Montecalvo and Navasero (2021) [16], who observed increased mortality at 4–5 days post-treatment depending on larval age.

3.5 Effect of entomopathogens on fifth instar larvae of FAW

The mortality of fifth instar larvae showed reduced effectiveness compared to earlier instars (Table 6). At 120 HAT, maximum cumulative mortality of 10.0% was observed for *B. thuringiensis*, *M. rileyi*, and *M. anisopliae*. Mortality initiated at 72 HAT with *B. bassiana* causing 7.50% and *B. thuringiensis* and *M. rileyi* each causing 5.0%. No mortality was recorded for *H. indica*. Similar findings were reported by Idrees *et al*. (2021) [10], who recorded 7.8% mortality in fifth instar larvae treated with *B. bassiana*.

3.6 Effect of entomopathogens on sixth instar larvae of FAW

The efficacy of entomopathogens against sixth instar larvae (Table 7) was minimal, with no significant differences observed among treatments up to 120 HAT. Mortality began at 96 HAT, with *B. bassiana* causing 5.0% and *B. thuringiensis* 2.50%. No mortality was recorded for other treatments. These findings support the view that younger larvae are more susceptible to pathogens than older instars (Montecalvo and Navasero, 2021) [16].

3.7 General effect of entomopathogens on all larval instars of FAW

The bioassay results (Fig. 1) revealed that early instars of FAW are more susceptible to entomopathogens, with maximum mortality recorded at 120 HAT. Mortality declined significantly in fifth and sixth instar larvae. Among the treatments, *B. thuringiensis* applied through the leaf dip method caused the highest overall mortality (15.56%), followed by *B. bassiana* (11.61%) and *M. anisopliae* (10.0%).

The effectiveness of *B. thuringiensis* was most pronounced in second and third instars, causing 27.78% and 25.0% mortality, respectively. *B. bassiana* caused consistent mortality (15.0%) across second, third, and fourth instars (Fig. 2). These findings align with studies by Patil *et al*. (2014) [18] and Montecalvo and Navasero (2021) [16], who reported higher susceptibility in early larval stages.

Table 1: List of entomopathogens used in bioassay studies on FAW larvae

Treatment	Concentration	Dose	Trade Name	Source of Supply
T_1-*Bacillus thuringiensis* subsp. *kurstaki* 5% WP	16000 IU/mg	2 g/L water	Minchu	Multiplex
T_2-*Beauveria bassiana* 1.15% WP	$1x10^8$ cfu/g	2 g/L water	BABA	Multiplex
T_3-*Metarhizium rileyi* 1% WP	$2x10^8$ cfu/g	5 g/L water	-	UAS, Raichur
T_4-*Metarhizium anisopliae* 1.15% WP	$2x10^8$ cfu/g	5 g/L water	Raita Mitra	UAS, Raichur
T_5-*Heterorhabditis indica*WP	$1x10^8$ IJs/ g	5 g/L water	Soldier	Multiplex
T_6-Untreated Control	-	-	-	-

Table 2: Effect of topical application of entomopathogens on egg hatching of FAW

Treatment	Concentration	Dose/ Litre Water	Corrected Egg (%) Failed To Hatch
T_1-*Bacillus thuringiensis*	16000 iu/mg	2g	0.00 (0.71) ^{c}
T_2-*Beauveria bassiana*	$1x10^8$ cfu/g	2g	12.50(3.56) ^{ab}
T_3-*Metarhizium rileyi*	$2x10^8$ cfu/g	5g	12.50(3.25) ^{ab}
T_4-*Metarhizium anisopliae*	$2x10^8$ cfu/g	5g	15.00(3.88) ^{a}
T_5-*Heterorhabditis indica*	$1x10^8$ IJs/ g	5g	5.00(1.97) ^{bc}
S.E(m)±			0.563
CD (0.05%)			1.698

Figures in parentheses are transformed (square root √x+0.5) values

Table 3: Effect of entomopathogens on mortality of second instar larvae of FAW

Treatments	Concentration	Dose/ litre water	Corrected Cumulative Mortality (%) After Different Hours of treatment				
			24 HAT	48 HAT	72 HAT	96 HAT	120 HAT
T_1-*B. thuringiensis*	16000 iu/mg	2g	5.00 (1.97)	15.28 (3.54)	20.28 (4.48)	22.78 (4.73)	27.78 (5.12)
T_2-*B.bassiana*	1x10^8 cfu/ g	2g	0.00 (0.71)	10.56 (2.99)	13.06 (3.62)	15.56 (3.94)	15.56 (3.94)
T_3-*M. rileyi*	2x 10^8 cfu/ g	5g	2.50 (1.34)	10.00 (2.93)	15.00 (3.81)	17.50 (4.13)	17.50 (4.13)
T_4-*M. anisopliae*	2x 10^8 cfu/ g	5g	0.00 (0.71)	7.50 (2.61)	15.00 (3.89)	15.00 (3.88)	15.00 (3.88)
T_5-*H. indica*	1 × 10^8 IJs/ g	5g	0.00 (0.71)	7.78 (2.65)	15.28 (3.92)	15.28 (3.91)	15.28 (3.91)
S.E(m)±			0.433	0.806	0.443	0.463	0.540
CD (0.05%)			NS	NS	NS	NS	NS

Figures in parentheses are transformed (square root √x+0.5) values, HAT-Hours after treatment

Table 4: Effect of entomopathogens on third instar larvae of FAW

Treatments	Concentration	Dose/ litre water	Corrected Cumulative Mortality (%) After Different Hours of treatment				
			24 HAT	48 HAT	72 HAT	96 HAT	120 HAT
T_1-*B. thuringiensis*	16000 iu/mg	2g	0.00 (0.71)	15.00 (3.89)	22.50^a (4.78)	25.00 ^{a} (5.03)	25.00^a (5.03)
T_2-*B.bassiana*	1x10^8 cfu/ g	2g	7.50 (2.30)	12.50 (3.25)	15.00^{ab} (3.88)	15.00^{ab} (3.88)	15.00^{ab} (3.88)
T_3-*M. rileyi*	2x 10^8 cfu/ g	5g	0.00 (0.71)	2.50 (1.34)	7.50^c (2.61)	7.50 ^{c} (2.61)	7.50 ^{c} (2.61)
T_4-*M. anisopliae*	2x 10^8 cfu/ g	5g	2.50 (1.34)	10.00 (3.24)	12.50^{bc} (3.56)	12.50^{bc} (3.56)	12.50^{bc} (3.56)
T_5-*H. indica*	1 × 10^8 IJs/ g	5g	0.00 (0.71)	7.50 (2.61)	12.50^{bc} (3.26)	12.50^{bc} (3.56)	12.50^{bc} (3.56)
S.E(m)±			0.512	0.592	0.402	0.407	0.407
CD (0.05%)			NS	NS	1.212	1.227	1.227

Figures in parentheses are transformed (square root √x+0.5) values, HAT-Hours after treatment

Table 5: Effect of entomopathogens on fourth instar larvae of FAW

Treatments	Concentration	Dose/ litre water	Corrected Cumulative Mortality (%) After Different Hours of treatment				
			24 HAT	48 HAT	72 HAT	96 HAT	120 HAT
T_1-*B. thuringiensis*	16000 iu/mg	2g	2.50 (1.34)	2.50 (1.34)	7.50 (2.61)	10.00 (3.24)	12.50 (3.56)
T_2-*B.bassiana*	1x10^8 cfu/ g	2g	2.50 (1.34)	7.50 (2.61)	12.50 (3.56)	12.50 (3.56)	15.00 (3.88)
T_3-*M. rileyi*	2x10^8 cfu/ g	5g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	7.50 (2.61)	12.50 (3.56)
T_4-*M. anisopliae*	2x10^8 cfu/ g	5g	0.00 (0.71)	2.50 (1.34)	10.00 (2.93)	12.50 (3.56)	12.50 (3.56)
T_5-*H. indica*	1x10^8 IJs/ g	5g	0.00 (0.71)	0.00 (0.71)	7.50 (2.30)	10.00 (2.93)	10.00 (2.93)
S.E(m)±			0.401	0.491	0.641	0.500	0.467
CD (0.05%)			NS	NS	NS	NS	NS

Figures in parentheses are transformed (square root √x+0.5) values, HAT-Hours after treatment

Table 6: Effect of application of entomopathogens on fifth instar larvae of FAW

Treatments	Concentration	Dose/ litre water	Corrected Cumulative Mortality (%) After Different Hours of treatment				
			24 HAT	48 HAT	72 HAT	96 HAT	120 HAT
T_1-*B. thuringiensis*	16000 iu/mg	2g	0.00 (0.71)	0.00 (0.71)	5.00 (1.97)	10.00 (2.93)	10.00 (2.93)
T_2-*B.bassiana*	1x10^8 cfu/ g	2g	0.00 (0.71)	0.00 (0.71)	7.50 (2.30)	7.50 (2.30)	7.50 (2.30)
T_3-*M. rileyi*	2x10^8 cfu/ g	5g	0.00 (0.71)	0.00 (0.71)	5.00 (1.97)	10.00 (3.24)	10.00 (3.24)
T_4-*M. anisopliae*	2x10^8 cfu/ g	5g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	7.50 (2.30)	10.00 (2.93)
T_5-*H. indica*	1x10^8 IJs/ g	5g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
S.E(m)±			0.00	0.00	0.629	0.702	0.662
CD (0.05%)			NS	NS	NS	NS	NS

Figures in parentheses are transformed (square root √x+0.5) values, HAT-Hours after treatment

Table 7: Effect of application of entomopathogens on sixth instar larvae of FAW

Treatments	Concentration	Dose/ litre water	Corrected Cumulative Mortality (%) After Different Hours of treatment				
			24 HAT	48 HAT	72 HAT	96 HAT	120 HAT
T_1-*B. thuringiensis*	16000 iu/mg	2g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	2.50 (1.34)	2.50 (1.34)
T_2-*B.bassiana*	$1x10^8$ cfu/ g	2g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	2.50 (1.34)	5.00 (1.97)
T_3-*M. rileyi*	$2x10^8$ cfu/ g	5g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
T_4-*M. anisopliae*	$2x10^8$ cfu/ g	5g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
T_5-*H. indica*	$1x10^8$ IJs/ g	5g	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
S.E(m)±			0.00	0.00	0.00	0.401	0.427
CD (0.05%)			NS	NS	NS	NS	NS

Figures in parentheses are transformed (square root √x+0.5) values, HAT-Hours after treatment

3.8 Variation of results

The observed variations in the effectiveness of entomopathogens could be attributed to differences in fungal strains, product formulations, or geographical variations in FAW populations. Where, Acharya *et al.* (2020) [2] reported 100% mortality of sixth instar larvae treated with *H. indica* at higher concentrations (50 IJ's/larva), while our study recorded no mortality for this pathogen. Such discrepancies emphasize the need for localized testing of biopesticides to optimize pest management strategies.

4. Conclusion

The findings concluded that the entomopathogens, particularly *B. thuringiensis* and *B. bassiana*, are efficient in managing early instar larvae of FAW. However, reduced efficacy against older instars suggested the importance of timely application for effective pest control

5. References

1. Abbott WS. A method of computing the effectiveness of an insecticide. J Econ Entomol. 1925;18:265-7.
2. Acharya R, Hwang HS, Mostafiz MM, Yu YS, Lee KY. Susceptibility of developmental stages of the fall armyworm, *Spodoptera frugiperda*, to entomopathogenic nematodes. Insects. 2020;11(1):868.
3. Akutse KS, Kimemia JW, Ekesi S, Khamis FF, Ombura LV, Subramanian S. Ovicidal effects of entomopathogenic fungal isolates on the invasive fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). J Appl Entomol. 2019;143(1):626-34.
4. Boemare N, Akhurst R, Mourant R. DNA relatedness between *Xenorhabdus* spp. (Enterobacteriaceae), symbiotic bacteria of entomopathogenic nematodes, and a proposal to transfer *Xenorhabdus* luminescens to a new genus, Photorhabdus gen. nov. Int J Syst Evol Microbiol. 1993;43(2):249-55.
5. Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M, Witt A. Fall armyworm: impacts and implications for Africa. Outlooks Pest Manag. 2017;28:196-201.
6. Espinel C, Cotes A. Sublethal effects of Nomuraea rileyi on development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Insect Pathogens and Insect Parasitic Nematodes. IOBC/wprs Bull. 2008;31(2):257-60.
7. Faria M, Lopes RB, Souza DA, Wraight SP. Conidial vigor vs. viability as predictors of virulence of entomopathogenic fungi. J Invertebr Pathol. 2015;125:68-72.
8. Hominick WM, Reid AP, Bohan D, Brisco BR. Entomopathogenic nematodes: biodiversity, geographical distribution and the convention on biological diversity. Biocontrol Sci Technol. 1996;6(3):317-32.
9. Hoverman JT, Mihaljevic JR, Richgels KL, Kerby JL, Johnson PT. Widespread co-occurrence of virulent pathogens within California amphibian communities. EcoHealth. 2012;9(3):288-92.
10. Idrees A, Qadir ZA, Akutse KS, Afzal A, Hussain M, Islam W, *et al*. Effectiveness of entomopathogenic fungi on immature stages and feeding performance of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae. Insects. 2021;12:1044.
11. Kebede M, Shimalis T. Outbreak, distribution and management of fall armyworm, *Spodoptera frugiperda* J.E. Smith in Africa: The status and prospects. Acad Agric J. 2019;3:3551-3568.
12. Khan MA, Ahmad W. The management of Spodopteran pests using fungal pathogens. In: Biocontrol of Lepidopteran Pests, Soil Biology. Springer; c2015, p. 123-60.
13. Gutierrez LR, Rosas AR, Jaber BLF, Ochoa MJ, Vargas AM, Ramirez GM, Dominguez RO. Virulence of five entomopathogenic fungi (Hyphomycetes) against *Spodoptera frugiperda* (Lepidoptera: Noctuidae) eggs and neonate larvae. Vedalia Rev Int Control Biol. 1996;3(1):35-39.
14. Liu SS, Zhang GM. Effects of Bacillus thuringiensis on eggs of three lepidopterous pests of crucifer vegetable crops. In: Sivapragasam A, Loke WH, Hussan AK, Lim GS, editors. The Management of Diamondback Moth and Other Crucifer Pests. Proceedings of the Third International Workshop; c1997, p. 109-12.
15. Monnerat R, Martins E, Queiroz P, Orduz S, Jaramillo G, Benintende GB, *et al*. Genetic variability of *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) populations from Latin America is associated with variations in susceptibility to Bacillus thuringiensis Cry toxins. Appl Environ Microbiol. 2006;72(11):7029-35.
16. Montecalvo MP, Navasero MM. Metarhizium (=Nomuraea) rileyi (Farlow) Samson from Spodoptera exigua (Hübner) cross infects fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) larvae. Philipp J Sci. 2021;150(1):193-9.

17. Montezano DG, Specht A, Gómez SDR, Specht RVF, Silva SJC, *et al*. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. Afr Entomol. 2018;26(2):286-300.
18. Patil RK, Bhagat YS, Halappa B, Bhat RS. Evaluation of entomopathogenic fungus, Nomuraea rileyi (Farlow) Samson for the control of groundnut *Spodoptera litura* (F.) and its compatibility with synthetic and botanical pesticides. J Biopesticides. 2014;7(Suppl):106-15.
19. Souza ML, Sanchesa MM, de Souza DA, Faria M, EspinelCorreal C, Sihler W, Lopes RB. Within-host interactions of Metarhizium rileyi strains and nucleopolyhedroviruses in *Spodoptera frugiperda* and Anticarsia gemmatalis (Lepidoptera: Noctuidae). J Invertebr Pathol. 2019;162:10-8.
20. Tambo JA, Day RK, Godwin LJ, Silvestri S, Beseh PK, Oppong MB, *et al*. Tackling fall armyworm (*Spodoptera frugiperda*) outbreak in Africa: An analysis of farmers' control actions. Int J Pest Manag. 2019;66(4):298-310.
21. Wandee W, Ongpo L, Apichat V, Det W. Efficacy of Thai indigenous entomopathogenic nematodes for controlling fall armyworm (*Spodoptera frugiperda*) (J.E. Smith) (Lepidoptera: Noctuidae). Egypt J Biol Pest Control. 2021;31(1):149.
22. Wraight SP, Ramos ME, Avery PB, Jaronski ST, Vandenberg JD. Comparative virulence of Beauveria bassiana isolates against lepidopteran pests of vegetable crops. J Invertebr Pathol. 2010;103(3):186-99.