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Research Article

Biochemical studies on fall armyworm (*Spodoptera frugiperda*) infested with spores of entomopathogenic fungi *Beauveria bassiana*

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ABSTRACT: Agriculture faces considerable reduction in productivity due to pests. India is an agriculture-based country and has achieved magnificent strides in self-dependence in many crops, including maize. Bihar is the major maize producer but facing loss of productivity due to several insect pests. In the present study, the fall armyworm (*Spodoptera frugiperda*) was studied for its management through entomopathogenic fungi, *Beauveria bassiana*. The adult insects were collected from four different districts of north Bihar, which are major maize producers. Different doses of spores were used to infest the insect and monitor changes in certain biochemical parameters associated with their ability to combat the infection and associated with their survival. They showed that the phenol oxidase and peroxidase activity increased in a dose dependent against fungal pathogen infection and showed a reduction in total carbohydrate and protein, while the lipid concentrations showed a decrease at low spore counts followed by an increase at moderate spore count and again a decrease at higher spore counts. Therefore, entomopathogenic fungus *B. bassiana* is able to infect the adult stage of fall armyworm and can be used for the management of this important pest of maize by damaging the metabolic activity, leading to early death. The infested insects would not be able to reproduce or produce pre-infected eggs, thus reducing their outbreak year after year.

KEYWORDS: *Beauveria bassiana,* entomopathogenic fungi, fall armyworm, insect pest, maize

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INTRODUCTION

Maize (*Zea mays* L.) is well known for its high value as a staple food and its widespread use in building, animal feed, and fuel and is one of the most important and widely grown cereal crops (Abebe & Feyisa, 2017). In terms of rural households, maize is also the most significant staple crop. The majority of maize crop is consumed as grain or green cobs (Nigussie *et al.*, 2002). Due to its many benefits, it is the most productive of the major cereal crops and ranks second in terms of production area (Abebe & Feyisa, 2017).

Although maize is still more productive than other main cereal crops, it is currently below its potential. Numerous production limitations, including inadequate cultural methods, low fertility, moisture stress, and pest management techniques, are mostly to blame for the low output (Tufa & Ketema, 2016). One of the main causes of the low yields that maize agriculture is currently experiencing is arthropod pests. In the field, more than 40 bug species have been reported on maize. While the spotted stalk borer (*Chilo partellus*), maize stalk borer (*Busseola fusca*), and several termite species (Macrotermes and Microtermes spp.) have long been considered important pests, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) is a more recent invading species and commonly named Fall Armyworm (FAW), is now the major insect pest causing substantial yield losses of maize in different states of India (Wang *et al.*, 2023).

In warm, humid climates, the migratory insect pest known as FAW is known to seriously harm maize crops (Ayala *et al.*, 2013; Clark *et al.*, 2007; Chen *et al.*, 2023).

Chemical control is the most common method for the control of the insect pest in agricultural areas (Kumar *et al.*, 2022). However, the chemical control of this pest appears

to be rather challenging due to the resistance established against applied toxicants like pyrethroids. Conventional pest management practices heavily depend on synthetic insecticides, which may adversely impact human health, non-target species, and the environment (Aktar *et al.*, 2009). As a result, there is growing interest in creating sustainable pest control strategies, including employing Entomopathogenic Fungi (EPF) as biological control agents (Gillespie, 2000; Kenis *et al.*, 2022). Entomopathogenic fungi are significant natural pathogens of arthropods and are primarily used for the biological control of insect infestations (Mahmood & Parwez, 2024). These fungi have demonstrated a promising ability to colonise endophytically a wide variety of plant species (Wilson, 1995). This feature provides multiple benefits to plants that include double protection against insect pests and plant diseases (Jaber & Ownley, 2018), and growth promotion (Jaber & Enkerly, 2017).

Beauveria bassiana (Bals.-Criv.) Vuill. is an entomopathogenic fungus widely distributed worldwide (Ownley *et al.*, 2008). This fungus has been isolated as a naturally occurring endophyte from different plant species (Vega, 2008). In addition, it has been introduced artificially by using different techniques in corn (Wagner & Lewis, 2000), soybean (Russo *et al.*, 2015), potato (Jones, 1994), cotton (Jones, 1994), jimsonweed (Jones, 1988), tomato (Allegrucci *et al.*, 2017), date palm (Gomez-Vidal *et al.*, 2006), banana (Akello *et al.*, 2007), coffee (Posada *et al.*, 2007), to evaluate its potential for the bio-control of insect pests.

When a Lepidopteran insect is infected by a fungus, a typical response is significant increase in the activity of phenol oxidase and peroxidase enzymes, while the levels of total carbohydrates, proteins, and lipids generally decrease, indicating the insect is utilising its energy reserves to fight the infection; this is primarily due to the activation of the insect's immune response, where these enzymes play a key role in melanisation and encapsulation of the invading pathogen (Shereen *et al.*, 2012).

Aggregations of moths from one generation can rapidly disperse over 500 km from the site of emergence, facilitated by wind fronts (FAO, 2017; Pogue, 2002), until they reach sexual maturity and become prepared to mate (Rose *et al.*, 1975). Consequently, the primary aim of the present work is to evaluate the effectiveness of the entomopathogenic fungus *B. bassiana* as a biological control agent against the fall armyworm, *S. frugiperda*. The study also seeks to investigate the biochemical responses of the insect following fungal infection, thereby contributing to the development of sustainable and eco-friendly pest management strategies in maize fields across India.

MATERIALS AND METHODS

Collection of insects

Adult fall armyworm (*S. frugiperda*) were collected by trapping with a net from the different maize fields of Purnea, Madhepura, Supaul and Saharsa districts and brought to the laboratory of the P. G. Department of Zoology, B. N. Mandal University, Madhepura.

Experimental design

The insects were distributed in four (04) groups, designated as Group I, Group II, Group III and Group IV for the insect populations of Purnea, Madhepura, Saharsa and Supaul districts, respectively. These groups were further divided into seven (07) sub-groups, each having five (05) insects each for different dose treatments with 5 replicates (n = 5) and were designated as A, B, C, D, E, F and G for 10^2, $10^{3,}$ $10^{4,}$ 10^5, 10^6, 10^7 and 10^8 spores/ml, respectively. Test group insects were first surface sterilised by dipping them in 75% ethanol solution for a few seconds, followed by rinsing with sterilised distilled water and finely treating them with 0.5% sodium hypochlorite for 1 min, and rinsed thrice with sterilised distilled water. Insects were kept in sterilised bottles capped with cotton plugs.

Entomopathogenic fungi infection

Test group insects were infested with the spores of *B. bassiana* by dipping them in respective spore suspensions to infect them. Test groups A, B, C, D, E, F and G were dipped in 10^2, $10^{3,}$ $10^{4,}$ 10^5, 10^6, 10^7 and 10^8 spores/ml, respectively, while the control group were treated with a suspension of 0.5% Tween 20. The haemolymph was extracted after 48 h of fungal infestation, pooled with a pinch of thiourea and then used for the estimation of different biochemical parameters to trace the transitory biochemical changes during progression of fungal pathogenesis.

Haemolymph sampling

This procedure was conducted exclusively under non-starvation conditions. The insects were cooled for 30 minutes at 40°C before bleeding. A leg was surface sterilised with 70% ethanol and severed between the coxae and femur. After 48 h of infestation with fungal spores in different doses for different experimental groups, the haemolymph samples were collected from untreated and treated groups. Haemolymph samples were obtained in accordance with

the method of Abd El-Kawy (1981). The haemolymph of each adult fall armyworm was collected using a disposable micropipette and subsequently aggregated within each experimental group. The sample size was 5 µl.

Estimation of Phenoloxidase (PO)

Phenoloxidase activity was determined as described by Ishaaya (1971) in a reaction mixture consisting of 0.5 ml phosphate buffer (0.1 M, pH 7), 200 µl enzyme solution and 200 µl catechol solution (2%). The substrate and other components of the reaction mélange were individually incubated at the reaction's optimal temperature (25ºC) before the reaction was initiated. The enzyme reaction was initiated by the addition of catechol solution. The optical density was determined, and a zero adjustment was made to the sample blank at 405 nm.

Estimation of Peroxidase (POD)

Peroxidase activity was determined according to Vetter *et al.* (1958). According to this, 1 ml of 0.3% hydrogen peroxide (in distilled water) and 1% o-phenylenediamine (in 95% ethyl alcohol; fresh every 4 h) reagents are added to the 200 µl sample in which the colour is to be formed. The reaction is permitted to continue for 5 min before being terminated by the addition of 2 ml of saturated sodium bisulfite. To prepare the reagent blank for each sample, a dye is added first, followed by sulfite, and finally hydrogen peroxide. The sulfite inhibits the enzyme, rendering it inactive when hydrogen peroxide is introduced. The samples are centrifuged for 5 min at 3000 rpm. The absorbance of the clear supernatant is measured at 340 nm after it is decanted into a colorimeter tube. The corresponding blank is used to configure the colorimeter to 100% transmittance for each sample. The enzyme activity was quantified as the change in absorbency at 340 nm/min/gm.

Determination of total proteins

Total proteins were determined by the method of Bradford (1976). According to this, 100 mg of Coomassie Brilliant blue G-250 was dissolved in 50 ml of 95% ethanol to create the protein reagent. 100 ml of 85% (W/V) phosphoric acid was added to this mixture. A final volume of 1 L was obtained by diluting the resultant solution. 50 µl of the sample solution or 50 µl of serial concentrations containing 10-100 µg of bovine serum albumin were pipetted into test tubes to produce the standard curve. After two minutes and before one hour, the absorbance at 595 nm was measured against a blank made from 1 ml of phosphate buffer and 5 ml of protein reagent.

Determination of total carbohydrates

Total carbohydrates were estimated in hemolymph by the phenol-sulfuric acid reaction of Dubois *et al.* (1956). Total carbohydrates were extracted from the haemolymph and prepared for assay according to Crompton and Birt (1967). Five to ten haemolymph samples were homogenised with 0.3 $HCLO_4$ (5 ml) at 0ºC for 1 min. Centrifugation for three minutes at 2000 RPM was used to remove insoluble debris, and two rounds of re-dispersion and centrifugation were performed in ice-cold $HCLO_4$ (5 ml). A colorimetric tube was filled with 0.5 ml of phenol (20 per cent w/v) and 100 µl of the haemolymph. The sugar solution was replaced with distilled water to create blanks. At 490 nm, the absorbance of the distinctive yellow-orange hue is measured in comparison to a blank. The formula for total carbohydrates is µg glucose/gm fresh weight.

Determination of total lipids

Total lipids were estimated by the methods of Knight *et al.* (1992) using phosphovanillin reagent prepared by dissolving 0.6 mg pure vanillin in 10 ml ethanol and completed to 100 ml with distilled water. The sample (250 ml) was added to 5 ml concentrated sulfuric acid and placed in a test tube and heated for ten minutes in a boiling water bath. The digest was added to the phosphovanillin reagent (6 ml) once it had cooled to room temperature. The produced colour was measured at 525 nm against the reagent blank after 45 min. The optical density was measured in mg lipids/ml haemolymph and compared to a reference standard.

Data analysis

Each experiment was replicated 5 times, and the outcomes of biochemical analyses were combined from the three determinations. The data were collected, organised, and analysed statistically with the SPSS software program. The importance of the main effects was assessed using ONE-WAY ANOVA. The importance of different treatments was assessed using the Range test ($p \leq 0.05$)

RESULTS

Phenoloxidase (PO) activity

Data shown in Table 1 showed that the infestation caused by the *B. bassiana* induced changes in phenoloxidase activity for all the experimental doses. At lower doses, the PO activity was found to be low, but at higher dose treatment groups, the enzyme activity was estimated to be elevated (Table 1 and Figure 1).

Table 1. Phenol oxidase activity in relation to dose of infestation with *B. bassiana* spores

No. of Spores/ ml	Haemolymph pooled Volume (µl)	Phenol Oxidase Activity (48 hrs Post Infestation)				ANOVA
		G1	G2	G3	G4	
Control	**100**	**0.45±0.52**	**0.45±0.52**	**0.45±0.52**	**0.45±0.52**	**F=0.0138 Df=3 (p<0.05)**
1 X10^2	100	0.38±0.21	0.32±0.08	0.29±0.07	0.31±0.11	
1 X10^3	100	0.22±0.17	0.24±0.20	0.21±0.08	0.35±0.23	
1 X10^4	100	0.44±0.22	0.39±0.41	0.41±0.12	0.48±0.05	
1 X10^5	100	0.85±0.07	0.74±0.04	0.82±0.14	0.89±0.21	
1 X10^6	100	1.24±0.22	1.21±0.36	1.29±0.47	1.31±0.26	
1 X10^7	100	1.88±0.44	1.91±0.38	1.82±0.45	1.90±0.37	
1 X10^8	100	2.42±0.27	2.36±0.37	2.47±0.17	2.56±0.24	

G1, G2, G3, G4 = Groups of fall armyworm from Purnia, Saharsa , Madhepura, Supaul respectively. All data are significant p<0.05.

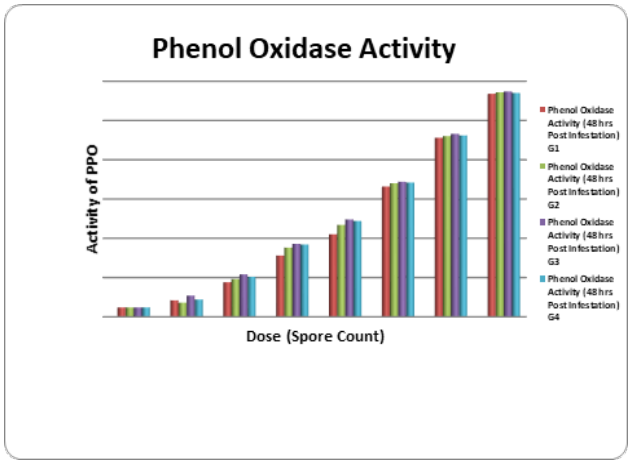


Figure 1. Phenol Oxidase activity in relation to dose of infestation with *B. bassiana* spores.

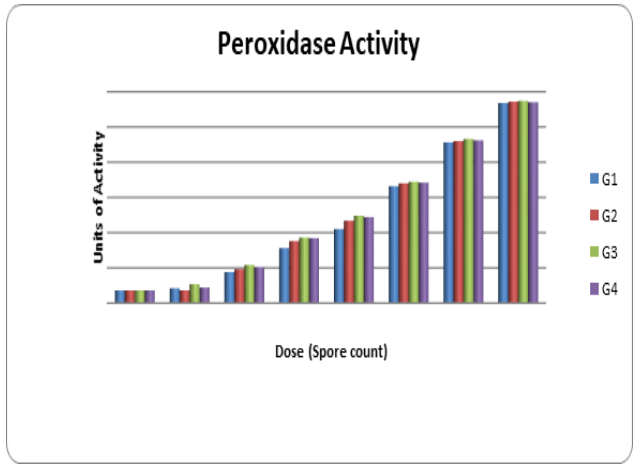


Figure 2. Peroxidase activity in relation to dose of infestation with *B. bassiana* spores.

Peroxidase (POD) activity

The findings indicated that substantial differences ($p \leq 0.05$) existed in Peroxidase activity for all seven treatment groups. The activity of peroxidase was revealed to have an increasing order from a lower dose of spore (10^2 spores/ml) to a higher dose of spore (10^8 spores/ml). The lowest (0.18±0.07) and highest (2.86±0.44) activity of Peroxidase (PO) was associated with spore counts of 10^2 and 10^8 spore/ml, respectively (Table 2 and Figure 2).

Total carbohydrates, proteins and lipids contents

Total carbohydrate, protein and lipid contents were altered independently with the dosage and modified according to the treatment method. There was a significant decrease in total carbohydrate and protein contents at all doses compared with control (Tables 3, 4 and Figures 3, 4). Reduction in total lipid concentration was noticed for lower spore counts (10^2, 10^3 and 10^4 spores/ml) and again showed an increase at spore concentration 10^5 and 10^6, and finally

Table 2. Peroxidase activity in relation to dose of infestation with *B. bassiana* spores

No. of Spores/ ml	Haemolymph pooled Volume (µl)	Peroxidase Activity (48 hrs Post Infestation)				ANOVA
		G1	G2	G3	G4	
Control	**100**	**0.18±0.01**	**0.18±0.01**	**0.18±0.01**	**0.18±0.01**	
1 X10^2	100	0.21±0.08	0.18±0.07	0.27±0.08	0.22±0.03	
1 X10^3	100	0.44±0.04	0.48±0.03	0.54±0.04	0.51±.07	
1 X10^4	100	0.78±0.07	0.88±0.08	0.93±0.05	0.92±0.42	**F=0.00963 Df=3 (p<0.05)**
1 X10^5	100	1.05±0.22	1.17±0.32	1.24±0.26	1.22±.54	
1 X10^6	100	1.66±0.27	1.70±0.61	1.72±0.31	1.71±0.44	
1 X10^7	100	2.28±0.34	2.30±0.31	2.33±0.43	2.31±0.38	
1 X10^8	100	2.84±0.26	2.86±0.44	2.87±0.51	2.85±0.22	

G1, G2, G3, G4 = Groups of fall armyworm from Purnia, Saharsa, Madhepura, Supaul respectively. All data are significant p<0.05).

Table 3. Total carbohydrate in relation to dose of infestation with *B. bassiana* spores

No. of Spores/ml	Haemolymph pooled Volume (µl)	Carbohydrate concentration (48 hrs Post Infestation)				ANOVA
		G1	G2	G3	G4	
Control	**100**	**1.76±0.22**	**1.76±0.22**	**1.76±0.22**	**1.76±0.22**	
1 X10^2	100	1.62±0.11	1.55±0.25	1.60±0.21	1.58±0.28	
1 X10^3	100	1.44±0.14	1.48±0.33	1.51±0.24	1.41±0.22	
1 X10^4	100	1.08±0.13	0.97±0.42	1.12±0.36	1.18±0.51	**F =0.01853 Df= 3 (p<0.05)**
1 X10^5	100	0.88±0.42	0.81±0.81	0.87±0.43	0.83±0.54	
1 X10^6	100	0.62±0.33	0.67±0.47	0.65±0.28	0.70±0.31	
1 X10^7	100	0.54±0.32	0.51±0.24	0.55±0.43	0.59±0.33	
1 X10^8	100	0.38±0.22	0.31±0.44	0.41±0.38	0.44±0.29	

G1, G2, G3, G4 = Groups of fall armyworm from Purnia, Saharsa, Madhepura, Supaul respectively. All data are significant p<0.05.

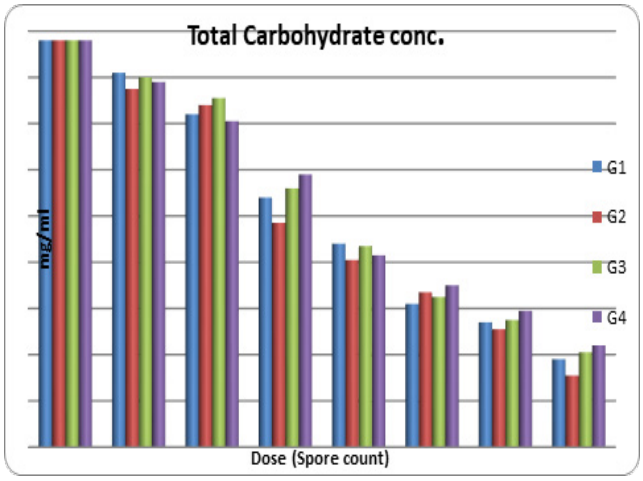


Figure 3. Total carbohydrate in relation to dose of infestation with *B. bassiana* spores.

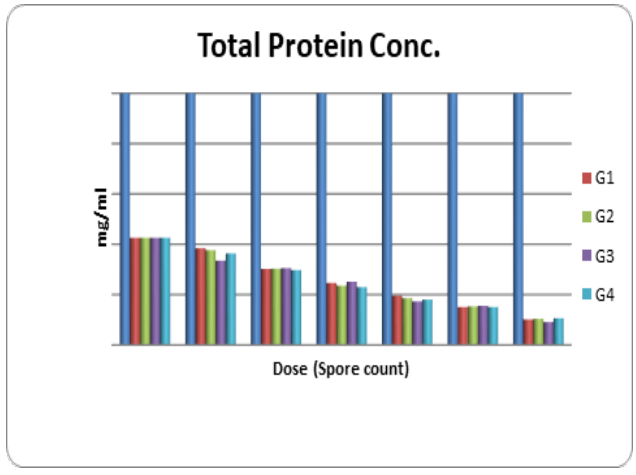


Figure 4. Total Protein in relation to dose of infestation with *B. bassiana* spores.

Table 4. Total protein in relation to dose of infestation with *B. bassiana* spores

No. of Spores/ ml	Haemolymph pooled Volume (µl)	Protein concentration (48 hrs Post Infestation)				ANOVA
		G1	G2	G3	G4	
Control	**100**	**42.55±0.34**	**42.55±0.34**	**42.55±0.34**	**42.55±0.34**	
1 X10^2	100	38.42±0.28	37.61±0.35	33.50±0.41	36.38±0.28	
1 X10^3	100	30.24±0.36	30.31±0.44	30.52±0.52	29.72±0.36	
1 X10^4	100	24.66±0.31	23.52±0.38	25.08±0.22	22.95±0.44	**F=0.00904 Df =3 (p<0.05)**
1 X10^5	100	19.51±0.33	18.57±0.41	17.25±1.21	18.04±0.32	
1 X10^6	100	15.08±0.33	15.31±0.20	15.57±0.57	15.04±0.33	
1 X10^7	100	10.12±0.18	10.33±0.38	09.08±0.62	10.55±0.44	
1 X10^8	100	8.51±0.38	8.86±0.67	8.28±0.38	8.05±0.52	

G1, G2, G3, G4 = Groups of fall armyworm from Purnia, Saharsa, Madhepura, Supaul respectively. All data are significant p<0.05.

the lipid concentration decreased at higher spore counts (10^7 and 10^8) treatment group after 48 hours of the experiment (Table 5 and Figure 5). This may be due to the secretion of steroidal intermediates at milder doses of spore count infections by the entomopathogenic fungi *B. bassiana;* at higher spore count, the decrease in lipid concentration may reflect the lipid utilisation by the pathogenic fungi along with their possible degradation.

Table 5. Total lipid in relation to dose of infestation with *B. bassiana* spores

No. of Spores/ ml	Haemolymph pooled Volume (µl)	Lipid concentration (48 hrs Post Infestation)				ANOVA
		G1	G2	G3	G4	
Control	**100**	**12.25±1.22**	**12.25±1.22**	**12.25±1.22**	**12.25±1.22**	**F =0.16381 Df=3 (P<0.05)**
1 X10^2	100	10.15±0.71	10.64±0.55	10.44±0.62	11.04±1.05	
1 X10^3	100	08.85±0.22	09.06±0.82	09.14±0.45	09.33±0.62	
1 X10^4	100	06.12±0.24	06.54±0.92	07.08±0.97	07.11±0.76	
1 X10^5	100	08.43±0.63	08.57±0.65	08.66±0.21	08.85±0.46	
1 X10^6	100	10.53±0.68	11.37±0.55	11.23±1.02	11.21±0.88	
1 X10^7	100	07.32±0.28	08.74±0.55	09.42±0.38	09.25±0.94	
1 X10^8	100	05.34±1.14	05.95±0.98	05.74±1.36	05.62±0.84	

G1, G2, G3, G4 = Groups of fall armyworm from Purnia, Saharsa, Madhepura, Supaul respectively. All data are significant p<0.05.

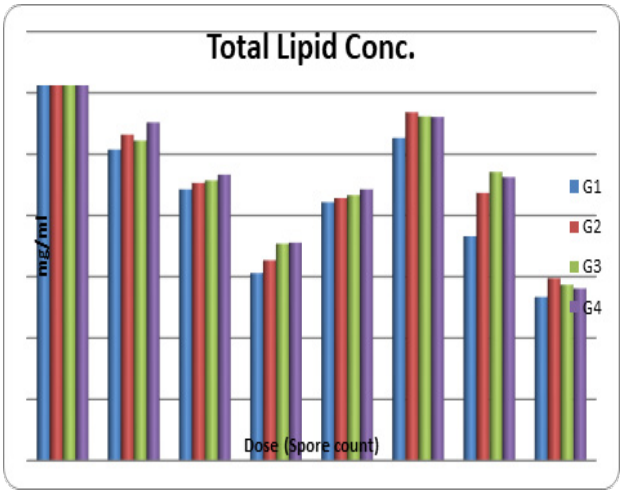


Figure 5. Total lipid in relation to dose of infestation with *B. bassiana* spores.

DISCUSSION

The above results revealed that the fungi affect the adult fall armyworm in a dose-dependent manner, in agreement with Barve *et al*., (2025) confirm these results. The findings were similar to the work of Arthurs and Thomas (2001), noted the host changes of *S. gregaria* locusts infected with *M. anisopliae* increased movements within 72 hours of infection. This conclusion is in agreement with (Moore, 2002), who noted that infection by pathogens imposes significant fitness costs on hosts, reducing survival and the rate of reproductive output. Coop and Kyriazakis (2001) reported that the ability of the host to fight and withstand infection depends on its biochemical stability, specifically of those involved in host immune defence mechanisms. This is in agreement with previous studies that have demonstrated that starvation of the host increases parasite virulence (Brown *et al.*, 2000). The findings of the present study regarding Phenol Oxidase and Peroxidase activities were inconsistent across various treatment methods and dosages, that increases linearly with the spore concentration used for infestation of different experimental groups. This result coincided with the finding of Trudeau *et al.* (2001), reported invasion of the insect body and haemolymph occurs once the fungus has passed through the cuticle of the external insect skeleton. Conidia connect to the cuticle of an appropriate host and germinate, starting a

series of recognition and enzyme activation processes in both the host and the fungal parasite. The (PO) and other cascade enzymes are activated as a result of the defensive reactions to fungal infection. This finding is in accordance (Hagstrum, 1983) noted the increase in Phenol Oxidase (PO) activity may be beneficial to *H. hebetor*, as increased levels of PO may help suppress microbial infection during the time interval. Entomopathogenic fungal infection may result in declining haemolymph protein and PO titers over the course of the infection until death of the host insect pest (Gillespie *et al.,* 2000; Mullen & Goldsworthy, 2006), whereas *Beauveria* infection increases active PO levels in *Melanoplus sanguinipes* (Gillespie & Khachatourians, 1992). In addition, Silva *et al.* (2000) demonstrated that fungal infection suppresses insect phenoloxidase activity.

This finding is in agreement with (Gillespie *et al.,* 2000) observed reduction in total protein content of the adult haemolymph of *S. gregaria* during the course of infection with *M. anisopliae*. The loss of soluble proteins from the host's haemolymph during parasitism could result from the parasite secreting proteolytic enzymes into the insect's hemocoel, leading to the hydrolysis of the host's proteins. This finding agreed with that obtained by McKinstry and Steinaus (1970) who were able to separate electrophoretically septicaemic and fresh plasma of *G. mellonella* infected with *pseudomonas aeurginosa* and detected a reduction in the amount of protein and this agreement with (Highnam & Hill, 1969) who noted protein metabolism and excretion are all regulated hormonally and disturbance of the host's endocrine balance by the parasite could be responsible for reduced protein concentrations in the host haemolymph.

After 48 hours of infection with *B. bassiana* at all doses and treatments, the findings of the present study showed a decrease in total carbohydrate contents of infected hosts. These findings are in accordance with those of Rutherford and Webster (1978) who reported reduction in the individual carbohydrates in the haemolymph of infected locusts with nematodes. Lee *et al.* (2002) reported that carbohydrates provide the major source of energy and protein used for growth. The observed pattern in the insect's immune response relates to how it reacts to different doses of fungus. At low doses, the immune system isn't strongly activated, resulting in lower lipid levels. Medium doses are optimal, triggering a strong immune reaction that requires significant lipid mobilisation, thus increasing lipid concentration. At high doses, the fungus overwhelms the host, leading to cytotoxic effects that hinder the immune response and cause quicker death, resulting in lower lipid levels. This non-linear relationship can be understood as follows: low doses do not challenge the immune system, medium doses prompt a robust response with increased lipids, and high doses compromise the host's defenses, depleting available lipids for the fungus that slightly differs from the results of Hawlitzky and Boulay (1986) reported significant declines in lipids of parasitised larvae *Anagasta kuehniella* by *Phanerotoma flavitestacea,* are a normal feature with the general scope of endoparasite action on host chemical composition. It was concluded from these findings that decreases in total carbohydrates and lipid contents lead to reduce the flighting capability of the host against entomopathogenic fungi. This conclusion is in agreement with Seyoum *et al.* (1994), who reported that adults of *S. gregaria* infected with *M. anisopliae* had reduced flight capability. The parasite's depletion of metabolites may result in physiological abnormalities in the host, including altered enzyme activity and decreased levels of protein, carbohydrates, and lipids in the hemolymph.

Therefore, Entomopathogenic fungus is one of the biological control agents that serves as a useful alternative for pest management and control instead of harmful chemicals (Aktar *et al.*, 2009; Fancelli *et al.*, 2013; Oluwadara *et al.*, 2023). *B. bassiana* is found to be effective in altering the physiological parameters of the fall armyworm (*S. frugiperda*). The infestation of B. bassiana within the insect results in the secretion of toxins such as beauvericin, bassianin, bassianolide, tenellin, cyclosporine and oxalic acid (Idrees *et al.*, 2023; Dubovskiy, 2022). These metabolites alter the common metabolism of the fall armyworm, resulting in deviation from normal parameters. The enzymatic activities such as phenol oxidase, peroxidase, and amount of total carbohydrates, proteins and lipids show deviation from their routine profile (Keswani *et al.*, 2013; Capinera, 2017).

These altered biochemical parameters lead to overall mortality, as it is triggered by other associated factors (Desneux *et al.*, 2007; Miao *et al.*, 2014). This study highlights the potential of the entomopathogenic fungus *B. bassiana* as an eco-friendly biological control agent

against the invasive fall armyworm, a major pest of maize. The findings demonstrate that fungal infection alters key biochemical parameters, leading to physiological stress and mortality in the pest, thereby supporting the development of sustainable and environmentally safe pest management strategies.

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AUTHOR CONTRIBUTION

BBM conceptualized the study. NK collected resources. BBM supervised the study. NK wrote the manuscript. BBM reviewed and edited the manuscript. Both authors read and approved the final manuscript for publication.