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RESEARCH ARTICLE

Bio-Efficacy of *Fusarium humuli* and *Fusarium incarnatum* (Hypocreales: Nectriaceae) Against Larvae of *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) Under Controlled Conditions

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ABSTRACT

Spodoptera frugiperda has impaired the productivity of staple crops in Tanzania since it was first reported in 2017. The overutilization of synthetic insecticides as an immediate remedy has led to new ecological problems along effects on public health. Using entomopathogenic fungi (EPF) is perceived as a safer way, and therefore, *Fusarium incarnatum* (Vw3) and *Fusarium humuli* (Vw5) from the SUA germplasm collection were tested against *S. frugiperda* larvae at levelled concentrations; C1, C2 and C3 (10^9,10^8 and 10^7 conidia ml^{-1}) alongside 0.1% Triton X-100 and Banophos 720 EC (20 ml/20 L) as negative (C-) and positive (C+) controls, respectively. The findings showed C+ inflicted the highest death rates (84% and 97% for Vw3 and Vw5, respectively), followed by C1 (48.8% and 55.5% for Vw3 and Vw5, respectively) and C2 (22.2%, 28.8% for Vw3 and Vw5, respectively). Moreover, C3 inflicted mortalities by 11.1% and 12.2% for Vw3 and Vw5 respectively, while C- inflicted mortalities by 7.7% and 1.1% for Vw3 and Vw5, respectively. Significant differences were observed in concentrations and ages of the insects. However, more studies are recommended to validate their safety and compatibility with other IPM components prior to qualifying the EPF for the control of *S. frugiperda*.

Keywords: Entomopathogenic fungi, biological control, *Fusarium incarnatum*, *Fusarium humuli*, *Spodoptera frugiperda*, *Zea mays*.

INTRODUCTION

Spodoptera frugiperda J.E smith, a moth under the order Lepidoptera and family Noctuidae, is a recent global worry insect from the time when it was first reported in tropical and subtropical regions of America and later in Africa in 2016 (Cock et al., 2017). The insect pest affects staple crops, which are directly linked to numerous individuals in several countries. Maize, sorghum, rice, cowpea, soybeans, sugarcane, groundnuts, round potato, cotton, papaya, Napier grass, grape, and orange and various kinds of ornamental and vegetable crops are some examples of hosts for the pest (Firake and Behere, 2020).

The larvae are in the most injurious stage as they consume foliage and kernels leading to reduced yield quality and quantity (Sisay et al., 2019). In Africa, the pest is reported to diminish yearly maize production by 21% to 53% in the absence of management measures, resulting in economic losses ranging from US $ 2481 to US $ 6187 million (Day et al., 2017). Reproducing at high rates, quick and distant dispersion, polyphagy, and existence for the entire year, has largely encouraged the utilization of synthetic insecticides as a control strategy (Bajracharya et al., 2019). However, conventional synthetic insecticides require routine applications for successful control programs, yet they are costly. Therefore, as a result, it becomes difficult for smallholders to purchase them during outbreaks (Kiva et al., 2022). Likewise, injudicious use of conventional pesticides has been linked to destroyed fauna, pest resistance, and resurgence (CABI, 2019). Reports indicate resistance in more than 500 species of arthropods to the common pesticides, and the situation worsens with time (Sinha et al., 2016).

Adherence to the planting calendars (Babendreier et al., 2020), tilling to expose the pupae to harsh environments, and use of pheromone-equipped traps and intercropping patterns have been recommended to curb moth populations along with boosting the natural enemies' populations (Djidjonri et al., 2021; Li et al., 2021). Others, like push-pull and the use of host plant resisting varieties (HPR), have also proved to reduce *S. frugiperda* infestations in fields. Prasanna et al. (2018) reported 86% reduced infestations in fields equipped with the technology compared to the non-treated ones. However, HPR is still mostly practiced in developed countries, while the adoption rate is still low in African countries. As a result, there are no scientifically proven *S. frugiperda*-resistant maize cultivars despite progress (CABI, 2019).

The raised public and environmental health awareness has recently made the natural enemies, particularly microbes, be considered the promising control methods in developing countries (Kiva et al., 2022). Since they occur naturally in fields, are easy to multiply, safe, and cheap (Sinha et al., 2016), EPF are now preferred over bacteria and viruses for pest control programmes (Hadj Taieb et al., 2020). They create metabolites that impair the immune systems and eventually killing the pests (Idrees et al., 2021). Some EPFs form mycorrhizal connections with plants which improve plants' nutrients absorption ability besides tolerance to adverse conditions (Moonjely et al., 2016). For instance, *Beauveria bassiana* and *Metarhizium anisopliae* have been recognized as colonizers of cassava plants and therefore enhancing protection against soil pests (Greenfield et al., 2016).

Though more than 750 species are reported as potential EPF (Norjmaa et al., 2019), *Beauveria* and *Metarhizium* remained mostly researched genera leaving many others unattended. Chandler (2017) states that, three percent of all World EPF-based products have been commercialized in Africa. Shortages of suppliers, few investments in research, and few registered products hinder the utilization of EPF in African countries (Nordey et al., 2021). As a result, only one *Aspergillus*-based mycopesticide (*Vuruga biocide*), particularly for controlling *S. frugiperda* and *Tuta absoluta* is available in the Tanzanian markets. The situation necessitates other exploratory studies and testing of other fungi species which are potentially entomopathogenic to crop pests. This study aimed at evaluating the bio-efficacy of *F. incarnatum* and *F. humuli* obtained from Tanzania ecologies against larvae of *S. frugiperda* to support efforts of identifying more virulent species besides lowering the likelihood of pest resistance and resurgence in fields.

MATERIALS AND METHODS

Experimental site

This study was conducted between February 2022 and October 2022 in the Mycology laboratory and screen houses of the Department of Crop Science and Horticulture (DCSH) located at Sokoine University of Agriculture (SUA), Tanzania (6.8520°S and 37.6576°E). For the optimum growth of the isolates, the incubation room was maintained at photoperiods of 12:12 light-dark, temperatures of 28±2°C, and relative humidity of 75%.

Establishment of plant materials

Maize, *Zea mays* seedlings (one plant per pot) were grown for both oviposition and feeding the *S. frugiperda* larvae. The plants were established in plastic pots of 1 L placed on iron meshed tables heightened at 1 m above the ground under the plastic film roofed screen house at SUA's Horticulture unit, Tanzania following procedures by Munywoki et al. (2022). The screen house had cemented floor with insect-proof nets (0.6 mm) at the sides to prevent the entrance of untargeted insects.

Establishment of S. frugiperda colonies

The fourth instars larvae of *S. frugiperda* were collected in unsprayed maize fields at the SUA crop museum located in Morogoro, Tanzania (S $06^0$50'53.136″ E $37^0$39'12.000″). They were kept in plastic vials (2.7 cm width and 11.5 cm height) capped with sterile cotton wool to the SUA horticulture unit's screen house. Larvae were transferred into aerated, plastic dishes (10x25x25 cm) initially sterilized with 70% alcohol and provided with fresh maize leaves that were changed in 24 hours, along with sterilized sand for pupation. The pupa in non-capped containers was conveyed into aerated rearing cages (60×45×45 cm) placed on similar iron meshed tables. The emerging adults were placed into separate rearing cages at a ratio of 5:5 (Male: Female) respectively, with potted maize plants for oviposition and a clean petri dish holding a sterile, 10% soaked cotton wool for feeding the adults, procedures by Thaochan and Sausa-Ard (2017). The egg batches on potted plants were collected though slicing the leaves and were placed in aerated, sterilized plastic dishes of 10x25x25 cm at 28°C until the emerging of larvae, procedures as per Prasanna et al. (2018)

Isolates acquisition and pathogenicity tests

The pure cultures of *F. humuli* and *F. incarnatum* were obtained from SUA individual germplasm collections and were chosen for their speedy growth and abundantly sporulation on oatmeal agar, OTA with cetyltrimethylammonium bromide, CTAB. The pure cultures were multiplied on OTA (basal medium) and cetyltrimethylammonium bromide, CTAB (selective media), 50 g/L oat, 0.6 g/L CTAB, 15 g/L agar, 0.5 g/L chloramphenicol after being autoclaved at 121°C for 15 min as per Ramírez-Rodríguez et al. (2016). Plates were incubated for 14 days in a 12:12 light-dark photoperiod, 28±2^{0}C and 75% RH until strains grew in full, procedures as per Ávila-Hernández et al. (2020).

Prior to bioassays, pathogenicity tests were carried out by immersing ten younger larvae of *S. frugiperda* for a minute in a sterilized glass bottle (5×10 cm) holding a millilitre of 10^9 spores/ml of each fungal strain as per Thaochan and Sausa-Ard (2017). The concentration of the validating suspensions was generated with the aid of a light microscope (Leica CME Buffalo, NY 1349522X USA) and adjusted with a hemocytometer (Neubauer chamber, Germany) after removing mycelial fragments by filtering through three layered sterile cheese cloths, the procedure by Boni et al. (2021). Larvae were transferred to 70% alcohol sterilized plastic dishes (17x12x8 cm) covered with a thin mesh of 0.1 mm affixed with rubber bands. Larvae were supplied with rinsed, fresh, and tender maize leaves, which were changed after 24 hours. The tests were repeated three times and observations on larvae mortalities continued for ten days post-infection (DPI). Following the pathogenicity tests, which showed the ability of *F. humuli* and *F. incarnatum* to kill 80% and 70% of *S. frugiperda* larvae, respectively, within a range of 2 to 10 DPI, the strains were qualified for bioassay procedures.

Bioassays formulations and applications

Spores were gently scraped from the 14 days aged cultures of both species by suspending them in 10 ml of sterile distilled water simultaneously with 0.1% Triton X-100 for creating a stock solution, procedures as per Zekeya et al. (2019). The concentrations of stock suspensions were estimated using procedures by Boni et al. (2021), and the initial concentration was revealed as 1.0×10^9 conidia/ml and 1.0×10^{10} conidia/ml for *F. humuli* and *F. incarnatum* respectively. The preceding was directly taken as among the working concentrations, while the later was adjusted accordingly to 1.0×10^9 conidia/ml and saved the same. The other two working concentrations, 1.0×10^8 and 1.0×10^7 conidia/ml of each species were prepared by adding sterile distilled water to a specified volume of stock solution at 25±1^{0}C as per Zekeya et al. (2019).

To each cohort of three grouped larvae stages; (instars one and two), (instars three and four) and (instars five and six), ten representatives were immersed in each working concentration (10^9, 10^8 and 10^7 conidia/ml) of each fungal strain separately for 20 seconds. The larvae were then transferred into aerated, sterilized plastic dishes (10x25x25 cm) and supplied with rinsed, fresh leaves of maize as per Cruz-Avalos et al. (2019), while maintaining 26±1°C and 75±2% RH. Factorial experiments under CRD with three factors i.e., fungal conidial concentrations, fungal isolate, and larval stage/age were used to compare the efficacy of collected indigenous fungi, *F. humuli* and *F. incarnatum* against larvae of *S. frugiperda*. Experiments were replicated thrice with 0.1% Triton X-100 and

Banophos 720 EC (20 ml/20 L) as negative and positive controls, respectively.

Assessment

The dead *S. frugiperda* larvae were counted after a lapse of 24 hours through 10 days after administering the three different concentrated conidial suspensions of each fungus besides negative and positive controls. The dead larvae were surface sterilized with 1% Sodium hypochlorite solution, NaOCl and washed with distilled water before being placed in Petri dishes (60x10 mm) with lined and wet blotter paper for facilitating mycelial growth. The petri dishes were sealed and incubated at 28±2^{0}C and 75% RH as per Thaochan and Sausa-Ard (2017). On the fourth day of incubation, cadavers were checked for mycosis signs with a dissecting microscope (Leica Zoom 2000 No. Z45V). Emerging mycelia were harvested using a sterile inoculating needle and transplanted onto plates made up of OTA+CTAB for confirmation procedures.

Statistical analysis

Cumulative mortality data from bioassays for 10 DPI were cleaned, arranged, and logarithmic transformed to attain a normal distribution before being subjected to the analysis of variance (ANOVA). Mean separation was achieved using Tukey's HSD test at 0.05. R' statistical package version 4.2.2 (R Development Core Team, 2012) was used to determine the effects of various concentration levels of fungal bioassays, isolate type, and ages towards deaths of *S. frugiperda* larvae compared to controls.

RESULTS

Bio-efficacy of F. humuli and F. incarnatum against S. frugiperda larvae

The laboratory findings have shown that the three spore concentrations of *F. humuli* and *F. incarnatum* were toxic to *S. frugiperda* larvae (Table 1) although the virulence differed gradually according to the administered concentration. Within 24 hours post-infection, no mortalities were recorded in fungal treated larvae, while positive controls were only settings with earlier reports of deaths (Figure 1). Fungal bioassays started showing effects on larvae after 48 hours, and before dying, the larvae were observed to lose appetite and movements with addition of shedding their cuticles (Figure 2). The colony characteristics and the macroconidia from the cadavers revealed similarity to the ones used during infecting process, and generally, mortalities were increased gradually with the exposure period through 10 DPI.

Table 1. Percentage mortalities of *S. frugiperda* larvae by various treatments of Vw3 and Vw5 along positive and negative controls under laboratory conditions

Isolate	Concentration	% Mortality
Vw3	C-	7.777778
Vw3	C+	84.44444
Vw3	C1	48.88889
Vw3	C2	22.22222
Vw3	C3	11.11111
Vw5	C-	1.111111
Vw5	C+	97.77778
Vw5	C1	55.55556
Vw5	C2	28.88889
Vw5	C3	12.22222

C-=negative control, C+=positive control (Banophos 720 EC), C1=fungal concentration of 1.0×10^9 conidia/ml, C2=fungal concentration of 1.0×10^8 conidia/ml, C3=fungal concentration of 1.0×10^7 conidia/ml.

The effect of diverse concentrations of F. humuli and F. incarnatum on mortalities of *S. frugiperda* larvae

Regarding the isolate used, the findings shown considerable larval deaths in bioassays with the highest concentrations as opposed to declining trends in lower concentrated ones (Table 1). Yet the cumulative larval mortalities showed that C+ was leading (84% and 97% for Vw3 and Vw5 respectively) followed by fungal concentrations, C1 (48.8% and 55.5% for Vw3 and Vw5 respectively) besides C2 by 22.2% and 28.8% for Vw3 and Vw5 respectively (Figure 3). Moreover, C3 inflicted mortalities by 11.1% and 12.2% for Vw3 and Vw5 respectively. However, C- caused very low mortalities (7.7% and 1.1% for Vw3 and Vw5 respectively).

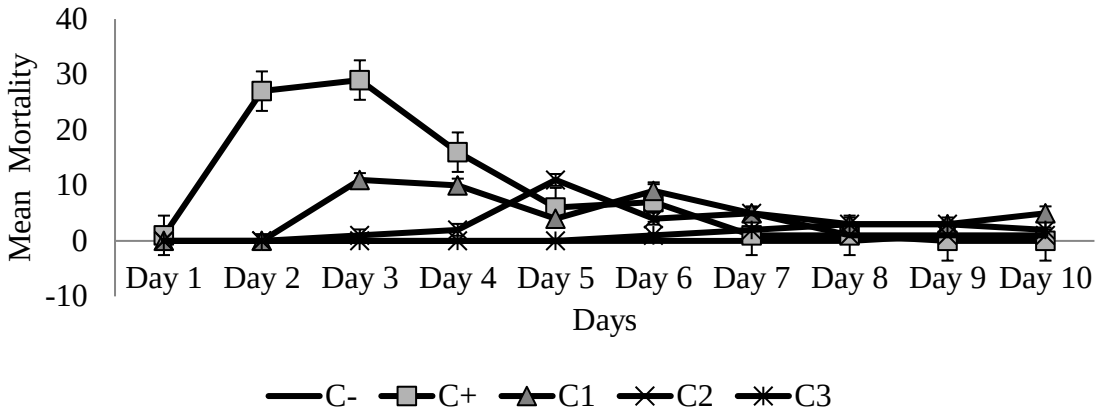

Figure 1. Daily mortality of *S. frugiperda* larvae inflicted by various fungal concentrations along positive and negative controls. C-=negative control, C+=positive control, C1=fungal concentration of 1.0×10^{9} conidia/ml, C2=fungal concentration of 1.0×10^{8} conidia/ml, C3=fungal concentration of 1.0×10^{7} conidia/ml.

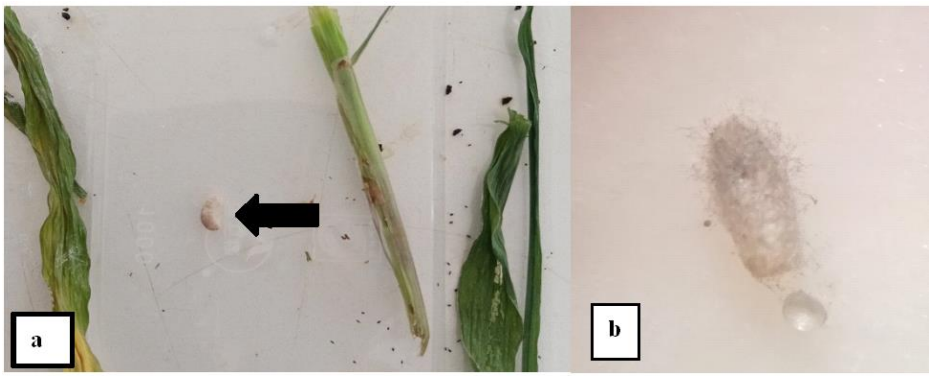

Figure 2. (a) *S. frugiperda* larvae shedding its cuticle as a strategy of escaping fungal infection (b) typical mycosis observed externally on the *S. frugiperda* cadaver due to fungal infection after the cadaver was incubated for 4 days at 28 ± 2^{0}C and 75% RH as per Thaochan and Sausa-Ard (2017).

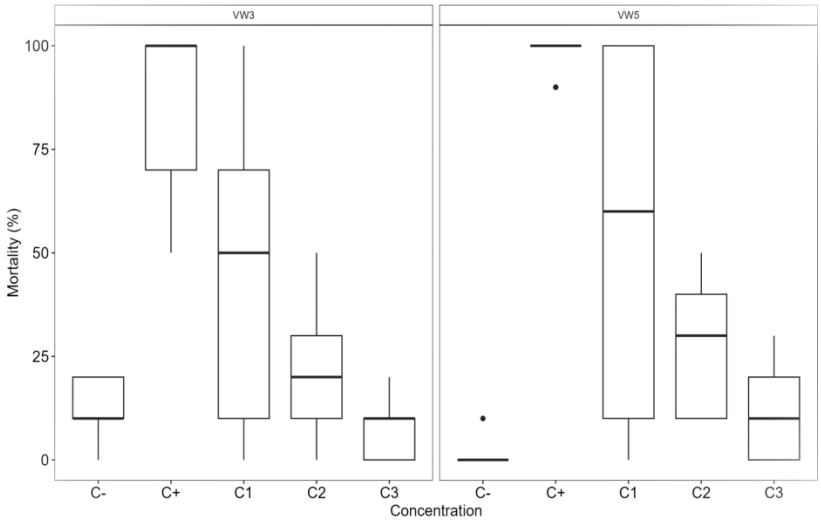

Figure 3. *S. frugiperda* larvae mortalities inflicted by various fungal concentrations along positive and negative controls. C-=negative control, C+=positive control, C1=fungal concentration of 1.0×10^{9} conidia/ml, C2=fungal concentration of 1.0×10^{8} conidia/ml, C3=fungal concentration of 1.0×10^{7} conidia/ml.

The concentration in its entity has indicated highly significant effects on larvae mortalities (p<0.0001), while the species of fungus had no significant influence on the larvae mortalities (p=0.64) (Table 2). The interactions between the used fungal species and the concentrations indicated significant effects on larvae mortalities (p=0.0001). Moreover, the Post Hoc analyses using Student-Newman-Keuls tests (SE=0.18, df=60) indicated higher mortality rates in higher concentrated bioassays than lower ones. Interestingly, the comparisons between C1 and C2, as well as C- and C3 showed no significant effects on larvae mortalities.

Table 2. Mortalities of *S. frugiperda* larvae inflicted by two fungal species in three levelled spore concentrations of *F. humuli* and *F. incarnatum* and various instar ages under laboratory conditions

Source of variation	df	Sum Sq	Mean Sq	F value	p value
Age of Insect (AG)	2	31.37	15.68	24.72	<0.0001*
Isolate (Iso)	1	0.13	0.13	0.21	0.64ns
Concentration (Conc)	4	129.25	32.31	50.91	<0.0001*
AG:Iso	2	0.76	0.38	0.6	0.55ns
AG:Conc	8	37.33	4.66	7.35	<0.0001*
Iso:Conc	4	16.89	4.22	6.65	0.0001*
AG:Iso:Conc	8	1.77	0.22	0.35	0.94ns

* Indicates a significant difference, ns=non-significant difference.

The relationship between mortality and the age of S. frugiperda larvae

The results showed a significant effect (p<0.0001) of fungal bioassays towards various age groups of the larvae (Table 2). The lower instar stages of *S. frugiperda* were more vulnerable towards different levels of fungal concentrations besides positive control. The vulnerability of the individuals became lesser as the larvae became older towards the pupa stage (Figure 4). Additionally, Tukey's multiple comparisons of means at a 95% family-wise confidence level showed a significant difference in larvae mortalities inflicted by the isolates between S3 and S1 (p=0.0033) (Table 3) with a non-significant difference between S2 and S1 (p=0.46). Moreover, a marginally significant difference was found between S3 and S2 (p=0.08).

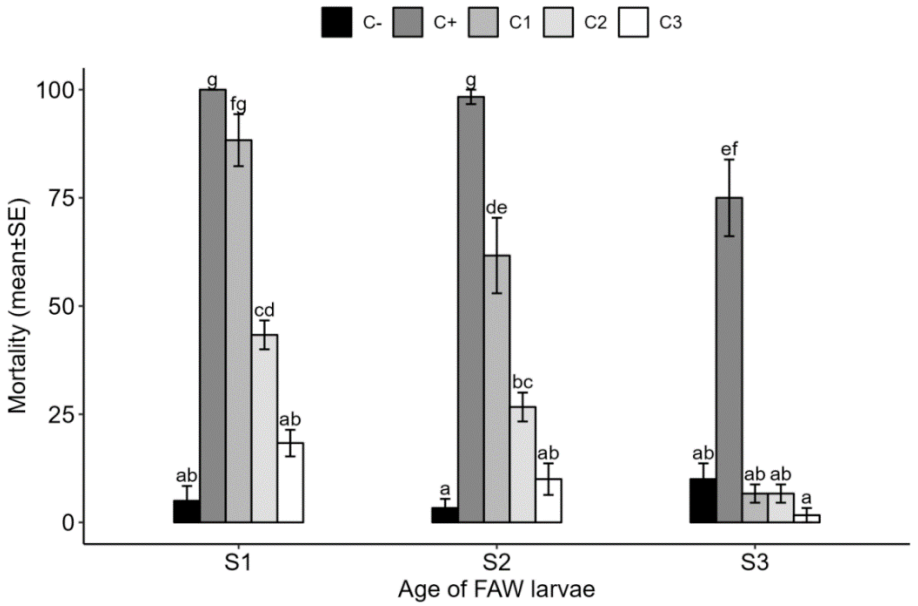

Figure 4. Mortalities of *S. frugiperda* larvae across various age groups. S1=instars 1 and 2, S2=instars 3 and 4, S3=instars 5 and 6. Means followed by similar letters are not significantly different at p<0.005.

Table 3. The Tukey multiple comparisons of means mortalities for grouped larval stages of *S. frugiperda* at a 95% family-wise confidence level

Age	diff	lwr	upr	p
S2-S1	-11	-33.01	11.01	0.46ns
S3-S1	-31	-53.01	-8.98	0.0033*
S3-S2	-20	-42.01	2.01	0.08ns

* Indicates a significant difference, ns=non-significant difference.

Comparative virulence of the isolates

The findings of this study showed no clear evidence to reject the null hypothesis, as there was no significant difference (p=0.64) between the fungal treatments (Table 2). The two fungal species, *F. incarnatum* and *F. humuli* had more or less the same median total mortalities (Figure 5) and therefore nothing concrete was found as proof that one isolate was more virulent compared to the other.

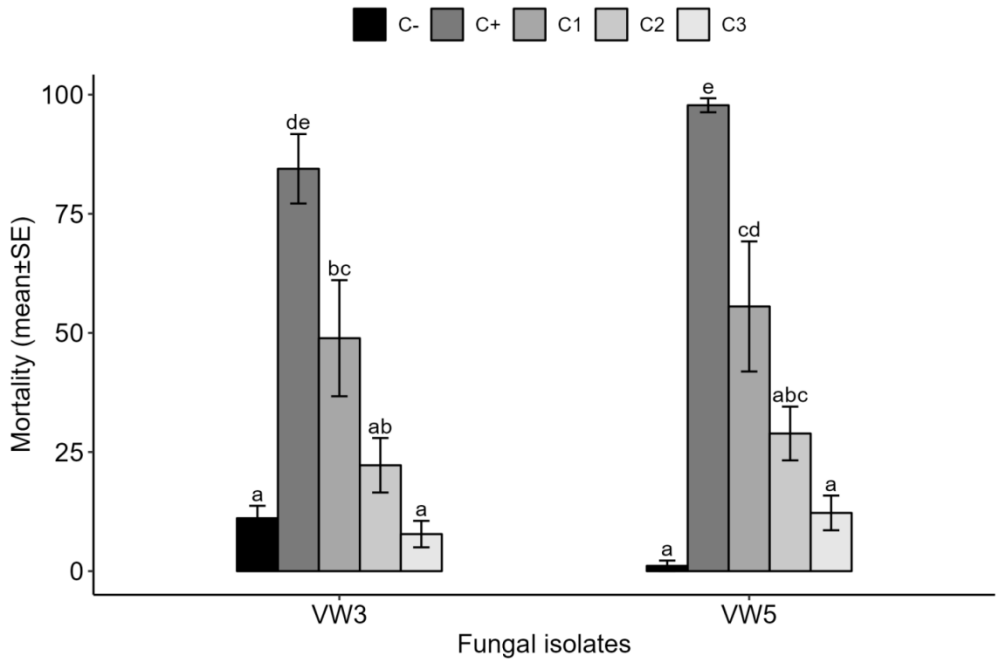

Figure 5. Mortalities of *S. frugiperda* larvae by two different fungal isolates, Vw3 and Vw5 under laboratory conditions. Vw3=*F. incarnatum* and Vw5=*F. humuli*. Means followed by similar letters are not significantly different at p<0.005.

DISCUSSION

The present study has shown higher cumulative mortalities of *S. frugiperda* larvae by highly concentrated bioassays compared to the slightest ones for both *F. incarnatum* and *F. humuli*. This observation is in agreement with the report by Al-Ani et al. (2018), who found that the topmost conidial concentration, 10^9 of *Beauveria bassiana* killed a significant number of *Tribolium confusum* adults relative to the follow-up lower concentrations. Highly concentrated suspensions offer plentiful chances for the insects' pests to come into contact with entomopathogenic fungi spores. It is widely known that EPF enters insects in various ways; through the cuticle, through natural openings as well as by being ingested by the insect (Litwin et al., 2020). Therefore, increasing the dosages has been evidenced to improve the performance of the EPF as they allow multiple avenues for host entry, causing epizootics and eventually killing the insects sooner compared to lower doses (Mnyone et al., 2011). Aligned with the previous statement, Asi et al. (2009) found that exposure of Aphids, *Aphis*

fabae to fungal spores for longer periods and at their higher spore concentrations resulted in increased mortalities to the pest. A similar observation was also put forward by Boni et al. (2021) and Zekeya et al. (2019) who deduced that the higher the conidial concentration of *Aspergillus spp* applied on *Aphis fabae* and tomato leaf miner, *Tuta absoluta* Meyrick respectively, the higher the mortality cases were reported.

The feeding behaviour and the biological development of *S. frugiperda* larvae were disrupted when EPF was applied to them. This observation agrees with Zekeya et al. (2019), who found that the EPF-treated *Tuta absoluta* larvae spent much time to pupate compared to shorter periods in negative controls. On the other hand, the conventional synthetic insecticide, Banophos 720 EC (20 ml/20 L) has shown quick knockdown of *S. frugiperda* larvae compared to EPF formulations and negative controls respectively. This is because they underwent thorough improvements which make them more effective and broad-spectrum (Mehinto et al., 2020).

Although larvae were killed slowly by EPF bioassays compared to synthetic insecticides, but they still showed their virulence against *S. frugiperda* larvae. Most of the time, the larvae typically died 48 hours after contracting the infection from EPF with higher spore concentrations. The tendency for killing grew even more slowly on other lower-concentrated suspensions. Several scholars support this observation; for instance, Sani et al. (2020) reported plugging appressoria into the host as a prerequisite for nourishment purposes made EPFs kill their host slowly. Furthermore, enzymes and other compounds like beauvericin, which are partly produced using the hosts' resources are also reported to equip EPF with the ability to disrupt the insects' regular functions with immune systems in particular and ultimately result in their deaths. A similar observation was also made by Mehinto et al. (2020) and Mnyone et al. (2011), who also found that the EPF, *B. bassiana* applied to legume pod borer, *Maruca vitrata* Fabricius (Lepidoptera: crambidae) and *Anopheles gambiae* respectively were gradually killed from the second day following applications as opposed to quicker actions by their positive controls' counterparts.

It was also observed that the instars' ages were differently affected by the EPF formulations. The lower growth stages of *S. frugiperda* were more vulnerable to dissimilar concentrations levels of *F. incarnatum* and *F. humuli* besides positive controls. At their higher stages of growth (instars 5 and 6), fewer mortality cases were reported compared to instars 1 and 2. This observation inferred the hypothesis put forward that the susceptibility of the instars depreciates with age. The previous studies reported similarly that the second instar cotton leafworm larvae, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) were killed at a rate of 98.67% by *Penicillium citrinum* (Herlinda et al., 2020). Another study by Ruiz-Nájera et al. (2013) reported 12.99% mortality to third-instar *S. frugiperda* larvae which seemed lower compared to the rates in second instars. At this juncture, it is looked that the higher larval growth stages achieved by *S. frugiperda* could be attributed to the development of some abilities to resist fungal infections. Bosa et al. (2004) speculated the same that the higher growth stages of S. frugiperda develop additional components at their integuments which make them resist fungal penetration. This result is also support of Kaleem Ullah et al. (2022), who reported about the development of some detoxifying enzymes in some insect pests which attribute them resistance to insecticides. Those few observations necessitate further studies on the abilities of higher instar stages of *S. frugiperda* to resist insecticides. However, moulting which was observed in this study is seen as an initiative taken by larvae to avoid infection. The finding is in agreement with that of Meekes (2001), who reported on the shedding of cuticles to aid inoculum losses and eventually reduction of the chances of infections. Moreover, the older larvae stages have seemed to be equipped with better immunological responses to conidia attachments than those in younger stages, Shahriari et al. (2021) report the same.

On the other hand, it is well known that *Fusarium* species are ubiquitous pathogens of crops in temperate, semitropical, and tropical zones. They seriously reduce crop output and cause financial losses by infecting fruits, vegetables, and cereals (Al-Rabia et al., 2021). *F. incarnatum*, a member of the *Fusarium incarnatum-equiseti* species complex (FIESC) is uniquely reported to pose threats to public health by producing secondary metabolites i.e., trichothecenes on cereals which lead to some skin infections i.e., keratitis (Wang et al., 2019). Additionally, *F. incarnatum* is associated with fruit rot in bell peppers (Ramdial et al., 2016) and in muskmelon (Wonglom & Sunpapao, 2020). On the other hand, *F. humuli* was reported to cause wilt disease in Chinese yam in Jiangxi, China (Li et al.,

2022). However, some reports are at odds with those observations, for instance, Park et al. (2023) conducted pathogenicity tests of various fungal species on beach vitex plants and found that the ones inoculated with *F. humuli* were symptomless which indicated the non-pathogenic attribute of the isolate to those plants and therefore regarded the fungus as potential endophytes. Moreover, *F. humuli* has been frequently isolated from *Musa nana*, *Ligustrum* lucidum, Cedrela spp, Vinca major and Osmanthus spp (Wang et al., 2022). In all mentioned plants the fungi were there as endophytes and probably the plants were benefiting due to this existence.

The situation accelerates discussions and further studies on the utilization of the members of this group as entomopathogens. Despite being mentioned several times as plant pathogens, some Fusarium species are potential in controlling insect pests of economic importance. Pelliza *et al.* (2011) listed 13 *Fusarium* species capable of killing insects under Coleoptera, Diptera, Hemiptera, Hymenoptera, and Lepidoptera. The similar secondary metabolites, i.e. trichothecenes (T-2) they employ to invade some plant hosts, are used to make insects sick and eventually cause their deaths. Potential Fusarium species are reported to impose notable mortalities to insects' pests with host specificity as an added attribute; however, there are few reported cases of the damage to host plants caused by the ones previously believed to cause only insects deaths (Pelliza et al., 2011). Nevertheless, with the gradual killing ability of EPF, it remains to be a cheap, resilient and safer *S. frugiperda* control strategy that can contribute to reducing crop damage by intervening in the activities and physiological qualities of insects such as feeding, oviposition, growth, and mating (Idrees et al., 2021). Moreover, the utilization of this technology has been endorsed as it can control even the pest that has developed resistance towards conventional synthetic insecticides (Mnyone et al., 2011).

CONCLUSION

This study's results show pesticide effects in *F. incarnatum* and *F. humuli* to larval stages of *S. frugiperda,* especially the younger ones, and hence can be used for the course. However, metabolite profiling along with a full understanding of how these fungi species are compatible with other IPM components, is inevitable. An understanding will help decide whether it should be used singly, along with conventional pesticides, or in rotation. Moreover, it has remained unclear if the insects would be affected by these fungi in field conditions and therefore with link to the previous discussion on mycotoxins production, it is not recommended to utilize the fungal species as BCA in real-World situations until the pending issues are resolved.

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DISCLOSURE STATEMENT

The author declares no competing interests

AUTHORS' CONTRIBUTIONS

EN and GR conceptualize the study, EN did the experiments collected data, analysed and interpreted them along drafting the manuscript. LC and GR reviewed the manuscript and added some inputs. The entire team of authors have read and approved the final draft of the manuscript.

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