J. Trop. Plant Pests Dis.
Vol. 26, No. 1, March 2026
Pages: 23–30

ISSN: 1411-7525
E-ISSN: 2461-0399
DOI : 10.23960/j.hptt.12623-30

RESEARCH PAPER

Fusarium keratoplasticum TKKS-1: A potential native entomopathogenic fungus to control Armyworm, *Spodoptera litura* Fabricus (Lepidoptera: Noctuidae), on mustard plants

Abdul Sahid, Ni'matuljannah Akhsan, & Fety Sundari

Manuscript received: 26 December 2024. Revision accepted: 3 May 2025. Available online: 26 November 2025.

ABSTRACT

The use of entomopathogen (insect pathogen) is one of the effective strategies for managing insect pests. This study aimed to evaluate the efficacy of the entomopathogenic fungus *Fusarium keratoplasticum* against *Spodoptera litura* larvae under laboratory conditions and to assess its potential in controlling infestations on mustard plants. The pathogenicity of the fungal isolate was tested against third-instar *S. litura* larvae at a concentration of 1×10^7 conidia/mL. Both fungal isolates caused 100% larval mortality, however, *F. keratoplasticum* acted more rapidly than *Beauveria bassiana,* reaching 100% mortality within 6 days, compared to 9 days for *B. bassiana*. The virulence of *F. keratoplasticum* was further evaluated using a Simple Completely Randomized Block Design (SCBD) consisting of five treatments with different conidial concentrations (1×10^6, 2×10^6, 4×10^6, 8×10^6, and 1×10^7 conidia/mL) and an untreated control. A commercial *B. bassiana formulation* (1×10^7 conidia/mL) served as a comparison. The application technique involved direct exposure of *S. litura* larvae to the fungal suspensions. The LC_{50} value of *F. keratoplasticum* was 2.74×10^6 conidial/mL, while the LT_{50} value at 1×10^7 conidia/mL was 2.96 days, significantly shorter than that of *B. bassiana* (LT_{50} = 3.63 days). Under semi-field conditions, *F. keratoplasticum* demonstrated superior effectiveness in controlling *S. litura* larvae on mustard plants, achieving complete mortality more rapidly than under laboratory conditions and outperforming *B. bassiana*. These findings indicate that *F. keratoplasticum* has strong potential to be developed as a biopesticide.

Keywords: Attack intensity, armyworm, biological control, pathogenicity, virulence

INTRODUCTION

Armyworm (*Spodoptera litura* Fab.) is a highly polyphagous pest known for its destructive impact on more than 40 plant families, including major field crops and vegetables (EFSA Panel on Plant Health (PLH) et al., 2019). In the Asia Pacific region, *S. litura* larvae are among the most damaging insect pests, capable of severe defoliation that results in substantial yield losses (Song et al., 2024). Pest-induced damage remains a persistent challenge in agriculture, and chemical insecticides are the most commonly employed control method due to their perceived effectiveness and practicality. However, the excessive use of chemical insecticides has led to serious concerns regarding pesticide residues on vegetables, posing risks to human health and causing adverse environmental effects. Consequently, there is a growing need for pest management strategies that are both effective and environmentally sustainable.

Entomopathogenic fungi (EPF), a group of soil-dwelling microorganisms, have emerged as promising eco-friendly agents for insect pest control. These fungi infect and kill their hosts, primarily insects and other arthropods, by penetrating the cuticle and colonizing internal tissues, making them valuable components of integrated pest management (IPM) systems. Unlike synthetic insecticides, EPF exert immediate lethal effects because of their biological infection process. Nevertheless, they offer several advantages: reduced risk of pest resistance, minimal non-target toxicity, and safety for humans and beneficial organisms (Bamisile et al., 2021).

Fusarium keratoplasticum, a member of the *Fusarium solani* species complex (FSSC), is typically known as a human and plant pathogen but has received limited attention for its potential as a biocontrol agent. Although its pathogenicity in immunocompromised hosts and keratitis cases has been well documented (Szalinski et al., 2021; Isobe et al., 2024), the entomopathogenic properties of *F. keratoplasticum* remain largely unexplored. Closely related *Fusarium* species, such as *F. oxysporum*, have demonstrated

Corresponding author:
Abdul Sahid (abdulsahid@faperta.unmul.ac.id)

Department of Agroecotechnology, Faculty of Agriculture, Mulawarman University. Jl. Paser Balengkong, Samarinda, Indonesia 75123

insecticidal capabilities through cuticle penetration and mycotoxin production (Abbas et al., 2020). Moreover, *F. keratoplasticum* exhibits ecological traits typical of entomopathogenic fungi, such as soil persistence and keratinolytic activity, which may facilitate insect infection (Short et al., 2011). The interactions between *Fusarium* species and agroecosystems, such as those involving glucosinolate-producing plants like mustard (*Brassica* spp.) used in biofumigation, further suggest potential for *F. keratoplasticum* to influence pest populations (Praneetha et al., 2025).

Recent evidence indicates that a native isolate, *Fusarium keratoplasticum* TKKS-1, obtained from decayed oil palm empty fruit bunches (OPEFB) in East Kalimantan, Indonesia, exhibits promising entomopathogenic potential. Laboratory assays have demonstrated its pathogenicity and virulence against *S. litura* larvae (Sahid & Kusumaningtyas, 2023). However, the use of *Fusarium* species as biocontrol agents remains limited due to concerns about phytopathogenicity and toxin production (Santos et al., 2020). Since mustard is a *Fusarium*-susceptible crop, it provides a relevant system to assess whether *F. keratoplasticum* TKKS-1 poses phytopathogenic risks under semi-field conditions.

Therefore, this study aimed to evaluate the effectiveness of the native entomopathogenic fungus *F. keratoplasticum* TKKS-1 in controlling *S. litura* larvae on mustard plants under semi-field conditions. A commercial EPF isolate, *Beauveria bassiana*, was included as a benchmark, as it is widely used as a microbial insecticide against various agricultural pests. Prior to the semi-field trials, the virulence of the *F. keratoplasticum* TKKS-1 isolate was reassessed under laboratory conditions against third-instar *S. litura* larvae to confirm its pathogenicity following one year of subculturing on PDA medium.

MATERIALS AND METHODS

Research Site. This research was conducted at the Laboratory of Plant Pest and Diseases, Faculty of Agriculture, Mulawarman University, Indonesia. The semi-field (greenhouse) experiment was performed in a cultivation area located in Samarinda, East Kalimantan Province, Indonesia.

Source of Fungal Isolates. The *F. keratoplasticum* TKKS-1 isolate used in this study was obtained from the culture collection of the Laboratory of Plant Pest and Diseases, Faculty of Agriculture, Mulawarman University. The isolates was originally isolated from decayed oil palm empty fruit bunches (OPEFB) collected from an oil palm plantation in East Kalimantan. The *B. bassiana* isolate (Natural BVRTM, PT. Natural Nusantara) used for comparison was purchased from an agricultural supply store in Samarinda, East Kalimantan. Both fungal isolates were cultured on potato dextrose agar (PDA; Himedia, India) supplemented with 1% yeast extract and 0.2 g/L chloramphenicol, and incubated at 26 ºC under 70–80% relative humidity.

***Spodoptera litura* Rearing.** Larvae of *S. litura* were collected from long bean (V*igna unguiculata* subsp. *sesquipedalis*) fields in Lempake Village, Samarinda, East Kalimantan. The larvae were brought to the laboratory and reared in plastic cylindrical containers (30 cm diameter × 40 cm height) covered with gauze. Mustard (*Brassica juncea*) leaves were provided as feed, which were replaced daily with fresh leaves.

Pupating larvae were transferred into smaller plastic containers (15 cm diameter × 20 cm height) and subsequently placed inside gauze cages (30 × 30 × 30 cm^3) containing mustard plants to facilitate oviposition. Emerging adults were fed with 10% honey applied to cotton pads hung inside the cage. Hatched eggs were transferred to new containers (23 cm diameter × 15 cm height) and continuously fed with fresh mustard leaves. Third-instar larvae from the laboratory-reared colony were used for all pathogenicity bioassays.

Preparation of Conidial Suspension. Fungal isolates were grown on autoclaved PDA plates and incubated at 26 ºC for 10 days. Fully developed conidia were harvested by flooding each culture plate with sterile distilled water containing 0.05% Tween 80 as a wetting agent, and the surface was gently scraped with a sterile spatula. The resulting suspension was filtered through sterile cheesecloth to remove mycelial fragments. Conidial concentrations were determined using an Improved Neubauer hemocytometer (Superior Marienfeld, Germany).

Pathogenicity Test. The pathogenicity of *F. keratoplasticum* TKKS-1 against *S. litura* larvae was evaluated at concentration of 1×10^7 conidia/mL. *B. bassiana* was tested at the same concentration for comparison. Third-instar larvae were directly sprayed with 2 mL of conidial suspension using a hand atomizer. Control larvae were sprayed with sterile distilled water containing 0.05% Tween 80.

Each treatment consisted of five larvae per container (11 cm diameter × 5.5 cm height) and was

replicated four times. Larval mortality was recorded every 24 hours for ten days. Mortality data were corrected using Abbott's formula (Abbott, 1925):

$$P = \left[\frac{C - T}{C}\right] \times 100\%$$

P = Estimated percentage of larvae killed by the fungus;
C = Percentage of living control larvae;
T = Percentage of surviving treated larvae .

Dose-Mortality Response of *F. keratoplasticum* TKKS-1 Against *S. litura* Larvae. To determine the dose–mortality relationship, third-instar *S. litura* larvae were treated with five serial conidial concentrations of F. keratoplasticum TKKS-1 (1×10^6, 2×10^6, 4×10^6, 8×10^6, and 1×10^6 conidia/mL). Control larvae were sprayed with 0.05% Tween 80 solution. Each treatment contained five larvae and was replicated four times. Larval mortality was recorded daily for ten days. The median lethal concentration (LC_{50}) and median lethal time (LT_{50}) values were determined using probit analysis. All bioassays were conducted at 26 ºC, 70–80% relative humidity, and a 12:12 h (L:D) photoperiod.

Bioassay Under Greenhouse Conditions. Mustard plants for were grown in a greenhouse maintained at 29 ± 2 ºC and 75–90% relative humidity. Plants were cultivated in polybags, with two plants per polybag, and placed inside gauze cages ($50 \times 50 \times 50$ cm³). Standard agronomic practices were followed, except for insecticide application.

Third-instar *S. litura* larvae were released onto the plants 12 hours prior to treatment. The experiment was arranged in a randomized block design with four replications and included four *F. keratoplasticum* treatments (4×10^6, 8×10^6, 1×10^7 conidia/mL, and untreated control) and one *B. bassiana* treatment (1×10^7 conidia/mL). Conidial suspensions were applied uniformly to the entire plant surface using a hand sprayer. Pest damage was assessed qualitatively based on a damage score (v) assigned to each plant. Explanations of scores and categories are described in Table 1. The intensity of pest attack (IS) was calculated using the following formula:

$$IS = \frac{\sum vi \times ni}{N \times Z} \times 100\%$$

IS = Intensity of attack (%);
vi = Score score;
ni = Number of samples at each damage score;
N = Total number of samples;
Z = Highest damage score.

Data analysis. Differences in larval mortality among treatments were analyzed using one-way analysis of variance (ANOVA). Mean comparisons were performed using Tukey's test at a 5% significance level ($\alpha = 0.05$) in SPSS version 16.0 (SPSS Inc., Chicago, IL, USA, 2007). Probit analysis was conducted to calculate LC_{50} and LT_{50} values.

RESULTS AND DISCUSSION

Pathogenicity of *F. keratoplasticum* TKKS-1 Against *S. litura* Larvae Under Laboratory Condition. The present study demonstrated that *F. keratoplasticum* TKKS-1 caused 100% mortality of *S. litura* larvae within six days after treatment at a concentration of 1×10^7 conidia/mL (Figure 1). This result is consistent with our previous findings, which reported complete larval mortality at a concentration of 1 x 10^6 conidia/mL (Sahid & Kusumaningtyas, 2023). No mortality occurred in the control group, indicating that *F. keratoplasticum* TKKS-1 was highly pathogenic to third-instar *S. litura* larvae.

When compared to *B. bassiana*, *F. keratoplasticum* TKKS-1 exhibited faster virulence, achieving 100% mortality within six days, whereas *B. bassiana* required nine days to reach the same effect. The slower action of *B. bassiana* might be attributed to decreased spore viability caused by prolonged storage of the commercial product.

The isolation of *Fusarium* species from decayed

Table 1. Categories and scores of pest damage

Damage score (V)	Damage level (%)	Category
0	0	Healthy
1	≤ 25	Light
2	>25–50	Moderate
3	>50–75	Heavy
4	>75	Very heavy

Source: BPTD (2011).

oil palm empty fruit bunches (OPEFB) suggests that this genus can persist as a soil-dwelling saprophyte and decomposer. Research on the entomopathogenic potential of *F. keratoplasticum* has been limited, primarily because this species is often associated with human infections (fusariosis). Human-pathogenic *Fusarium* species typically produce melanin, which contributes to virulence and can be visually recognized as yellow-to-brown pigmentation in culture (Chiewchanvit et al., 2017; James et al., 2022). In this study, no melanin pigmentation was observed in *F. keratoplasticum* TKKS-1 colonies (Figure 2C), suggesting that the isolate used was non-pathogenic to humans.

Members of the *Fusarium* genus are widely recognized as destructive plant pathogens and mycotoxin producers (da Silva Santos et al., 2020; Sharma & Marques, 2018). Therefore, their phytopathogenic potential must be carefully evaluated before use as biocontrol agents. Sharma & Marques (2018) reported that the pathogenicity of *Fusarium* species is linked to the presence of specific virulence genes such as *fmk1*, *fgb1*, and *gas1*, which are typically absent in entomopathogenic *Fusarium*. Some studies have also shown that entomopathogenic *Fusarium* isolates are often host-specific and require distinct adaptations to parasitize non-insect hosts (da Silva Santos et al., 2020).

The results of this study confirm that *F. keratoplasticum* TKKS-1 possesses strong entomopathogenic activity against *S. litura* larvae. Similar findings have been reported for other *Fusarium* species with insecticidal properties, including *F. verticillioides* (Pelizza et al., 2011), *F. solani* (Mantzoukas et al., 2022), *F. ploriferatum* and *F. keratoplasticum* (Chehri, 2017; Guo et al., 2018). These studies collectively support the potential of *Fusarium* spp. as alternative microbial control agents against major agricultural pests.

Dose-Mortality Response of *F. keratoplasticum* TKKS-1 againts *S. litura* Larvae. Larval mortality increased proportionally with higher conidial concentrations of *F. keratoplasticum* TKKS-1 (Table 2). The highest mortality was recorded at 1×10^7 conidia/mL. Probit regression analysis revealed an LC_{50} value of 2.16×10^6 conidia/mL on day 6, which was slightly higher than that previously reported (1.02

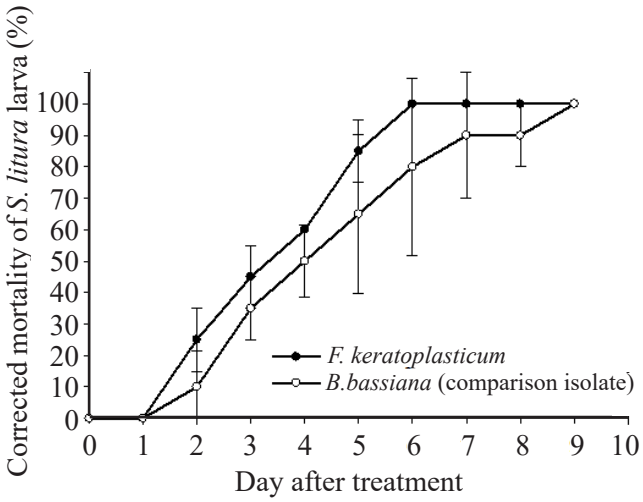

Figure 1. Mortality rate (%) of *S. litura* larvae treated with conidial suspension (1×10^7 conidia/mL) of *F. keratoplasticum* and *B. bassiana* (for comparison) over 9 days after treatment.

Figure 2. Infection and re-isolation of *F. keratoplasticum* TKKS-1 from *S. litura* larvae. A. Dead *S. litura* larvae in soil; B. Symptons of *S. litura* larvae two weeks after death; C. Colony of *F. keratoplasticum* TKKS-1 re-isolated from dead larvae; D. Hyphae and conidia of *F. keratoplasticum* TKKS-1 isolated from dead *S. litura* larvae.

× 10^6 conidia/mL; Sahid & Kusumaningtyas, 2023). Similarly, the LT_{50} value at a concentration of 1 × 10^6 conidia/mL was 6.45 days, approximately 1.7 times longer than in the earlier study.

This reduction in virulence may be attributed to the continuous subculturing of the isolate on PDA medium without supplementation of insect body materials. As reported by Han et al. (2010), successive cultivation of entomopathogenic fungi on nutrient-rich media such as PDA can lead to attenuation of virulence. Supplementing the culture medium with insect-derived substrates can rejuvenate fungal virulence by enhancing the production of cuticle-degrading enzymes and secondary metabolites (Saputro et al., 2019; Afandhi et al., 2023).

When compared to commercial *B. bassiana*, *F. keratoplasticum* TKKS-1 demontrated greater virulence (Table 3). At a concentration of 1 × 10^7 conidia/mL, the LT_{50} of *F. keratoplasticum* TKKS-1 was 2.96 days, which was faster than that of *B. bassiana* (3.63 days). This finding indicates that the native *F. keratoplasticum* TKKS-1 isolate possesses superior pathogenic efficiency and may serve as a potential biocontrol agent for *S. litura* management in crop systems.

Bioassay Studies under Greenhouse Condition. The greenhouse bioassay demonstrated that *F. keratoplasticum* TKKS-1 exhibited high efficacy in suppressing *S. litura* infestation on mustard plants. As shown in Table 4, the highest pest attack intensity was observed in the control treatment on day 7 after planting (97.75%), and all larvae pupated by day 8. In contrast, the lowest attack intensity was recorded in the treatment with *F. keratoplasticum* TKKS-1 at a concentration of 1 × 10^7 conidia/mL (6.94%). No further increase in damage intensity was observed after day 2, as all larvae had died. The dead *S. litura* larvae are shown in Figure 2A.

Two weeks after larval death, individuals infected by *F. keratoplasticum* TKKS-1 exhibited visible white mycelial growth emerging from their cuticle surfaces (Figure 2B). The presence of *F. keratoplasticum* in the infected cadavers was confirmed through re-isolation and subsequent culturing on PDA medium (Figure 2C & 2D).

For the comparative treatment, the commercial *B. bassiana* isolate caused a pest attack intensity of 36.90%. Similar to *F. keratoplasticum*, no further damage progression was observed after day 3, indicating that all larvae had died (Table 4). These findings demonstrate that *F. keratoplasticum* TKKS-1 was more effective in suppressing *S. litura* larvae than the commercial *B. bassiana* formulation.

Under laboratory conditions, *F. keratoplasticum* TKKS-1 achieved 100% larval mortality within

Table 2. Dose-mortality effect of *F. keratoplaticum* TKKS-1 against third-instar *S. litura* larvae six days after treatment

Conidial concentration (conidia/mL)	Means of corrected mortality (%)*	Regression equation	LC_{50} (conidia/mL)
1 × 10^6	25.00 ± 10.00 a	y = 2.5867x – 11.286	1.98 × 10^6
2 × 10^6	45.00 ± 10.00 b		
4 × 10^6	60.00 ± 16.33 bc		
8 × 10^6	80.00 ± 00.00 cd		
10 × 10^6	100.00 ± 00.00 d		

*Different letter are significant different at $p < 0.05$.

Table 3. Median lethal time (LT_{50}) of EPF isolates against third-instar *S. litura* larvae at a the conidial concentration of 1 × 10^7 conidia/mL

EPF isolate	Concentration (conidia/mL)	Regression equation	LT_{50} (day)
F. keratoplasticum TKKS-1	1 × 10^6	y = 6.8977x – 0.5825	6.45
	2 × 10^6	y = 4.5145x + 1.5673	5.76
	4 × 10^6	y = 6.7956x + 0.375	4.79
	8 × 10^6	y = 6.5134x + 0.9761	4.15
	1 × 10^7	y = 5.1366x + 1.6399	2.96
B. bassiana (Comparison isolate)	1 × 10^7	y = 5.3511x + 2.0045	3.63

six days, whereas *B. bassiana* required nine days. Interestingly, under greenhouse conditions, complete larval mortality occurred more rapidly for both fungi. This enhanced efficacy is likely associated with favorable environmental conditions such as optimal temperature, relative humidity, and limited solar radiation, which enhance entomopathogenic fungal (EPF) infection and sporulation (Acheampong et al., 2020). During the experiment, temperature and humidity ranged from 27–31 ºC and 75–90%, respectively. These conditions fall within the optimal range for EPF activity, as temperatures between 28–30 ºC and relative humidity of 70–90% are considered ideal for successful field applications (Mishra et al., 2015; Saleem & Ibrahim, 2019; Acheampong et al., 2020).

Importantly, no foliar symptoms of *Fusarium* crown or root rot were observed on mustard plants throughout the experiment, indicating that *F. keratoplasticum* TKKS-1 exhibited no phytopathogenic effects under greenhouse conditions. Figure 3 illustrates the leaf damage caused by *S. litura* infestation.

Overall, these findings suggest that the native isolate *F. keratoplasticum* TKKS-1 demonstrates strong potential as a safe and effective biological control agent for defoliator insect pests such as *S. litura*. Its high virulence, combined with a lack of phytopathogenicity symptoms, supports its candidacy for further development as a biopesticide in sustainable pest management programs.

CONCLUSION

The findings of this study demonstrated that the indigenous entomopathogenic fungus (*F. keratoplasticum* TKKS-1) exhibited superior effectiveness in controlling third-instar *S. litura* larvae compared to the commercial entomopathogenic fungus *B. bassiana* under both laboratory and greenhouse conditions. Application of *F. keratoplasticum* TKKS-1 as a direct spray at a concentration of 1×10^7 conidia/mL under greenhouse conditions proved highly effective and may serve as a promising component of integrated pest management (IPM) programs targeting *S. litura* larvae.

Table 4. Attack intensity of third-instar *S. litura* larvae on mustard plants under three conidial concentrations of *F. keratoplasticum* TKKS-1, compared with control and *B. bassiana* (comparison isolate)

Treatment	Attack intensity (%)									
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Control (Aquadest)	8.53	23.30	36.84	55.69	73.94	85.85	97.75	-	-	-
F. keratoplasticum (4×10^7 conidia/mL)	12.50	16.50	-	-	-	-	-	-	-	-
F. keratoplasticum (8×10^7 conidia/mL)	7.06	11.70	-	-	-	-	-	-	-	-
F. keratoplasticum (1×10^7 conidia/mL)	3.32	6.94	-	-	-	-	-	-	-	-
B.bassiana (1×10^7 conidia/mL)	14.70	32.50	36.90	-	-	-	-	-	-	-

Figure 3. Leaf damage (white circles) on mustard plants caused by *S. litura* infestation under different treatments. A. Control; B. *F. keratoplasticum* TKKS-1 treatment; C. *B. bassiana* treatment.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Ugiannur and Devi Tentiana for their valuable assistance during the experiments and for maintaining *S. litura* colonies in the laboratory.

FUNDING

There is no funding source for this research.

AUTHORS' CONTRIBUTIONS

AS and NA conceptualized and designed the experiment, analyzed the data, interpreted the results, and prepared the manuscript. NA. contributed to data analysis and interpretation. FS. conducted the pathogenicity and virulence assays and reared *Spodoptera litura* larvae. All authors read and approved the final manuscript.

COMPETING INTEREST

The authors declare that they have no competing interest.

REFERENCES

Abbott WS. 1925. A method of computing the effectiveness of an insecticide. *J Econ Entomol*. 10(2): 265–267. https://doi.org/10.1093/jee/18.2.265a

Abbas C, Xiang D, Wei H, Liu S, Yi G, Lyu S, Guo L, & Li C. 2020. Predicting virulence of *Fusarium oxysporum f.* sp. Cubense based the production of Mycotoxin using a linear regression model. *Toxins* (*Basel*). 12(4): 254. https://doi.org/10.33990/toxins12040254

Acheampong MA, Coombes CA, Moore SD, & Hill MP. 2020. Temperature tolerance and humidity requirements of select entomopathogenic fungal isolates for future use in citrus IPM programmes. *J. Invertebr. Pathol.* 174: 107436. https://doi.org/https://doi.org/10.1016/j.jip.2020.107436

Afandhi A, Rachmawati R, Syib'li MA, & Zain HAU. 2023. Performance and virulence of the entomopathogenic fungi *Beauveria bassiana* grown in media derived from biodegradable agricultural wastes enriched with cricket powder. *AGRIVITA J. Agric. Sci.* 45(2): 261–270. http://dx.doi.org/10.17503/agrivita.v45i2.4113

Bamisile BS, Akutse KS, Siddiqui JA, & Xu Y. 2021. Model application of entomopathogenic fungi as alternatives to chemical pesticides: Prospects, challenges, and insights for next-generation sustainable agriculture. *Front. Plant Sci*. 12: 741804. https://doi.org/10.3389/fpls.2021.741804

BPTD. 2011. *Strategi Pengendalian Hama Penyakit Tanaman Tembakau*. BPTD PTP Nusantara II. Medan.

EFSA Panel on Plant Health (PLH), Bragard C, Dehnen-Schmutz K, Di Serio F, Gonthier P, Jacques MA, Miret JAJ, Justesen AF, Magnusson CS, Milonas P, Navas-Cortes JA, Parnell S, Potting R, Reignault PL, Thulke HH, Van der Werf W, Civera AV, Yuen J, Zappalà L, Malumphy C, Czwienczek E, & MacLeod A. 2019. Pest categorisation of *Spodoptera litura. EFSA Journal.* 17(7): e05765. https://doi.org/10.2903/j.efsa.2019.5765

Chehri K. 2017. Molecular identification of entomopathogenic *Fusarium* species associated with *Tribolium* species in stored grains. *J Invertebr. Pathol.* 144: 1–6. https://doi.org/https://doi.org/10.1016/j.jip.2017.01.003

Chiewchanvit S, Chongkae S, Mahanupab P, Nosanchuk J, Pornsuwan S, Vanittanakom N, & Youngchim S. 2017. Melanization of *Fusarium keratoplasticum* (*F. solani* species complex) during disseminated Fusariosis in a patient with acute leukemia. *Mycopathologia.* 182: 879–885. https://doi.org/doi: 10.1007/s11046-017-0156-2

da Silva Santos AC, Diniz AG, Tiago PV, & de Oliveira NT. 2020. Entomopathogenic *Fusarium* species: A review of their potential for the biological control of insects, implications and prospects. *Fungal Biol. Rev.* 34(1): 41–57. https://doi.org/10.1016/j.fbr.2019.12.002

Guo Z, Pfohl K, Karlovsky P, Dehne HW, & Altincicek B. 2018. Dissemination of *Fusarium proliferatum* by mealworm beetle *Tenebrio molitor*. *PloS One.* 13(9): e0204602. https://doi.org/10.1371/journal.pone.0204602

Han Z, Xie Y, Xue J, & Fan J. 2010. Effect of multi-generation culture on virulence of *Lecanicillium*

lecanii in different media. *Wei Sheng Wu Xue Bao.* 50(2): 211–221.

Isobe M, Kato S, Suzuki M, Nannya Y, Takahashi S, & Konuma S. 2024. Disseminated *Fusarium keratoplasticum* infection with myocardial involvement in an adult cord blood transplant recipient. *Mycopathologia.* 189: 95. https://doi.org/10.1007/s11046-024-00900-y

James JE, Santhanam J, Zakaria L, Rusli NM, Bakar MA, Suetrong S, Sakayaroj J, Razak MFA, Lamping E, & Cannon RD. 2022. Morphology, phenotype, and molecular identification of clinical and environmental *Fusarium solani* species complex isolates from Malaysia. *J. Fungi.* 8(8): 845. https://doi.org/10.3390/jof8080845

Mantzoukas S, Kitsiou F, Lagogiannis I, & Eliopoulos PA. 2022. Potential use of *Fusarium* isolates as biological control agents: *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) case study. *Appl. Sci.* 12(17): 8919. https://doi.org/10.3390/app12178918

Mishra S, Kumar P, & Malik A. 2015. Effect of temperature and humidity on pathogenicity of native *Beauveria bassiana* isolate against *Musca domestica* L. *J. Parasit Dis.* 39(4): 697–704. https://doi.org/10.1007/s12639-013-0408-0

Praneetha TP, Masih SA, Addesso R, Maxton A, & Sofo A. 2025. Brassicaceae isothiocyanate-mediated alleviation of soil-borne diseases. *Plants.* 14: 1200. https://doi.org/10.3390/plants14081200

Pelizza SA, Stenglein SA, Cabello MN, Dinolfo MI, & Lange CE. 2011. First record of *Fusarium verticillioides* as an entomopathogenic fungus of grasshoppers. *J. Insect Sci.* 11(1): 70. https://doi.org/10.1673/031.011.7001

Sahid A & Kusumaningtyas P. 2023. Characterization and virulence of two indigenous entomopathogenic fungal isolates from decayed oil palm empty fruit bunches against *Spodoptera litura* (Lepidoptera: Noctuidae). *Biodiversitas.* 24(2): 1192–1199. https://doi.org/10.13057/biodiv/d240260

Saleem AR & Ibrahim RA. 2019. Assessment of the virulence and proteolytic activity of three native entomopathogenic fungi against the larvae of *Oryctes agamemnon* (Burmeister) (Coleoptera: Scarabaeidae). *Egypt J. Biol. Pest Control.* 29: 21. https://doi.org/10.1186/s41938-019-0120-1

Santos ACdS, Diniz AG, Tiago PV, & Oliveira NTd. 2020. Entomopathogenic *Fusarium* species: A review of their potential for the biological control of insects, implications and prospects. *Fungal Biol. Rev.* 34(1): 41–57. https://doi.org/https://doi.org/10.1016/j.fbr.2019.12.002

Saputro TB, Prayogo Y, Rohman FL, & Alami NH. 2019. The virulence improvement of *Beauveria bassiana* in infecting *Cylas formicarius* modulated by various chitin based compounds. *Biodiversitas*. 20(9): 2486–2493. https://doi.org/10.13057/biodiv/d200909

Sharma L & Marques G. 2018. Fusarium, an entomopathogen—a myth or reality?. *Pathogens*. 7(4): 93 https://doi.org/10.3390/pathogens7040093

Short DPG, O'Donnell K, Zhang N, Juba JH, & Geiser DM. 2011. Widespread occurrence of diverse human pathogenic types of the fungus Fusarium detected in plumbing drains. *J. Clin. Microbiol.* 49(12): 4264–4272. https://doi.org/10.1128/jcm.05468-11

Song Y, Cang X, He W, Zhang H, & Wu K. 2024. Migration activity of *Spodoptera litura* (Lepidoptera: Noctuidae) between China and the South-Southeast Asian region. *Insects*. 15(5): 335. https://doi.org/10.3390/insects15050335

Szaliński M, Zgryźniak A, Rubisz I, Gajdzis M, Kaczmarek R, & Przeździecka-Dołyk J. 2021. *Fusarium* keratitis—Review of current treatment possibilities. *J. Clin. Med*. 10(23): 5468. https://doi.org/10.3390/jcm10235468