

การเปรียบเทียบระดับความเป็นพิษของสารกำจัดแมลงสังเคราะห์และเชื้อ *Bacillus thuringiensis* var. *kurstaki* และ *Bacillus thuringiensis* var. *aizawai* ต่
หนอนกระทู้ข้าวโพดลายจุด *Spodoptera frugiperda* (J.E. Smith)
(Lepidoptera: Noctuidae)

Comparative Toxicity of Synthetic Insecticides and *Bacillus thuringiensis* var. *kurstaki* and *Bacillus thuringiensis* var. *aizawai* against the Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae)

นิชานันท์ เกินอาษา^{1*} และ ณัฐริกา เอี่ยมสกุล¹
Nichanun Kernasa^{1} and Natharika Iemsakul¹*

Received 9 April 2026, Revised 19 June 2026, Accepted 1 July 2026

ABSTRACT

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) is an important pest of corn. It was first reported to have spread into Thailand in late 2018, with significant outbreaks in the provinces of Mae Hong Son, Tak, Kanchanaburi, and Nakhon Sawan. The fall armyworm starts damaging corn from 7 days after planting until the corn reaches the ear stage by feeding on the leaves, shoots, and ears, causing severe damage. There are several methods of controlling *S. frugiperda* larvae with the most common being the use of insecticides. The objective of this study was to determine the toxicity levels of insecticides and biopesticides (*Bacillus thuringiensis*) to fall armyworm. The experiment was conducted using the leaf-dipping method, where corn leaves were dipped into insecticides and then fed to the larvae. The results showed that after 24 hours, the insecticide Lambda-cyhalothrin had the lowest toxicity, with an LC₅₀ value as high as 49.344 ppm, while the insecticide Emamectin benzoate had the highest toxicity, with an LC₅₀ value as low as 2.578 ppm. The bioinsecticides *Bt.* var. *kurstaki* and *Bt.* var. *aizawai* were found to be less toxic than Emamectin benzoate, with LC₅₀ values of 2.521×10¹¹ and 3.011×10¹¹ CFU/ml, respectively. These findings can be used as a guideline for selecting effective insecticides available in the market for controlling fall armyworm. Additionally, to prevent resistance development in pests, it is recommended to implement an integrated resistance management (IRM) strategy, which is part of integrated pest management (IPM), when making decisions on insecticide use.

Keywords: Insecticides, Bioinsecticides, Toxicity levels, Fall armyworm

^{1*} ภาควิชากีฏวิทยา คณะเกษตร กำแพงแสน มหาวิทยาลัยเกษตรศาสตร์ วิทยาเขตกำแพงแสน ต.กำแพงแสน อ.กำแพงแสน จ.นครปฐม 73140

Department of Entomology, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, KamphaengSaen Campus, Kamphaeng Saen, Kamphaeng Saen, Nakhon Pathom 73140, Thailand.

* Corresponding author Tel. 06-3049-9987 E-mail address: agropk@ku.ac.th

บทคัดย่อ

หนอนกระทู้ข้าวโพดลายจุด *Spodoptera frugiperda* JE Smith เป็นแมลงศัตรูพืชที่สำคัญของข้าวโพด พบว่ามีการระบาดเข้าสู่ประเทศไทยเมื่อปลายปี พ.ศ.2561 โดยมีการแพร่กระจายเป็นจำนวนมากอยู่ที่จังหวัด แม่ฮ่องสอน ตาก กาญจนบุรี และ นครสวรรค์ หนอนกระทู้ข้าวโพดลายจุดจะเริ่มทำลายข้าวโพดตั้งแต่อายุ 7 วัน ถึงข้าวโพดออกฝัก โดยจะกัดกินยอด ใบ และฝัก ทำให้เกิดความเสียหายเป็นอย่างมาก การป้องกันกำจัดหนอนกระทู้ข้าวโพดลายจุดทำได้หลายวิธี แต่วิธีที่นิยมมากที่สุด คือ การใช้สารฆ่าแมลงในการป้องกันกำจัด การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อทราบระดับความเป็นพิษของสารฆ่าแมลงและเชื้อบีทีต่อหนอนกระทู้ข้าวโพดลายจุด *S. frugiperda* ทำการทดลองโดยวิธีจุ่มใบข้าวโพดในสารฆ่าแมลงแล้วให้หนอนกิน (leaf-dipping method) ผลการทดลองพบว่า ในเวลา 24 ชั่วโมง สารฆ่าแมลงที่มีระดับความเป็นพิษต่ำที่สุดคือ Lambda-cyhalothrin ซึ่งมีค่า LC_{50} สูงมากถึง 49.344 ppm ส่วนสารฆ่าแมลงที่มีระดับความเป็นพิษสูงที่สุดคือ Emeactin benzoate ซึ่งมีค่า LC_{50} ต่ำมากถึง 2.578 ppm ส่วน *Bt. var. kurstaki* และ *Bt. var. aizawai* มีระดับความเป็นพิษรองจาก Emeactin benzoate ซึ่งมีค่า LC_{50} ต่ำถึง 2.521×10^{11} และ 3.011×10^{11} CFU/ml ผลการศึกษานี้สามารถใช้เป็นแนวทางในการนำสารฆ่าแมลงที่มีประสิทธิภาพที่มีในท้องตลาดมาใช้ในการกำจัดหนอนกระทู้ข้าวโพดลายจุด *S. frugiperda* ได้ และเพื่อป้องกันแมลงเกิดการต้านทานต่อสารฆ่าแมลงควรนำแนวทาง integrated resistance management (IRM) ซึ่งเป็นส่วนหนึ่งของ integrated pest management (IPM) ร่วมด้วยเพื่อใช้ในการตัดสินใจในการใช้สารฆ่าแมลง

คำสำคัญ: สารฆ่าแมลง ชีวภัณฑ์จากจุลินทรีย์ ระดับความเป็นพิษ หนอนกระทู้ข้าวโพดลายจุด

Introduction

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is an invasive and highly destructive pest of maize and several economically important crops worldwide. Since its introduction into Africa and Asia, the pest has spread rapidly owing to its strong migratory capacity, high reproductive potential, and wide host range. Climatic conditions in South and Southeast Asia are highly favorable for its establishment and year-round survival, making the region particularly vulnerable to severe infestations (Du Plessis et al., 2020; Food and Agriculture Organization of the United Nations, 2019).

In Thailand, *S. frugiperda* was first reported in late 2018 and has since become a major insect pest of maize production. The larval stage is responsible for crop damage, feeding on leaves, whorls, and growing points from the seedling stage through reproductive development. Characteristic

symptoms include windowpaning, ragged leaves, extensive defoliation, and destruction of the plant growing point. Severe infestations can result in stunted growth, malformed ears, and substantial yield losses, thereby threatening food security and farmer income.

Management of *S. frugiperda* in many maize-producing areas relies heavily on synthetic insecticides because of their rapid knockdown effect and ease of application. Commonly used insecticides include compounds belonging to the diamide, spinosyn, avermectin, pyrethroid, and oxadiazine groups. However, intensive and repeated applications have raised concerns regarding insecticide resistance development, adverse effects on non-target organisms, environmental contamination, and increased production costs. Reports from several countries have documented reduced susceptibility of *S. frugiperda* populations to various insecticides,

highlighting the need for alternative and sustainable control measures.

Therefore, several control strategies are recommended for managing fall armyworm infestations. These include the use of natural enemies such as *Proreus simulans stali* and *Eocanthecona furcellata*, as well as chemical control methods. The Thai Department of Agriculture (2022) recommends several insecticides for effective control, including chlorantraniliprole 5.17% SC, spinetoram 25% WG, emamectin benzoate 5% WG, emamectin benzoate 1.92% EC, spinetoram + methoxyfenozide 30 + 6% SC, and lufenuron 5% EC, as well as the use of bioproducts derived from *Bacillus thuringiensis* var. *kurstaki*. Shi et al. (2023) chemical pesticides are currently one of the most effective ways to control the outbreak of *S. frugiperda* in the short-term due to their high economic efficiency. To achieve effective pest control using insecticides, it is important to study the toxicity levels of both chemical insecticides and *Bacillus thuringiensis* (Bt) strains against fall armyworm. *Bacillus thuringiensis* (Bt) has become one of the most widely used biological control agents against lepidopteran pests due to its high efficacy, environmental safety, and compatibility with integrated pest management (IPM) programs. *B. thuringiensis* produces crystalline (Cry) proteins during sporulation that become toxic when ingested by susceptible insect larvae. Following ingestion, the Cry toxins are activated in the alkaline midgut, bind to specific receptors on epithelial cells, and create pores in the gut membrane, resulting in feeding cessation, gut paralysis, septicemia, and ultimately larval death (Schnepf et al., 1998). Although both chemical insecticides and Bt-bioinsecticides are recommended for fall armyworm management in Thailand, information comparing the relative toxicity

of registered insecticides, *B. thuringiensis* var. *kurstaki*, and *B. thuringiensis* var. *aizawai* against local populations of *S. frugiperda* remains limited. Such information is essential for developing evidence-based recommendations for sustainable pest management and insecticide resistance management programs. This should be done with consideration for the safety of users and consumers, as well as the cost-effectiveness of the chosen control methods.

Objective

Assessment of toxicity is essential for determining the relative effectiveness of chemical insecticides and *Bacillus thuringiensis* (Bt)-based bioinsecticides against *S. frugiperda*. Toxicity data provide critical information for selecting effective control agents, optimizing pest management strategies, and monitoring changes in susceptibility associated with resistance development. Furthermore, comparative toxicity studies facilitate the identification of environmentally sustainable alternatives that can be incorporated into integrated pest management (IPM) programs while reducing reliance on conventional chemical insecticides. Therefore, the objective of this study was to determine the toxicity levels of insecticides and *Bacillus thuringiensis* var. *aizawai* and *Bacillus thuringiensis* var. *kurstaki* against *S. frugiperda*.

Materials and Methods

Preparation of Corn Plots

Sweet corn (*Zea mays* L. var. *saccharata*) cv. 'Supergold F1' was used as the host plant for rearing and bioassay experiments. Seeds were obtained from Seedline Co., Ltd., Nakhon Pathom, Thailand. Plants were grown in an insecticide-free greenhouse under natural environmental conditions without the use of chemical pesticides. Fully

expanded leaves were collected from healthy plants at the V4–V6 growth stage (approximately 25–30 days after planting) and used immediately for bioassays.

Preparation of *S. frugiperda*

Fall armyworm larvae were collected from a farmer's corn field in Kanchanaburi province, where no insecticides had been applied. The larvae were reared in an artificial diet (Southland Product Inc: Lake Village, A.R., U.S.A.) that placed in rounded plastic boxes, 23 diameter x 7.5 high until they developed into adult moths. Egg masses of *S. frugiperda* were collected from maize fields and transferred to the Department of Entomology, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom The eggs were maintained in plastic containers (15 × 10 × 5 cm) under controlled laboratory conditions at 25 ± 2°C, 70 ± 10% RH and a photoperiod of 14:10 h (L) until hatching.

Newly hatched larvae were reared on fresh sweet corn leaves Sweet corn (*Zea mays* L. var. *saccharata*) cv. 'Supergold F1' that were replaced daily. Larvae were maintained under the same environmental conditions throughout development. Pupae were collected and transferred to adult emergence cages (30 × 30 × 30 cm). Emerged adults were provided with a 10% honey solution as a food source. Wax paper sheets were placed inside the cages as oviposition substrates, and egg masses laid by adults were collected daily.

The laboratory colony was maintained for two generations before use in bioassays to minimize the effects of field-acquired stress and parasitoid contamination. For toxicity experiments, healthy 3rd-instar larvae (4–5 days old) of the F2 generation were selected. Prior to bioassays, larvae were kept individually in plastic cups, 5 diameter x

3 high. Only active and undamaged larvae were used in the experiments.

Preparation of Insecticides and Biopesticides

Seven insecticides and bioinsecticides were selected for the study, including Chlorfenapyr 10% SC, Chlorantraniliprole 5.17% SC, Lambda-cyhalothrin 2.5% EC, Indoxacarb 15% SC, Emamectin benzoate 1.92% EC, *Bacillus thuringiensis* var. *aizawai*, and *Bacillus thuringiensis* var. *kurstaki*. The actual active ingredient concentrations were calculated and serially diluted with sterile distilled water to obtain five concentrations for each treatment. The tested concentrations of Chlorfenapyr were 200, 20, 2, 0.2, and 0.02 ppm; Chlorantraniliprole were 116.32, 11.632, 1.1632, 0.1163, and 0.0116 ppm; Lambda-cyhalothrin were 25, 2.5, 0.25, 0.025, and 0.0025 ppm. Indoxacarb were 225, 22.5, 2.25, 0.225, and 0.0225 ppm; and Emamectin benzoate were 38.4, 3.84, 0.384, 0.0384, and 0.00384 ppm.

For the Bt formulations, stock suspensions were prepared at concentrations of 2.088×10^{11} CFU/ml for *Bt.* var. *aizawai* and 1.970×10^{11} CFU/ml for *Bt.* var. *kurstaki*. Serial ten-fold dilutions were prepared to obtain five concentrations for bioassay. The bacterial concentrations were determined using the standard plate count technique on nutrient agar medium and expressed as colony-forming units per milliliter (CFU/ml) following the methods described by Ben-Dov *et al.* (1997) and Aly *et al.* (2024).

Toxicity Testing of Insecticides and Biopesticides Against *S. frugiperda*

Toxicity tests were conducted using the leaf-dipping bioassay. Third instar larvae were then used for the experiment. The larvae were exposed to various concentrations of insecticides. Each concentration was tested with five replications, and

each replication contained ten larvae. The experiment was conducted under laboratory conditions at 27 ± 2 °C and 70 ± 10 %RH. Corn leaf sections, 5×5 cm were dipped in each treatment solution for 10 seconds and air-dried before being placed into rounded plastic containers, 7 diameter x 4 high containing ten larvae per replication. Sterile distilled water-treated leaves used as the control treatment. Mortality in the control was corrected using Abbott's formula when necessary when mortality in the control exceeded 5%, the observed mortality in treated groups was corrected using Abbott's formula (Abbott, 1925): Corrected mortality (%) = $[(Mt - Mc)/(100 - Mc)] \times 100$

where Mt is the observed mortality (%) in the treated group and Mc is the mortality (%) in the control group.

Mortality data were corrected only when control mortality was between 5 and 20%. Bioassays with control mortality exceeding 20% were discarded and repeated.

Observation and Data Collection

Mortality was observed and recorded at 24, 48, and 72 hours after exposure. The number of dead larvae was counted and documented at each interval.

Statistical Data Analysis

The LC₅₀ values were calculated using PoloPlus version 2.0 (LeOra Software, Berkeley, CA, USA). Toxicity among insecticides and bioinsecticides was compared based on the overlap of 95% confidence intervals. Treatments were considered significantly different when their confidence intervals did not overlap. Statistical analyses were performed using Statistix® version 8.0 (Analytical Software, Tallahassee, FL, USA).

Results

The toxicity levels of different insecticides against the 3rd instar larvae of *S. frugiperda* after 24 hours of exposure were found to vary significantly (Table 1). The insecticide Emamectin benzoate exhibited the highest toxicity, with the lowest LC₅₀ value of 2.578 ppm. Chlorantraniliprole followed with an LC₅₀ of 8.051 ppm. Chlorfenapyr and Indoxacarb showed similar toxicity levels, with LC₅₀ values of 13.425 ppm and 13.579 ppm, respectively. The insecticide with the lowest toxicity was Lambda-cyhalothrin, which had the highest LC₅₀ value at 49.344 ppm. The insecticide Lambda-cyhalothrin showed a relatively high χ^2 value ($\chi^2 = 21.411$, df = 3), indicating a poor fit to the probit model at $p < 0.05$. This result suggests heterogeneity in larval responses to the insecticide, which may be caused by differences in susceptibility among individuals, uneven exposure to treated leaf surfaces, or possible physiological tolerance within the tested population. Similar deviations from probit assumptions have been reported in insecticide bioassays when insect populations exhibit variable responses or when mortality data are not normally distributed (Robertson *et al.*, 2017). In addition, pyrethroid insecticides such as Lambda-cyhalothrin may induce inconsistent mortality responses in later larval instars due to detoxification enzyme activity and behavioral avoidance mechanisms (Sparks & Nauen, 2015). For the bioinsecticides, *Bt. var. kurstaki* and *Bt. var. aizawai* had comparable toxicity levels, with LC₅₀ values of 2.521×10^{11} C CFU/ml and 3.011×10^{11} CFU/ml, respectively. The LC₅₀ value of *Bt. var. kurstaki* obtained in the present study was considerably higher than that reported by Aly *et al.* (2024), who reported an LC₅₀ value of 0.2999 ppm against 3rd instar larvae of *S. frugiperda*. This difference may be attributed to several factors,

including differences in the units used for expressing bacterial concentration, larval instar, and bioassay methodology. In the present study, Bt concentrations were expressed as CFU/ml and tested against third instar larvae using the leaf-dipping method, whereas Aly *et al.* (2024) expressed concentrations in ppm and evaluated toxicity against second instar larvae under different laboratory conditions. Earlier larval instars are

generally more susceptible to *B. thuringiensis* toxins than older larvae because of their thinner peritrophic membrane and lower detoxification capacity (Glare & O' Callaghan, 2000). In addition, variations in Bt formulation, spore viability, feeding behavior, and exposure period may also contribute to differences in LC₅₀ values among studies.

Table 1 Toxicity levels (LC₅₀) of insecticides against the 3rd instar larvae of *S. frugiperda* after 24 hours of exposure

Insecticide	n	LC ₅₀	95%CL, ppm	Fit to Probit line		
				Slope ±SE	χ^2	df
Chlorfenapyr	50	13.425	6.243-25.126	0.735±0.091	0.766	3
Chlorantraniliprole	50	8.051	1.086-28.125	0.320±0.061	1.016	3
Lambda-cyhalothrin	50	49.344	1.566-8700.025	0.935±0.094	21.411	3
Indoxacrab	50	13.579	2.811-39.215	0.400±0.062	0.825	3
Emamectin benzoate	50	2.578	1.199-4.824	0.735±0.091	0.766	3
<i>Bt.aizawai</i>	50	3.011×10 ¹¹	1.487×10 ¹¹ -4.562×10 ¹²	0.344±0.060	0.259	3
<i>Bt.kurstaki</i>	50	2.521×10 ¹¹	7.409×10 ¹⁰ -9.133×10 ¹¹	0.318±0.060	0.301	3

Note: Control (distilled water): 0% mortality observed at 24 h.

Table 2 Toxicity levels (LC₅₀) of insecticides against 3rd instar larvae of *S. frugiperda* after 48 hours of exposure

Insecticide	n	LC ₅₀	95%CL, ppm	Fit to Probit line		
				Slope ±SE	χ^2	df
Chlorfenapyr	50	2.981	1.139-5.732	0.874±0.138	0.638	3
Chlorantraniliprole	50	0.480	0.017-2.533	0.343±0.069	1.669	3
Lambda-cyhalothrin	50	24.271	4.928-131.758	0.869±0.088	8.102	3
Indoxacrab	50	1.569	0.180-5.460	0.456±0.078	0.765	3
Emamectin benzoate	50	0.572	0.219-1.101	0.874±0.138	0.638	3
<i>Bt.aizawai</i>	50	2.120×10 ¹⁰	6.456×10 ⁹ -5.184×10 ¹⁰	0.454±0.067	2.823	3
<i>Bt.kurstaki</i>	50	1.459×10 ¹⁰	3.448×10 ⁹ -3.991×10 ¹⁰	0.407±0.066	4.537	3

Note: Control (distilled water): 0% mortality observed at 48 h.

The toxicity levels of various insecticides against the 3rd instar larvae of *S. frugiperda* at 48 hours of exposure also showed significant differences (Table 2). The insecticides Chlorantraniliprole and Eamectin benzoate exhibited the highest toxicity levels, with LC₅₀ values of 0.480 ppm and 0.572 ppm, respectively. Indoxacarb and Chlorfenapyr showed moderate toxicity, with LC₅₀ values of 1.569 ppm and 2.981 ppm, respectively.

The insecticide with the lowest toxicity was Lambda-cyhalothrin, which had the highest LC₅₀ value at 24.271 ppm, indicating significantly lower toxicity compared to the other insecticides. For the bioinsecticides, *Bt. var. kurstaki* and *Bt. var. aizawai* showed LC₅₀ values of 1.459×10^{10} and 2.120×10^{10} CFU/ml, respectively, with no statistically significant difference between them.

Table 3 Toxicity levels (LC₅₀) of insecticides against the 3rd instar larvae of *S. frugiperda* after 72 hours of exposure

Insecticide	n	LC ₅₀	95%CL, ppm	Fit to Probit line		
				Slope $\pm$ SE	χ^2	df
Chlorfenapyr	50	2.145	0.815-3.893	1.071 $\pm$ 0.208	1.441	3
Chlorantraniliprole	50	0.034	0.000-0.331	0.396 $\pm$ 0.092	1.970	3
Lambda-cyhalothrin	50	9.225	5.526-15.295	0.943 $\pm$ 0.098	4.520	3
Indoxacarb	50	0.230	0.007-1.124	0.548 $\pm$ 0.119	0.639	3
Eamectin benzoate	50	0.314	0.105-0.591	1.071 $\pm$ 0.208	1.441	3
<i>Bt. aizawai</i>	50	4.459×10^9	1.327×10^8 - 1.318×10^9	0.525 $\pm$ 0.081	0.180	3
<i>Bt. kurstaki</i>	50	2.871×10^9	1.212×10^8 - 1.348×10^9	0.497 $\pm$ 0.078	0.283	3

Note: Control (distilled water): 0% mortality observed at 72 h.

The toxicity levels of various insecticides against the 3rd instar larvae of *S. frugiperda* at 72 hours of exposure showed significant differences (Table 3). Chlorantraniliprole exhibited the highest toxicity, with the lowest LC₅₀ value of 0.034 ppm. Indoxacarb, Eamectin benzoate, and Chlorfenapyr showed similar toxicity levels, with LC₅₀ values of 0.230 ppm, 0.314 ppm, and 2.145 ppm, respectively. The insecticide with the lowest toxicity was Lambda-cyhalothrin, which had an LC₅₀ of 9.225 ppm, significantly higher than Chlorantraniliprole. Lu *et al.* (2020) the results showed that Chlorantraniliprole, Spinosad, Indoxacarb, abamectin and Methoxyfenozide had higher toxicity to newly hatched larvae; Chlorantraniliprole, Spinosad and

indoxacarb had higher toxicity to the third instar larvae; and compared with the newly hatched larvae, the LC₅₀ of the third instar larvae increased 78.06, 1.70, 11.73 and 23.09 times, respectively Guruprasad *et al.* (2025) reported that in terms of their larvicidal action 72 h after application, Chlorantraniliprole was found to be the most toxic, followed, in that order, by Eamectin benzoate, Flubendiamide, Spinetoram, Spinosad, and Azadirachtin. As for the biopesticides, *Bt. var. kurstaki* and *Bt. var. aizawai* showed LC₅₀ values of 2.871×10^9 and 4.459×10^9 CFU/ml respectively, with no statistically significant difference between them.

Table 4 Percentage of LC₅₀ values compared to the recommended application rates of insecticides

Insecticide	Recommended dose ppm	Percentage of LC ₅₀ as compared to field recommended dose		
		24 hr.	48 hr.	72 hr.
Chlorfenapyr	200	6.713	1.490	1.073
Chlorantraniliprole	116.32	6.921	0.412	0.029
Lambda-cyhalothrin	25	97.376	70.084	46.125
Indoxacarb	225	6.035	0.697	0.102
Emamectin benzoate	38.4	6.714	1.489	0.818
<i>Bt. aizawai</i>	2.088×10^{11}	44.205	10.153	2.136
<i>Bt. kurstaki</i>	1.970×10^{11}	27.970	7.406	1.457

In Table 4, Lambda cyhalothrin exhibited the lowest toxicity to *S. frugiperda*, with an LC₅₀ percentage compared to the recommended application rate as high as 97.376%. In contrast, the insecticides Indoxacarb, Chlorfenapyr, Emamectin benzoate, and Chlorantraniliprole had LC₅₀ percentages compared to the recommended application rates of 6.035%, 6.713%, 6.714%, and 6.921%, respectively, which were not as high. However, Tidke *et al.* (2021) reported that the laboratory bioassay studies indicated that Spinetorum 11.7% SC showed the most toxic insecticide for the 3rd instar larvae of *S. frugiperda*. The relative toxicity studies revealed that Spinetorum 11.7% SC was found 15 fold more toxic than Thiamethoxam 12.6% ZC + Lambda cyhalothrin 9.5% ZC at LC₅₀ level, while it was 35.25 fold more toxic over Pyriproxyfen 5% EC plus Fenpropathrin 15% EC at LC₉₀ level.

While, the bioinsecticides, *Bt. var. kurstaki* and *Bt. var. aizawai* demonstrated the LC₅₀ percentages of the recommended application rates of 27.970% and 44.205%, respectively, when compared at the 24-hour mark. Amein (2023) reported that *Bacillus thuringiensis* var. *kurstaki* showed significant toxicity against 2nd instar of

S. frugiperda, with an LC₅₀ value of 0.125 mg/mL under laboratory conditions. The difference between the LC₅₀ values obtained in the present study and those reported by Amein (2023) may be related to differences in Bt formulation, larval instar, bioassay procedures, and concentration units used in the experiments.

Conclusion

The present study demonstrated that the toxicity levels of insecticides and bioinsecticides against 3rd instar larvae of *S. frugiperda* varied significantly. Among the tested insecticides, Emamectin benzoate and Chlorantraniliprole showed the highest toxicity, with the lowest LC₅₀ values at 24–72 hours after exposure. Indoxacarb and Chlorfenapyr also exhibited good efficacy against the 3rd instar larvae. In contrast, Lambda-cyhalothrin showed the lowest toxicity, with relatively high LC₅₀ values throughout the experiment.

For the bioinsecticides, *Bt. var. kurstaki* and *Bt. var. aizawai* showed moderate toxicity against 3rd instar larvae of *S. frugiperda*, with no significant difference between the two strains.

The results of this study provide useful information for selecting effective insecticides and Bt products for the management of *S. frugiperda*.

larvae. The findings may also support Integrated Resistance Management (IRM) and Integrated Pest Management (IPM) programs to reduce the risk of insecticide resistance development and improve sustainable pest control strategies.

References

- Abbott, W.S. (1925). A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology*, 18(2), 265–267. <https://doi.org/10.1093/jee/18.2.265a>
- Aly M. Z., Aly, Y. Fangar, H. M, AL-Amgadorcid, Z. Ibrahim, H. M. & Salem, S. A. R. (2024). Comparative toxicity of the bacterium *Bacillus thuringiensis* subspecies *Kurstaki*, emamectin benzoate, and lufenuron on biological and physiological aspects of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), *Egyptian Journal of Zoology*. <https://doi.org/10.21608/ejz.2023.237079.1106>
- Amein, N. S. (2023). Toxicological and biochemical aspects of *Bacillus thuringiensis* var. *kurstaki* on fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *Egyptian Academic Journal of Biological Sciences*. 15(1), 63-68. <https://doi.org/10.21608/eajbsf.2023.290567>
- Ben-Dov, E., Zaritsky, A., Dahan, E., Barak, Z., Sinai, R., Manasherob, R., Khamraev, A., Troitskaya, E., Dubitsky, A., Berezina, N. & Margalith, Y. (1997). Extended screening by PCR for seven cry-group genes from field-collected strains of *Bacillus thuringiensis*. *Applied and Environmental Microbiology*, 63(12), 4883–4890. <https://doi.org/10.1128/aem.63.12.4883-4890.1997>
- Department of Agriculture. (2022). *Research and Development on the Control of Fall Armyworm, Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). DOA. https://drive.google.com/file/d/1gNThVEdNWsGdZPhJ6vNSgfN_RHffogo7/view
- Du Plessis, H. Schlemmer, M. & Van den Berg, J. (2020). The effect of temperature on the development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects*, 11(4). 228. <https://doi.org/10.3390/insects11040228>
- Food and Agriculture Organization of the United Nations. (2019). *Briefing note on FAO actions on fall armyworm in Asia*. FAO.
- Glare, T. R. & O'Callaghan, M. (2000). *Bacillus thuringiensis: Biology, Ecology and Safety*. John Wiley & Sons.
- Guruprasad, G. S. Masedi, O. Race, G. S. Guruprasad, S. & Udikeri, S. (2025). *Baseline toxicity and ovicidal action of different insecticides on new invasive insect pest into India: Fall armyworm, Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). <https://doi.org/10.21203/rs.3.rs-4859930/v1>
- Lu, Y. Tian, J. Zheng, X. Xu, H. Yang, Y. Yang, T. Shi, Z. & Lü, Z. (2020). Laboratory toxicity test of 6 chemical insecticides against *Spodoptera frugiperda*. *Journal of Environmental Entomology*, 42(2), 329-334.
- Robertson, J. L., Jones, M. M., Olguin, E. & Alberts, B. (2017). *Bioassays with Arthropods* (3rd ed). CRC Press. <https://doi.org/10.1201/9781315373775>

- Schnepf, E., Crickmore, N., Van Rie, J., Lereclus, D., Baum, J., Feitelson, J., Zeigler, D.R. & Dean, D.H. (1998). *Bacillus thuringiensis* and its pesticidal crystal proteins. *Microbiology and Molecular Biology Reviews*, 62(3), 775–806. <https://doi.org/10.1128/MMBR.62.3.775-806.1998>
- Shi, Y. He, L. Ding, W. Huang, H. He, H. Xue, J. Gao, Q. Zhang, Z. Li, Y. & Qiu, L. (2023). *Function analysis of CYP321A9 from Spodoptera frugiperda (Lepidoptera: Noctuidae) associated with emamectin benzoate, and a novel insecticide, cyproflanilide detoxification. Journal of Economic Entomology*, 116(5), 1812–1819. <https://doi.org/10.1093/jee/toad168>
- Sparks, T. C. & Nauen, R. (2015). IRAC: Mode of action classification and insecticide resistance management. *Pesticide Biochemistry and Physiology*. 121, 122–128. <https://doi.org/10.1016/j.pestbp.2014.11.014>
- Tidke, V. N. Kulkarni, U. S. & More, S. R. (2021). Screening of insecticides against fall armyworm, *Spodoptera frugiperda* (J. E. Smith). *Journal of Entomology and Zoology Studies*. 9(1), pp. 278-284.