Jurnal Perlindungan Tanaman Indonesia, Vol. 26, No. 2, 2022: 159–166
DOI: 10.22146/jpti.76195
Available online at http://jurnal.ugm.ac.id/jpti
ISSN 1410-1637 (print), ISSN 2548-4788 (online)

Research Article

Susceptibility of *Spodoptera frugiperda* J. E. Smith (Lepidoptera: Noctuidae) Collected from Central Java Province to Emamectin Benzoate, Chlorantraniliprole, and Spinetoram

Julia Nanda Suryani[1)]*, Y. Andi Trisyono[1)], & Edhi Martono[1)]

[1)]*Department of Plant Protection, Faculty of Agriculture, Universitas Gadjah Mada*
Jln. Flora No. 1, Bulaksumur, Sleman, Yogyakarta 55281 Indonesia

**Corresponding author. E-mail: nandajulia68@gmail.com*

Received July 12, 2022; revised August 10, 2022; accepted November 10, 2022

ABSTRACT

Spodoptera frugiperda J.E. Smith (Lepidoptera: Noctuidae) is a new pest on maize that has successfully spread to various regions in Indonesia. This pest can cause severe damage to the affected plants. Most farmers have relied on synthetic insecticides for control. This research was conducted to determine susceptibility level of *S. frugiperda* larvae to emamectin benzoate, chlorantraniliprole, and spinetoram insecticides by using the diet-dipping method. There is no registered insecticide to control *S. frugiperda*, so the three types of insecticides used were based on the recommendation of the Ministry of Agriculture of the Republic of Indonesia. Five field-collected population from Central Java and a laboratory populations of *S. frugiperda* were used to develop a baseline susceptibility for each insecticide. First instar larvae of *S. frugiperda* were placed in vials containing artificial diet treated with insecticides and an untreated control (treated with water only), observed for mortality on the seventh day and data was analyzed using probit. *S. frugiperda* from Tegowanu was the most susceptible to emamectin benzoate (LC_{50} = 0.11 mg/L), while the least susceptible population was from Wedi (LC_{50} = 0.39 mg/L) with the resistance ratio (RR) values of 0.45-folds and 1.60-folds compared to the laboratory population, respectively. *S. frugiperda* from Ngombol was the most susceptible population to chlorantraniliprole (LC_{50} = 12.63 mg/L), while the least susceptible population was from Tegowanu (LC_{50} = 30.29 mg/L) with RR values of 0.90- and 2.15-fold compared to the laboratory population, respectively. Meanwhile, *S. frugiperda* from Jogonalan was the most susceptible to spinetoram (LC_{50} = 2.75 mg/L), while the population from Wedi was the least susceptible (LC_{50} = 5.94 mg/L) with the RR values of 0.52- and 1.12-fold compared to the laboratory population. Field-collected *S. frugiperda* populations were still susceptible to the three tested insecticides tested and emamectin benzoate being the most toxic compared to spinetoram and chlorantraniliprole.

Keywords: *Spodoptera frugiperda*; susceptibility; synthetic insecticide; toxicity

INTRODUCTION

Spodoptera frugiperda J.E. Smith (Lepidoptera: Noctuidae) or commonly known as fall armyworm (FAW), originated from the tropic and subtropic regions of America. In 2016, *S. frugiperda* was detected in the African continent. It rapidly spread and was reported to be detected in almost completely across Sub Saharan Africa, Europe, and Asia. *S. frugiperda* can infest more than 350 plant species, including corn, paddy, sorghum, barley, sugarcane, vegetables and cotton. However, *S. frugiperda* cause most damage on corn and result in yield and economic loss (FAO, 2018; FAO & CABI, 2019; CABI, 2020). According to Early *et al.* (2018), yield loss caused by *S. frugiperda* reached 20–50% in African countries that also affected farmers. Maruthadurai & Ramesh (2020) also reported that *S. frugiperda* damage caused losses up to 16–52% for livestock fed in India.

Spodoptera frugiperda is a new pest that damage corn in Indonesia and has been first reported in 2019 at the District of Karo, North Sumatera and infested 1000 ha of corn field. This pest has been reported to infest corn fields in Lampung with damages reaching 30% (5-week old corn plants) and 10% (7-week old corn plants). Damage caused by *S. frugiperda* in four districts in Lampung reached 26.50–70%. In addition, *S. frugiperda* has been reported to infest corn fields in Banten and West Java. This pest can damage almost all parts of corn plants, including roots, leaves, tassel, ears, to cobs (Trisyono *et al.*, 2019; Lestari *et al.*, 2020; Sartiami *et al.*, 2020).

Spodoptera frugiperda is a new invasive species in Indonesia causing it to have have high adaptability and survivability. Insecticide application is still Indonesia farmers' main management option for *S. frugiperda* by, but intensive and unplanned insecticide use may cause insecticide resistances. Gutirrez-Moreno *et al.* (2019) showed *S. frugiperda* populations from Puerto Rico were resistant against various insecticides, RR_{50} against flubendiamide (500-folds), chlorantraniliprole (160-folds), methomyl (223-folds), thiodicarb (124-folds), permethrin (48-folds), chlorpyrifos (47-folds), zeta-cypermethrin (35-folds), deltamethrin (25-folds), triflumuron (20-folds), spinetoram (14-folds). Spinosad (8-folds), emamectin benzoate and abamectin (7-folds) showed lower resistance ratio. However, these compounds were still effective to manage *S. frugiperda* in Puerto Rico.

In contrast to Gutirrez-Moreno *et al.* (2019) findings, results from Zhao *et al.* (2020) that eight active ingredients, namely emamectin benzoate, spinetoram, chlorantraniliprole, chlorfenapyr, and lufenuron showed high toxicity against *S. frugiperda*, while lambda cyhalothrin and azadiractin showed lower toxicity. Similar findings were reported by Deshmukh *et al.* (2020) where laboratory bioassays showed that emamectin benzoate, chlorantraniliprole, and spinetoram showed higher toxicity compared to flubendiamide, indoxacarb, lambda cyhalothrin, and novaluron. Field efficacy trials during two planting seasons (June and September 2018) showed that chlorantraniliprol was effective and followed by emamectin benzoate, spinetoram, flubendiamide, indoxacarb, lambda cyhalothrin, and novaluron. This study was done to determine susceptibility level of field collected *S. frugiperda* larvae population from Central Java against three active ingredients, emamectin benzoate, chlorantraniliprole and spinetoram. Currently, there are no registered insecticides for *S. frugiperda*. Thus, insecticides used were ones recommended by the Republic of Indonesia's Ministry of Agriculture through Ministrial Decree of Republic Indonesia's Ministry of Agriculture Number 382/KPTS/SR.330/M/6/2020 on usage expansion of insecticide use. Results from this study will provide information to choose insecticides for *S. frugiperda* management in the field and prevent insecticide resistance among the population.

MATERIAL AND METHODS

Spodoptera frugiperda Populations and Rearing

Insects used for this study were from the laboratory and field collected populations. Insect populations were obtained from Management Technology Laboratory Sub Laboratory Pesticide Toxicology, Department of Plant Protection, Faculty of Agriculture, Universitas Gadjah Mada that was collected from the field and reared since 2019 on artificial diet. Artificial diet recipes followed the recipe for *Ostrinia furnacalis* that was developed by Y.A. Trisyono (unpublished) (Rahayu & Trisyono, 2018). Laboratory population was not exposed to insecticide to create a susceptible population. Field populations were collected from several districts across Central Java, including Purworejo (Regency of Ngombol, Village of Wonosari), Klaten (Regency of Wedi, Village of Pandes and Regency of Jogonalan, Village of Ngering), and Grobogan (Regency of Tanggungharjo, Village of Sugihmanik and Regency of Tegowanu, Village of Sukorejo). One hundred larvae were collected from corn plants in each location using "W" sampling method in 2021 (FAO, 2018).

Field collected larvae were placed into plastic vials (height 4.4 cm and diameter 3.4 cm) with corn leaf pieces and were reared in laboratory conditions on artificial diets. Larvae that developed into pupae were placed on petridishes. Pupae were placed in a wire cage to prevent moths from escaping (height 60 cm and width 50 cm) with a corn plant to develop into imagoes and oviposit on corn plant. This method refers to the standard method by sub Laboratory Pesticide Toxicology, Faculty of Agriculture, Universitas Gadjah Mada. Tests were done on 1st larvae from F_1 to F_4 generations.

Insecticides

Insectiicide used were emamectin benzoate =Abenz 22 EC; PT Advansia Indotani), chlorantraniliprole

(Prevathon 50 SC; PT Dupont Agricultural Products Indonesia) and spinetoram (Endure 120 SC; PT Dow AgroSciences Indonesia).

Susceptibility of *S. frugiperda* against Emamectin Benzoate, Chlorantraniliprole and Spinetoram

Preliminary tests

Methods followed ones from IRAC Susceptibility Test Methods Series (Metode No. 007, Versi 3.1) with two modifications, which were the use of diet-dipping and not changing diet until the end of observation period (7 days). Preliminary tests were conducted to obtain concentrations range that resulted in 5% and 95% mortality of test insects.

Test were done using a diet-dipping method by immersing artificial diets in insecticide solutions for 10 s and air-dried afterwards. Artificial diets were then placed into plastic vials that were 4.4 cm in height and 3.4 cm in diameter. One first instar larvae were placed into vials with treated or untreated vials. Highest concentration used refered to recommended concentration from each active ingredient and diluted by 10-folds for 4–6 times. This resulted into test concentration of 22-0.00022 mg/L for emamectin benzoate, 93-0.093 mg/L for chlorantraniliprole and 120-0.12 mg/L for spinetoram. Larvae were exposed to treated or untreated artificial diets for one week and mortality was recorded on the seventh day. Twenty 1st instar larvae from F_1–F_2 generation were used at each insecticide or control concentration. Tests were replicated for three times.

LC_{50} Estimation

Method used for this test followed one used in the preliminary studies. As much as 1 g of artificial diet was used on each treatment (untreated/insecticide treated). Larvae were placed into vials and vials were label to their respective insecticide concentration. Insecticide concentration used in this study consisted of six concentration and one control based on preliminary test. Concentration used for emamectin benzoate were between 0.002–2.2 mg/L with a quarter dilution, 0.38–93 mg/L for chlorantraniliprole and 0.05–12 mg/L for spinetoram with a third of dilution. Observation on mortality was done daily until 7 days. Twenty 1st instar larvae were used from F_1–F_4 were used at each concentration of insecticide or control and were replicated 3–5 times (number of replication varied depending on available larvae for each population).

Data Analysis

Mortality were corrected using an Abbott correction (Abbott, 1925) when mortality in untreated controls were < 20%. LC_{50} values were calculated using mortality at the 7 day after treatment and a probit analysis (Finney, 1971) in PoloJR (PoloSuite) Ver. 2.1 (LeOra Software, 2016). Resistence ratio (RR) was calculated by dividing LC_{50} of field collected populations by LC_{50} of laboratorry populations. The LC_{50} value were not significantly different between treatments if 95% confidence interval overlapped (Deshmukh *et al.*, 2020). To compare susceptibility of field population against all three active ingredients, results from all five populations were pooled and analyzed using a probit and compared to laboratory populations.

RESULTS AND DISCUSSION

Spodoptera frugiperda Susceptibility against Emamektin Benzoate

S. frugiperda populations from Regency of Ngombol, Wedi, Jogonalan, Tanggungharjo, and Tegowanu were still susceptible to emamectin benzoate based on LC_{50} of field populations that were not significantly different from LC_{50} of laboratory populations. The LC_{50} value ranged between 0.11–0.39 mg/L the most susceptible RR from Tegowanu population (RR = 0.45), followed by Tanggungharjo population (RR = 0.69), while lowest susceptibility was for Wedi population (RR = 1.60), followed by Ngombol (RR = 1.41), and Jogonalan (RR = 1.10) (Table 1).

Susceptibility level of *S. frugiperda* to emamectin benzoate was comparable to results from Ahissou *et al.* (2021). *S. frugiperda* populations collected from Burkina Faso had LC_{50} of 0.33–0.38 g/L (emamectin benzoate), 18–73 mg/L (methomyl), 58–430 mg/L (abamectin), 70–541 mg/L (deltamethrin), 199–377 mg/L (ethyl-chlorpyrifos), and 268–895 mg/L (lambda-cyhalothrin). Results from that study showed that emamectin benzoate was the most toxic insecticide. In India, emamectin benzoate was also reported to have LC_{50} of 0.11–0.12 ppm (Dileep Kumar & Murali Mohan, 2022). In the state of Mato Grosso, Brazil, *S. frugiperda* susceptibility against emamectin benzoate

Table 1. LC_{50} and resistance ratio (RR) of *Spodoptera frugiperda* larvae against emamectin benzoate

Location	Sub-location	n	Slope (± SE)	LC_{50} (95% CI; mg/L)	χ2	DF	RR
Laboratory		696	0.037 ± 0.004	0.24 (0.14-0.37) [a]	11.85	4	1
Central Java	Ngombol	588	0.035 ± 0.006	0.34 (0.04-0.57) [a]	7.72	3	1.41
	Wedi	597	0.025 ± 0.004	0.39 (N/A-N/A) [a]	17.85	3	1.60
	Jogonalan	358	0.007 ± 0.001	0.27 (0.09-1.80) [a]	2.66	3	1.10
	Tanggungharjo	497	0.015 ± 0.001	0.17 (0.05-0.64) [a]	22.29	3	0.69
	Tegowanu	358	0.010 ± 0.001	0.11 (0.002-0.69) [a]	13.16	3	0.45

* LC_{50} were not significantly different if 95% confidence interval (CI) overlapped
** RR = LC_{50} field population (Purworejo, Wedi, Jogonalan, Tanggungharjo, Tegowanu): LC_{50} susceptible population (laboratory)

Table 2. LC_{50} and resistance ratio (RR) of *Spodoptera frugiperda* larvae against chlorantraniliprole

Location	Sub-Location	n	Slope (± SE)	LC_{50} (95% CI; mg/L)	χ2	DF	RR
Laboratory		495	2.986 ± 0.240	14.10 (7.41-27.71) [a]	16.93	3	1
Central Java	Ngombol	689	2.675 ± 0.318	12.63 (7.25-17.94) [a]	8.60	4	0.90
	Wedi	693	3.492 ± 0.384	21.13 (14.19-28.77) [a]	8.03	4	1.50
	Jogonalan	237	3.048 ± 0.458	22.80 (5.34-42.88) [a]	0.16	1	1.62
	Tanggungharjo	592	3.482 ± 0.404	18.02 (9.22-27.21) [a]	8.40	3	1.28
	Tegowanu	353	3.676 ± 0.601	30.29 (13.01-46.87) [a]	5.55	3	2.15

* LC_{50} were not significantly different if 95% confidence interval (CI) overlapped
** RR = LC_{50} field population (Purworejo, Wedi, Jogonalan, Tanggungharjo, Tegowanu): LC_{50} susceptible population (laboratory)

was also done. Tested *S. frugiperda* population showed to be still susceptible to emamectin benzoate (RR = 1.01–7.31 folds). Besides to manage *S. frugiperda*, emamectin benzoate has been used to manage other Lepidoptera larvae on cereal and fiber crops (Rampelotti-Ferreira *et al*., 2021).

Spodoptera frugiperda Susceptibility against Chlorantraniliprole

S. frugiperda populations from Regency of Ngombol, Wedi, Jogonalan, Tanggungharjo, and Tegowanu were still susceptible to chlorantraniliprole based on LC_{50} of field populations that were not significantly different from LC_{50} of laboratory populations. LC_{50} value ranged between 12.63–30.29 mg/L with the most susceptible RR of Ngombol (RR = 0.90), while Tegowanu had the lowest susceptibility (RR = 2.15) (Table 2).

S. frugiperda susceptibility against chlorantraniliprole were similar to ones reported by Beuzelin *et al.* (2022), *S. frugiperda* from South Florida during 2017–2019 showed decreased susceptibility to chlorantraniliprole compared to laboratory populations. However, field studies in the same year showed that chlorantraniliprole was still effective to manage this pest and resulted in lower damage compared to other insecticides (indoxacarb, novaluron, or spinetoram). Field populations has LC_{50} within the range of 0.022–0.084 ppm and RR_{50} = 5.3–20.1 while LC_{90} between 0.112–0.471 ppm and RR_{90} = 14.3–60.3. Guo *et al.* (2022) reported that chlorantraniliprole had LC_{50} between 5.45 mg/L (Wuhan) to 55.37 mg/L (Shishou) (RR=10.16) that several *S. frugiperda* field populations have developed resistance against chlorantraniliprole. Pes *et al.* (2020) also reported that chlorantraniliprole and cyantraniliprole applicated using seed treatment caused 57.5±9.5% (chlorantraniliprole) and 40±8.1% (cyantraniliprole) larval mortality. Chlorantraniliprole was still efective to manage *S. frugiperda* in the field, and seed treatment is an alternative application method that can be used to manage *S. frugiperda* since beginning of planting seasons.

Spodoptera frugiperda Susceptibility against Spinetoram

S. frugiperda populations from Regency of Ngombol, Wedi, Jogonalan, Tanggungharjo and Tegowanu were still susceptible to spinetoram based on LC_{50} of field populations that were not significantly different from LC_{50} of laboratory populations. LC_{50} value ranged between 2.75–5.94 mg/L with lowest RR from Jogonalan population (RR = 0.52)

Table 3. LC_{50} and resistance ratio (RR) of *Spodoptera frugiperda* larvae against spinetoram

Location	Sub-location	n	Slope (± SE)	LC_{50} (95% CI; mg/L)	χ2	DF	RR
Laboratory		591	4.883 ± 0.558	5.29 (4.76-5.86) a	0.98	3	1
Central Java	Ngombol	470	5.176 ± 0.799	5.16 (1.44-10.76) a	10.30	3	0.98
	Wedi	692	4.391 ± 0.534	5.94 (3.92-8.18) a	10.26	4	1.12
	Jogonalan	555	0.731 ± 0.156	2.75 (1.34-7.98) a	1.33	3	0.52
	Tanggungharjo	554	3.841 ± 0.665	4.83 (0.11-8.65) a	15.12	4	0.91
	Tegowanu	585	3.636 ± 0.585	3.59 (0.002-6.32) a	10.47	3	0.68

* LC_{50} were not significantly different if 95% confidence interval (CI) overlapped
** RR = LC_{50} field population (Purworejo, Wedi, Jogonalan, Tanggungharjo, Tegowanu) : LC_{50} susceptible population (laboratory)

Table 4. LC_{50} comparison of *Spodoptera frugiperda* laboratory to field population (Central Java) against several insecticides

Insecticide	Location	n	Slope (± SE)	LC_{50} (95% CI; mg/L)	χ2	DF	RR
Emamectin benzoate	Laboratory	696	0.037 ± 0.004	0.24 (0.139-0.365) a	11.85	4	1
	Central Java	2497	0.022 ± 0.002	0.30 (0.002-0.568) a	0.59	4	1.25
Chlorantraniliprole	Laboratory	495	2.986 ± 0.240	14.10 (7.41-27.71) a	16.93	3	1
	Central Java	2564	3.189 ± 0.181	19.65 (16.127-23.221) a	9.53	4	1.39
Spinetoram	Laboratory	591	4.883 ± 0.558	5.29 (4.759-5.862) a	0.98	3	1
	Central Java	2777	3.586 ± 0.350	4.66 (N/A-7.444) a	54.29	4	0.88

* LC_{50} were not significantly different if 95% confidence interval (CI) overlapped
** RR = LC_{50} field population (Purworejo, Wedi, Jogonalan, Tanggungharjo, Tegowanu) : LC_{50} susceptible population (laboratory)

and highest from Wedi population (RR = 1.12) (Table 3).

Spinetoram effectively managed *S. frugiperda* in the field due to its high toxicity. Spinetoram was highly toxic against third instar *S. frugiperda* larvae compared to other tested insecticides. Based on LC_{50} values, relative toxicity of six tested insecticides showed that spinetoram was the most toxic followed by chlorantraniliprole + lambda cyhalothrin, pyriproxyfen + fenpropathrin, beta cyfluthrin + imidacloprid, quinalphos + cypermethrin, tiametoxam + lambda cyhalothrin (Tidke *et al.*, 2021). Guo *et al.* (2022) stated that spinetoram, lufenuron, and emamectin benzoate had the highest acute toxicity on *S. frugiperda*, while chlorantraniliprole, indoxacarb, tetra-chlorantraniliprole, chlorfenapyr, and lambda-cyhalothrin showed relatively lower toxicity. LC_{50} of spinetoram on *S. frugiperda* ranged between 0.33 mg/L in Xiangyang population to 2.10 mg/L for Zigui population (RR = 6.36) that implies that several *S. frugiperda* populations have low resistances development against spinetoram. Other research showed that LC_{50} of broflanilide and abamectin were the lowest and had values of 0.825 and 1.223 mg/L, followed by spinetoram of 1.408 mg/L, while bifenthrin and spinosad had the highest LC_{50} of 2.123 and 2.122 mg/L, respectively (Idrees *et al.*, 2022). This implies that spinetoram was still able to effectively manage *S. frugiperda*.

S. frugiperda Susceptibility Comparison between Laboratory and Field Populations

Spodoptera frugiperda were still susceptible to emamectin benzoate, spinetoram and chlorantraniliprole due to LC_{50} from laboratory and field populations were not significantly different even though LC_{50} varied between both populations their 95% confidence interval (CI) still overlapped. Emamectin benzoate had the highest toxicity on *S. frugiperda* (LC_{50} laboratory = 0.24 mg/L and field = 0.30 mg/L), compared to spinetoram (LC_{50} laboratory = 5.29 mg/L and field = 4.66 mg/L) and chlorantraniliprole (LC_{50} laboratory = 14.10 mg/L and field = 19.65 mg/L), with RR of laboratory populations to be 1-fold of all three insecticide and field population 1.25, 0.88 and 1.39-folds respsectively (Table 4).

High toxicity of emamectin benzoate against *S. frugiperda* have been reported by Yan *et al.* (2019) that tested Tianyang populations against 13 insecticides and showed that emamectin benzoate, spinosad and chlorantraniliprole had the highest toxicity (LC_{50} = 0.0015, 0.0062, and 0.0075 mg/L, and toxicity index = 480.47, 116.24, and 96.09). Nanning population was tested using 5 insecticides and showed that chlorantraniliprole had the highest LC_{50} of 0.0142 mg/L and toxicity index of 41.88. This implies that chlorantraniliprole was the most toxic compared to others. *S. frugiperda* Tianyang and Nanning populations had similar susceptibility against chlorantraniliprole. Ahmed *et al.* (2022) also stated synthetic insecticides that had significantly higher *S. frugiperda* larval mortality were emamectin benzoate (45%), followed by chlorpiryfos (40%) and chlorantraniliprole (38%). Similar results were reported by Bonni *et al.* (2020) laboratory study that showed high mortality was caused by emamectin benzoate (94.16 ± 2.6%), azadirachtin (80 ± 9.3%) and spinetoram (79.16 ± 4.91%). Meanwhile, spinetoram was effective to decrease plant damage by 70.77%, emamectin benzoate by 54.86% and azadirachtin by 36.36% in field conditions. Differences between laboratory and field studies may be caused by weather conditions after insectides were applicated. This study also showed effective active ingredients for *S. frugiperda* management.

Emamectin benzoate had the highest toxicity and can become an active ingredient that can be used to manage *S. frugiperda* in the field. Besides emamectin benzoate, spinetoram and chlorantraniliprole were also effective against *S. frugiperda*. The use of these three active ingredients in rotation is essential to minimalize insecticide resistant development in the field.

CONCLUSION

Spodoptera frugiperda collected from several regions in Central Java were still susceptible against emamectin benzoate, spinetoram, and chlorantraniliprol even though there were some variation among the five populations compared to laboratory population. Emamectin benzoate was the most toxic compared to spinetoram and chlorantraniliprole. The LC_{50} value of laboratory and field populations were 0.24 and 0.30 mg/L for emamectin benzoate, 5.29 and 4.66 mg/L for spinetoram and 14.10 and 19.65 mg/L for chlorantraniliprole, with RR of laboratory population of 1-fold for all three insecticides with field populations of 1.25, 0.88, and 1.39 folds.

ACKNOWLEDGEMENT

Authors would like to thank Sriyanto Harjanto as the laboratory technician of the Pesticide Toxicology Sub Laboratory that help provide the tools and materials during this study and Valentina Erline F. A., S.P., M.Sc. for assisting in data analysis. Data in this article are part of the first author's Master thesis.

LITERATURE CITED

Abbott, W.S. (1925). A Method of Computing the Effectiveness of an Insecticide. *Journal of Economic Entomology*, *18*, 265–267. https://doi.org/10.1093/jee/18.2.265a

Ahissou, B.R., Sawadogo, W.M., Bokonon-Ganta, A.H., Somda, I., Kestemont, M.P., & Verheggen, F.J. (2021). Baseline Toxicity Data of Different Insecticides against the Fall Armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) and Control Failure Likelihood Estimation in Burkina Faso. *African Entomology*, *29*(2), 435–444. https://doi.org/10.4001/003.029.0435

Ahmed, K.S., Idrees, A., Majeed, M.Z., Majeed, M.I., Shehzad, M.Z., Ullah, M.I., Afzal, A., & Li, J. (2022). Synergized Toxicity of Promising Plant Extracts and Synthetic Chemicals against Fall Armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) in Pakistan. *Agronomy*, *12*(6), 1289. https://doi.org/10.3390/agronomy12061289

Beuzelin, J.M., Larsen, D.J., Roldán, E.L., & Schwan Resende, E. (2022). Susceptibility to Chlorantraniliprole in Fall Armyworm (Lepidoptera: Noctuidae) Populations Infesting Sweet Corn in Southern Florida. *Journal of Economic Entomology*, *115*(1), 224-232. https://doi.org/10.1093/jee/toab253

Bonni, G., Houndete, T.A., Sekloka, E., Balle, R.A., & Kpindou, O.D. (2020). Field and Laboratory Testing of New Insecticides Molecules against *Spodoptera frugiperda* (JE Smith, 1797) Infesting Maize in Benin. *Issues in Biological Sciences and Pharmaceutical Research*, *8*, 65–71. https://doi.org/10.15739/ibspr.20.008

CABI. (2020). *Spodoptera frugiperda* (Fall Armyworm) In Invasive Species Compendium. https:// www.cabi.org/isc/datasheet/29810

Deshmukh, S., Pavithra, H.B., Kalleshwaraswamy, C.M., Shivanna, B.K., Maruthi, M.S., & Mota-Sanchez, D. (2020). Field Efficacy of Insecticides for Management of Invasive Fall Armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on Maize in India. *Florida Entomologist*, *103*(2), 221–227. https://doi.org/10.15739/ibspr.20.008

Dileep Kumar, N.T., & Murali Mohan, K. (2022). Variations in the Susceptibility of Indian Populations of the Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) to Selected Insecticides. *International Journal of Tropical Insect Science*, *42*(2), 1707–1712. https://doi.org/10.1007/s42690-021-00693-3

Early, R., González-Moreno, P., Murphy, S.T., & Day, R. (2018). Forecasting the Global Extent of Invasion of the Cereal Pest *Spodoptera frugiperda*, the Fall Armyworm. *NeoBiota*, *40*, 25–50. https://doi.org/10.3897/neobiota.40.28165

FAO. (2018). Integrated Management of the Fall Armyworm on Maize: A Guide for Farmer Field Schools in Africa. Retrieved from https://assets.accessagriculture.org/s3fs-public/FAO_ FFS_guide_for_FAW_control.pdf

FAO, & CABI. (2019). Community-based Fall Armyworm (*Spodoptera frugiperda*) Monitoring, Early Warning and Management: Training of Trainers Manual. https://www.cabdirect.org/cabdirect/abstract/20197200157

Finney, D.J. (1971). *Probit Analysis*, 3rd Ed. Cambridge: Cambridge University Press. https://doi.org/10.1002/jps.2600600940

Guo, Z., Guo, Z., Gao, J., Huang, G., Wan, H., He, S., Xie, Y., Li, J., & Ma, K. (2022). Detection of Insecticide Susceptibility and Target-site Mutations in Field Populations of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *International Journal of Pest Management*, 1–11. https://doi.org/10.1080/09670874.2022.2050835

Gutirrez-Moreno, R., Mota-Sanchez, D., Blanco, C.A., Whalon, M.E., Terán-Santofimio, H., Rodriguez-Maciel, J.C., & Difonzo, C. (2019). Field-evolved Resistance of the Fall Armyworm (Lepidoptera: Noctuidae) to Synthetic Insecticides in Puerto Rico and Mexico. *Journal of Economic Entomology*, *112*(2), 792–802. https://doi.org/10.1093/jee/toy372

Idrees, A., Qadir, Z.A., Afzal, A., Ranran, Q., & Li, J. (2022). Laboratory Efficacy of Selected Synthetic Insecticides against Second Instar Invasive Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) larvae. *PLoS ONE*, *17*(5), e0265265. https://doi.org/10.1371/journal.pone.0265265

LeOra Software. (2016). *PoloJR*, LeOra Software LLC, PO Box 563, Parma, MO 63870. http://www.LeOra-Software.com

Lestari, P., Budiarti, A., Fitriana, Y., Susilo, F.X., Swibawa, I.G., Sudarsono, H., Suharjo, R., Hariri, A.M., Purnomo, Nuryasin, Solikhin, Wibowo, L., Jumari, & Hartaman, M. (2020). Identification and Genetic Diversity of *Spodoptera frugiperda* in Lampung Province, Indonesia. *Biodiversitas Journal of Biological Diversity*, *21*(4), 1670–1677. https://doi.org/10.13057/biodiv/d210448

Maruthadurai, R., & Ramesh, R. (2020). Occurrence, Damage Pattern and Biology of Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on Fodder Crops and Green Amaranth in Goa, India. *Phytoparasitica*, *48*(1), 15–23. https://doi.org/10.1007/s12600-019-00771-w

Pes, M.P., Melo, A.A., Stacke, R.S., Zanella, R., Perini, C.R., Silva, F.M.A., & Carús Guedes, J.V. (2020). Translocation of Chlorantraniliprole and Cyantraniliprole Applied to Corn as Seed Treatment and Foliar Spraying to Control *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *PLoS ONE*, *15*(4), e0229151. https://doi.org/10.1371/journal.pone.0229151

Rahayu, T., Trisyono, Y.A., & Witjaksono. (2018). Fitness of Asian Corn Borer, *Ostrinia furnacalis*

(Lepidoptera: Crambidae) Reared in an Artificial Diet. *Journal of Asia-Pacific Entomology*, *21*(3), 823–828. https://doi.org/10.1016/j.aspen.2018.06.003

Rampelotti-Ferreira, F. T., Thiesen, L.V., Corassa, J. de N., Nardon, A., Santos, L.V. dos, Rosa, D., & Pitta, R.M. (2021). Effective Use of Emamectin Benzoate for the Management of *Spodoptera frugiperda* (J. E. Smith) in Maize. *BioAssay*, *12*, ba12001. https://doi.org/10.37486/1809-8460.ba12001

Sartiami D., Harahap, I.S., Kusumah, Y.M., & Anwar, R. (2020). First Record of Fall Armyworm (*Spodoptera frugiperda*) in Indonesia and its Occurence in Three Provinces. *IOP Conf. Series: Earth and Environmental Science*, *468*(1), 9. https://doi.org/10.1088/1755-1315/468/1/012021

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), 278-284. Retrieved from https://www.entomoljournal.com/archives/?year=2021&vol=9&issue=1&ArticleId=8159

Trisyono, Y.A., Suputa, S., Aryuwandari, V.E.F., Hartaman, M., & Jumari, J. (2019). Occurrence of Heavy Infestation by the Fall Armyworm *Spodoptera frugiperda*, a New Alien Invasive Pest, in Corn Lampung Indonesia. *Jurnal Perlindungan Tanaman Indonesia*, *23*(1), 156–160. https://doi.org/10.22146/jpti.46455

Yan, L., Qian, H., Ting, J., GuoQun, P., XianBin, J., ChengQiang, F., BiQiu, W., SuoSheng, H., Cheng, L., FengKuan, H., Yong, Z., & LiPing, L. (2019). Sensitivity Tests of Two *Spodoptera frugiperda* Populations to Commonly-used Insecticides in Guangxi. *Journal of Environmental Entomology*, *41*(5), 954–960. https://www.cabdirect.org/cabdirect/abstract/20203309724

Zhao, Y.X., Huang, J.M., Ni, H., Guo, D., Yang, F. X., Wang, X., Wu, S.F., & Gao, C.F. (2020). Susceptibility of Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith), to Eight Insecticides in China, with Special Reference to Lambda-cyhalothrin. *Pesticide Biochemistry and Physiology*, *168*, 104623. https://doi.org/10.1016/j.pestbp.2020.104623