

Efficacy of Microbial and Botanical Biopesticides against the Control of the Fall Armyworm (*Spodoptera Frugiperda*) in Maize

Trymore Kamunhukamwe^{1*}, Lisa-Liana Sakwa², Blessing Gumindoga³, Vimbai Samukange⁴

Scientific and Industrial Research and Development Centre (SIRDC) P.O. Box 66401574 Alpes Road
Hatcliffe, Harare, Zimbabwe

***Corresponding Author**

DOI: <https://doi.org/10.51584/IJRIAS.2026.11090012>

Received: 12 September 2026; Accepted: 17 September 2026; Published: 30 September 2026

ABSTRACT

The invasion of Fall Armyworm (*Spodoptera frugiperda*) in Sub-Saharan Africa, including Zimbabwe has caused a huge concern on food security. This has resulted in the extensive use of synthetic insecticides by the majority of small holder farmers as a response to control and reduce the spread of the pest and damage to maize. The continuous use of synthetic chemicals has caused a build-up of pest resistance, unintentional harmful consequences to the environment and human health. Therefore, effective, ecofriendly and sustainable alternative pest control approaches are needed. The present study assessed the efficacy of biopesticides as pest management option against the control of Fall Armyworm in Maize. The experiment consisted of seven treatments (7), namely five biopesticides [Dipel (*Bacillus thuringiensis*), Neem Seed Extract, Neem Leaf Extract, *Metarhizium anisopliae* and *Beauveria bassiana*], one synthetic insecticide (Nemesis) used as a positive control, and one untreated control. Each treatment was replicated three times in a randomized complete block design (RCBD). The application of the selected biopesticides was significantly effective in reducing the population of Fall Armyworm larvae and leaf damage. Dipel (Bt), Neem Seed Extract and Neem Leaf Extract performed significantly better than other biopesticides (*Metarhizium Anisopliae* and *Baeuveria Basiana*) in reducing the Fall Armyworm larval population. The lowest number of FAW larvae was recorded under the treatment of Dipel (2.3), followed by Neem Seed Extract (4.7) and Neem Leaf Extract (6.7). The control plot was extensively infested with FAW larvae and recorded the lowest maize grain yield. The biopesticides showed comparatively high efficacy against FAW and therefore can be recommended as a component for Climate Smart Integrated Pest Management (CSIPM), especially under the smallholder farmer farming system.

Keywords: Fall Armyworm, biopesticides, synthetic insecticides, Climate Smart Integrated Pest Management (CSIPM),

INTRODUCTION

Fall Armyworm (FAW) (*Spodoptera frugiperda*) is a destructive, polyphagous and migratory insect pest that feed on numerous plant species, including maize (*Zea mays* L.), wheat (*Triticum aestivum* L.), sorghum (*Sorghum bicolor* L.), and rice (*Oryza sativa* L.) (Prasanna et al., 2018). The adult moths are capable of migrating over 100 km in one night and up to 500 km in just one generation. The pest is capable of migrating quickly and easily throughout different geographic areas (Nagoshi et al., 2019). The introduction of FAW in Africa had caused the gradual displacement of the stem borer *Busseola fusca* as the main insect pest of maize (Baudron et al., 2019). In Zimbabwe, Fall Armyworm was first detected in Bubi District, Matabeleland North Province in September 2016. During the 2017 to 2018 maize growing season FAW had migrated to all provinces.

Due to its presence in the country, there has been extensive application of synthetic insecticides for the purpose of reducing crop damage and preventing further spread of the pest (Harrison et al., 2019a). Synthetic pesticides are toxic to numerous living things including people. Some known adverse effects on

human health include: lymphoma, leukemia, breast cancer, asthma, allergic reactions, and compromised immune systems. Repeated applications may lead to increased pesticide resistance, higher input costs, and deterioration of the environment (Pérez et al., 2000). Maize is the staple food in Zimbabwe, and it provides vital support to food security and generates income for thousands of smallholder farmers in sub-Saharan Africa (Tambo et al., 2021). In Zimbabwe, Fall Armyworm could potentially decrease maize production annually by approximately 264,000 tons, resulting in estimated lost revenues of around \$83 million (Cock et al., 2017). Therefore, a holistic and sustainable method is needed to manage Fall Armyworm in maize fields specifically for subsistence scale farmers in SSA who generally lack financial means and technical knowledge. An effective method for Fall Armyworm management will be an integrated approach that supports the current farming practices (Harrison et al., 2019b).

Alternatives to conventional FAW management methods are biological control technologies. They are environmentally safe and can replace chemical pesticides. Biological control that includes the use of biopesticides and parasitoids have received wide recognition as alternatives to chemical pesticides for direct fall armyworm control (Bateman et al., 2018; Sisay et al., 2019) and are key components of Integrated Pest Management (IPM) programs (Varshney et al., 2021). Several types of biopesticides such as those produced from *Azadirachta indica* (Neem) and *Bacillus thuringiensis* (Bt) have shown great potency against *Spodoptera frugiperda* (Babendreier et al., 2020). Despite their demonstrated success, however, usage rates of these new technologies remain low among farmers in Zimbabwe, Rwanda, Uganda, and Zambia (Tambo et al., 2020). Therefore, the focus of this research was on investigating the efficiency and effectiveness of using certain biopesticides for controlling Fall Armyworm on maize.

MATERIALS AND METHODS

Study Sites

The field trials were conducted in two ecological zones of Zimbabwe, which are Harare and Chiredzi. Harare is located in natural region 2b and received high rainfall of an average annual rainfall of 750-1,000 mm with average monthly temperatures between 25-28°C. Chiredzi is located in natural region 5 and received less rainfall of average of 400-600 mm per year with monthly temperatures averaging 28-35°C. Field trials were performed during the 2023/2024 maize growing season.

Trial Design and Management

This study was laid out in a randomized complete block design (RCBD) comprising five (5) different biopesticides, one (1) synthetic insecticide (positive control) and untreated control, repeated three (3) times. The experiment included seven (7) treatments: five biopesticides [Dipel (*Bacillus thuringiensis*), Neem Seed Extract, Neem Leaf Extract, *Metarhizium anisopliae*, and *Beauveria bassiana*], one synthetic insecticide (Nemesis) as a positive control, and one untreated control. Each treatment was replicated three times in a randomized complete block design (RCBD). The plots were arranged as 21 plots per site, with one plot of every treatment in each of the three blocks.

Maize hybrid variety (Sirda Maize 113) was sown at 75 cm x 25 cm in plots 10 m x 4 m in size, containing about 200 plants each. Basal fertilizer (Compound D: N7: P14: K7) was added when planting at a dosage of 300 kg/ha. Top-dressing was applied at 200 kg/ha of ammonium nitrate (34.5% nitrogen) four weeks after planting. All standard agricultural practices, including weeding and irrigation, were maintained throughout the crop growth stages. Pest monitoring was conducted from plant emergence to harvest time. Once pest infestation of 10% was observed, the treatments of Neem leaf extract, Neem seed extract, Dipel (Bt), *Metarhizium anisopliae*, *Beauveria bassiana*, and synthetic insecticide Nemesis (Emamectin benzoate) were administered. Each treatment was sprayed using a knapsack sprayer at 15, 35 and 42 days after emergence (DAE) according to the manufacturer's instructions. After every application, the sprayer was washed thoroughly. Control plots were given no treatment.

Preparation of Neem Leaves and Seeds Extracts

Fresh Neem leaves (*Azadirachta indica*) were dried and soaked in water at a ratio of 1:2 (500 g leaves in 1 liter of water) for 24 hours at room temperature. Then after soaking the leaves were crushed into smaller pieces and placed into a clean glass bottle. Additional water was added to the container. The mixture was vigorously shaken using an automated shaker. Finally, the solution was filtered through muslin cloth to isolate Neem leaf extract.

Dried Neem seeds were powdered. Fifty grams of powdered Neem kernels were wrapped in a clean piece of muslin cloth along with an emulsifier. The muslin bag containing the emulsifier and Neem powder was soaked overnight in 1 liter of water. On the next day, the muslin bag was squeezed tightly to produce Neem seed extract.

Table 2.4: List of Treatments and Application rates

Treatments	Type	Active Ingredient	Dosage (10 Litres of Water)
Nemesis	Synthetic Insecticide-Positive Control	Emamamectin Benzoate+Acetamprid	20 mls
Neem Seed Extract	Botanical biopesticide	Azadirachtin, Salamin, Nimbidin	100 mls
Neem Leaf Extract	Botanical biopesticide	Azadirachtin, Salamin, Nimbidin	60 mls
Dipel	Microbial biopesticide	Bacillus thuringiensis (Bt)	37grams
Metarhizium anisopliae	Microbial biopesticide	Proteases	
Bauveria basiana	Microbial biopesticide	Lipases, proteases and chitinases	40 grams
Untreated	Negative control		

Data Collection and Statistical Analysis

Data for FAW incidence and leaf damage was collected weekly during scouting for FAW in maize field trials. 20 consecutive plants in a row in 5 rows in each plot were randomly selected for data collection on FAW infestation level, larval population and leaf damage. Scouting and data collection on FAW incidence, density and leaf damage were done once a week in a semi-systematic manner (“W” pattern). Data were collected before and after application of the treatments for observations of differences.

The proportion of maize crops with signs or symptoms of FAW damage was recorded as FAW infestation, leaf damage was scored based on the severity or intensity of FAW damage using Davis Scale (1-9). Larval infestation (Number of larvae on plants) was recorded. The maize grain yield per treatment was also recorded. Data was analysed using Genstat Version 14 and Fisher's test for multiple comparisons of means. Harare and Chiredzi data were analysed separately because the trials were conducted at two different research sites representing contrasting agro-ecological conditions. Where the treatment effect was significant at $P < 0.05$, treatment means were separated using Fisher's protected least significant difference (LSD) at the 5% significance level. Treatment means sharing the same letter were considered not significantly different at $P < 0.05$.

Properties of Neem Biopesticides

As mentioned previously, extracts from both Neem seeds and leaves contain powerful compounds which have pestical properties. Neem is used to control several major agricultural insect pests including Fall Armyworm. Due to the availability of Neem trees in many African countries, extracts from both Neem seeds

and leaves are accessible for pest control purposes (Dougoud et al., 2019). Limonoids found in Neem seeds such as azadirachtin cause pestical activity primarily responsible for suppressing ecdysone which is required for molting from larval stages to adulthood. Suppression of ecdysone results in no additional moults or failure to develop properly to the adult stage ultimately leading to death (Ajenifujah-Solebo et al., 2019). Neem does not kill insects instantaneously rather they act as repellents, feeding deterrents, growth inhibitors and reproductive inhibitors. In addition to these functions Neem inhibits oviposition and prevents metamorphosis (Wahedi et al., 2017; Tulashie et al., 2021).

The properties of *Bacillus thuringiensis* (Bt)

A soil bacterium that produces naturally insecticidal proteins called delta-endotoxins. The proteins produced by *Bacillus thuringiensis* (Bt) have been specially developed to kill insects. These proteins are especially toxic to economically important insect pests. (Bravo et al., 2015). It is one of the most extensively utilized microbial biopesticides. (Abbas et al., 2022).

The properties of Fungal-based Biopesticides

Fungi such as *Metarhizium anisopliae* and *Beauveria bassiana* are natural fungi used to develop biopesticides. Their spores attack and penetrate the cuticle of insects. They then multiply inside the bodies of their hosts and finally release toxins that cause destruction of internal tissues and ultimately lead to the death of their host insects (Abbas et al., 2022). They are most often used to treat pests in the genus *Spodoptera*.

RESULTS AND DISCUSSION

Efficacy of Biopesticides on FAW Infestation and Larval Population

The application of bio-pesticides was significantly efficient and effective in reducing the population of FAW larvae. Higher efficacy was recorded under the treatments of Dipel (Bt), Neem Seed Extract and Neem Leaf Extract than other biopesticides (*Metarhizium Anisopliae* and *Baeuveria Basiana*) at both research trial sites; Harare and Chiredzi. The lowest number of FAW larvae was recorded under the treatment of Dipel (Bt) (16.78), followed by Neem Seed Extract (22.33) and Neem Leaf Extract (27.50) per sample of 100 plants at SIRDC Research Station in Harare (Table 4.1). Treatments of *Metarhizium anisopliae* and *Baeuveria basiana* recorded high FAW larvae and were at par (34.3 and 33.11) in reducing FAW larvae in maize plots. The lowest number of FAW larvae was recorded under the treatment of Dipel (Bt) (29.33), followed by Neem Seed Extract (35.33) and Neem Leaf Extract (38.33) per sample of 100 plants at Chiredzi Research Station (Table 4.2). Maize plots with high FAW infestation also recorded high number of larvae. (Table 4.1 and 4.2). The results concur with another study by (Keerthi et al., 2023) who observed that mortality caused by *Baeuveria basiana* and *Metarhizium anisopliae* was less effective, with no difference observed between them. The previous study by (Sisay et al., 2019) reported high larval mortality (>95%) of FAW larvae using a Neem Leaf and Seed Extract at 72 hours after application. *Metarhizium anisopliae* and *Beauveria bassiana* caused more than 80% mortality at 72hrs after treatment application. Studies conducted by (Varshney et al., 2021) revealed that the average number of FAW larvae /plant were significantly lower in biocontrol maize field using a combination of Neem oil, *Bacillus thuringiensis* and *Metarizium anisopliae* as compared to the farmers practices.

Efficacy of Biopesticides on Maize Leaf Damage

The results showed a decrease in leaf damage after applying biopesticides compared to untreated plots. There were significant differences in leaf damage under biopesticide treatments ($p < 0.05$) compared to untreated plants. The untreated maize plants were extensively damaged by FAW as evidenced by a high leaf damage score (8.23) compared to maize plots treated with biopesticides, which recorded a minimum leaf damage score (3.23 to 5.81) (Table 2). In another study, (Dhobi et al., 2020a) observed reduction in maize leaf damage after the application of Neem Extracts in comparison with other plant-based bio-pesticides (Tobacco decoction and *Lantana camara* leaf extract).

Table 4.1: Evaluation of biopesticides for FAW control in Maize at Harare-(SIRDC) Research Station

Treatment	FAW Infestation (%)	FAW Larvae/ 100 plants
Nemesis	34.00 a	13.89 a
Dipel (Bacillus Thuringiensis)	40.22 b	16.78 b
Neem Seed Extract	45.51 b	22.33 b
Neem Leaf Extract	48.23 b	25.44 b
Metarhizum Anisopliae	56.22 c	34.30 c
Baeuveria Basiana	59.44 c	33.11 c
Control	82.00 d	70.33 d
LSD (5%)	19.08	18.58
P value (5%)	0.001	0.001

*Means with the same letters in the same column are not significantly different at $P < 0.05$

Table 4.2: Evaluation of biopesticides for FAW control in Maize at Chiredzi Research Station)

Treatment	FAW Infestation (%)	FAW Larvae /100 plants
Nemesis	45.33 a	20.83 a
Dipel (Bacillus Thuringiensis)	50.22 b	29.33 b
Neem Seed Extract	65.00 b	35.33 b
Neem Leaf Extract	69 .11 b	38.83 b
Metarhizum Anisopliae	75.11 c	44.50 c
Baeuveria Basiana	77.56 c	42.17 c
Control	84.99 d	78.12 d
LSD (5%)	7.84	15.21
P Value	0.001	0.001

*Means with the same letters in the same column are not significantly different at $P < 0.05$

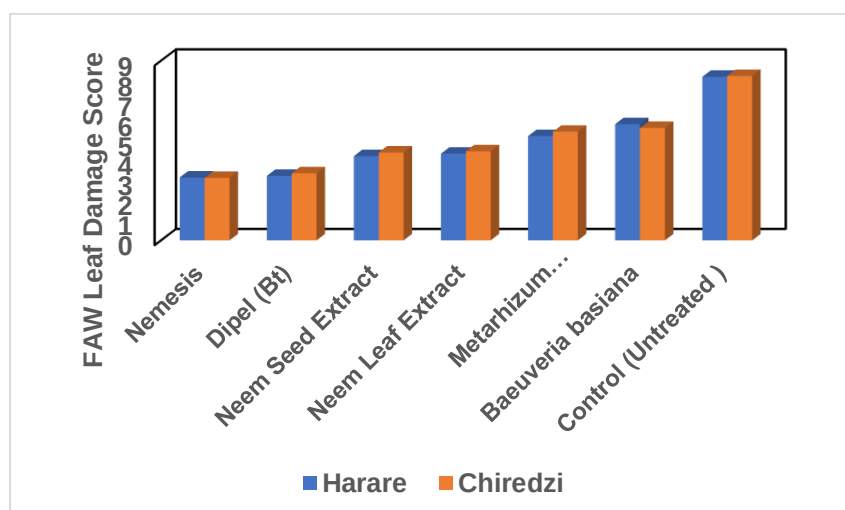


Figure 4.1: Mean leaf damage under different treatments of biopesticides

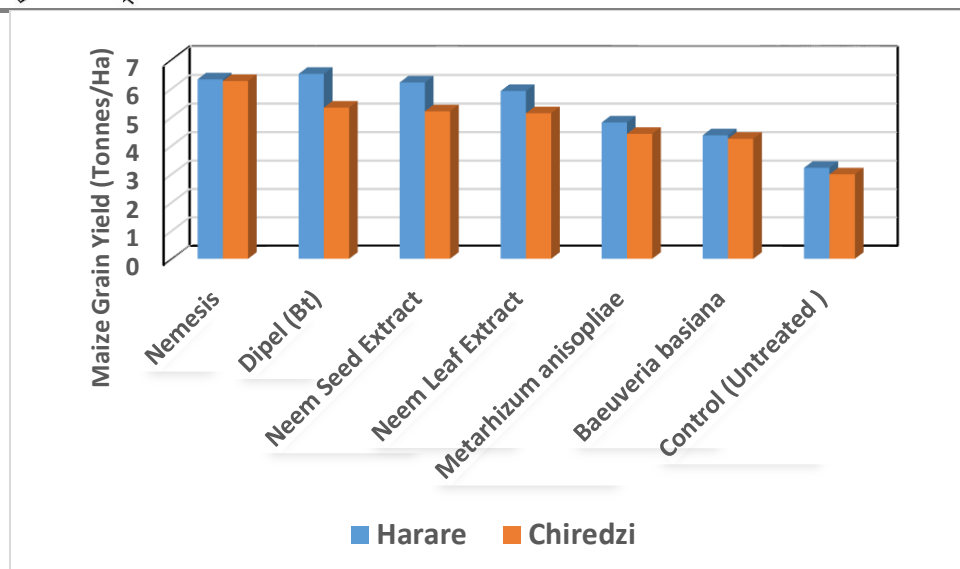


Figure 4.2: Mean Maize Grain Yield under different treatments of biopesticides

Efficacy of Biopesticides on Maize Grain Yield

There were no significant differences ($p < 0.05$) in maize grain yield treated with different biopesticides. However, Dipel (Bt), Neem Leaf Extract and Neem Seed Extract recorded high grain yield (5.9 to 6.2 tonnes) as compared to other biopesticides Metarhizium anisopliae and Beauveria bassiana (4.2 and 4.4 tonnes) (Figure 4.7). Studies by (Agboyi et al., 2023) found that the two tested neem products were as comparatively good as the positive control (Emamectin Benzoate) in terms of maize grain yield. Studies conducted by (Dhobi et al., 2020b) recorded high grain yield in the treatment with Bacillus thuringiensis, Beauveria bassiana, Azadirachtin, and Neem Seed Extract and low grain yield under green chilli water extract, L. camara leaf water extract and tobacco decoction. (Rioba & Stevenson, 2020) reported that neem seed cake extract was more active than leaf extract. This was attributed to the higher amounts of azadirachtin the most effective of the toxic tetranortriterpenoids, because 90% of azadirachtin is more intense in the neem cake after pressing the seeds.

CONCLUSION

The study evaluated five biopesticides, a synthetic insecticide (Nemesis) and an untreated control for management of Fall Armyworm in maize under field conditions in Harare and Chiredzi. The results demonstrated differences among treatments in FAW infestation, larval population, leaf damage and maize grain yield. Among the biopesticide treatments, Dipel (Bacillus thuringiensis), Neem Seed Extract and Neem Leaf Extract generally recorded lower FAW infestation and larval populations than Metarhizium anisopliae and Beauveria bassiana. The neem-based treatments and Dipel also recorded relatively high grain yields. There were significant differences in FAW infestation, larval population, leaf damage and maize grain among the biopesticides and synthetic insecticide (Nemesis) used in the experiment as a positive control. The use of biopesticides that are affordable, effective, ecofriendly and sustainable remains as a high priority. The biopesticides that were evaluated in this study can be safely recommended as alternatives to synthetic chemicals, as they have shown comparatively high efficacy and effectiveness against the control of Fall Armyworm in Maize. They also have embedded advantages of low environmental pollution, low toxicity level to humans, and reduction of the buildup of pest resistance as compared to synthetic insecticides. The findings indicated that selected biopesticides have potential for integration into climate-smart integrated pest management programmes for FAW in maize.

ACKNOWLEDGEMENTS

The financial support from the Rural Development Administration (RDA) of Korea under the Korea- Africa Food and Agriculture Initiative (KAFACI) programme is greatly appreciated for the successful

implementation of all project activities. The technical support and guidance from the Scientific and Industrial Research and Development Centre (SIRDC) management and research team at the Biotechnology Research Institute is also acknowledged.

REFERENCES

1. Abbas, A., Ullah, F., Hafeez, M., Han, X., Dara, M. Z. N., Gul, H., & Zhao, C. R. (2022). Biological Control of Fall Armyworm, *Spodoptera frugiperda*. *Agronomy*, 12(11), 1–16. <https://doi.org/10.3390/agronomy12112704>
2. Abia, D. M., & Seth, W. N. (2019). Effects of neem leaf extracts on Lepidopteran pest species attacking *Solanum macrocarpon* L. (Solanaceae) in southern Togo. *Journal of Entomology and Nematology*, 11(4), 50–57. <https://doi.org/10.5897/jen2019.0230>
3. Agboyi, L. K., Nboyine, J. A., Asamani, E., Beseh, P., Badii, B. K., Kenis, M., & Babendreier, D. (2023). Comparative effects of biopesticides on fall armyworm management and larval parasitism rates in northern Ghana. *Journal of Pest Science*, 96(4), 1417–1428. <https://doi.org/10.1007/s10340-023-01590-z>
4. Ajenifujah-Solebo, S. O. A., Ingelbrecht, I., Isu, N. R., Olorode, O., Saito, K., Nagahashi, R., Ikeda, M., Nakamura, Y., Agbo, B. E., Nta, A. I., Ajaba, M. O., Dissanayake, P. K., Namo, O. A. T., Opaleye, S. A., Béhou, Y. M., Péné, C. B., Piscoya, V. C., Singh, V. P., Cantalice, J. R. B., ... Santin, A. (2019). *Advances and Trends in Agricultural Sciences Vol. 1. Advances and Trends in Agricultural Sciences Vol. 1*, 17–26. <https://doi.org/10.9734/bpi/atias/v1>
5. B.M Prasanna , Huesing J.E, Eddy R, Peschke V.M, P. B. . (2018). *Fall Armyworm in Africa : Fall Armyworm in Africa : Food and Energy Security*.
6. Baudron, F., Zaman-Allah, M. A., Chaipa, I., Chari, N., & Chinwada, P. (2019). Understanding the factors influencing fall armyworm (*Spodoptera frugiperda* J.E. Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. *Crop Protection*, 120, 141–150. <https://doi.org/10.1016/j.cropro.2019.01.028>
7. Bravo, A., Martínez de Castro, D. L., Sánchez, J., Cantón, P. E., Mendoza, G., Gómez, I., Pacheco, S., García-Gómez, B. I., Onofre, J., Ocelotl, J., & Soberón, M. (2015). Mechanism of action of *Bacillus thuringiensis* insecticidal toxins and their use in the control of insect pests. *The Comprehensive Sourcebook of Bacterial Protein Toxins*, 858–873. <https://doi.org/10.1016/B978-0-12-800188-2.00030-6>
8. Cock, M., Day, R., Early, R., Godwin, J., Gomez, J., Moreno, P. G., Murphy, S. T., Oppong-Mensah, B., Phiri, N., & Pratt, C. (2017). Fall Armyworm: Impacts and Implications for Africa. *Outlooks on Pest Management*, 28(November), 196–201.
9. Dhobi, C. B., Zala, M. B., Verma, H. S., Sisodiya, D. B., Thumar, R. K., Patel, M. B., Patel, J. K., & Borad, P. K. (2020a). Evaluation of Bio-pesticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) in Maize. *International Journal of Current Microbiology and Applied Sciences*, 9(8), 1150–1160. <https://doi.org/10.20546/ijcmas.2020.908.127>
10. Dhobi, C. B., Zala, M. B., Verma, H. S., Sisodiya, D. B., Thumar, R. K., Patel, M. B., Patel, J. K., & Borad, P. K. (2020b). Evaluation of Bio-pesticides against Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) in Maize. *International Journal of Current Microbiology and Applied Sciences*, 9(8), 1150–1160. <https://doi.org/10.20546/ijcmas.2020.908.127>
11. Dougoud, J., Toepfer, S., Bateman, M., & Jenner, W. H. (2019). Efficacy of homemade botanical insecticides based on traditional knowledge. A review. In *Agronomy for Sustainable Development* (Vol. 39, Issue 4). Springer-Verlag France. <https://doi.org/10.1007/s13593-019-0583-1>
12. Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., & van den Berg, J. (2019). Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*, 243(May), 318–330. <https://doi.org/10.1016/j.jenvman.2019.05.011>
13. Keerthi, M. C., Suroshe, S. S., Doddachowdappa, S., Shivakumara, K. T., Mahesha, H. S., Rana, V. S., Gupta, A., Murukesan, A., Casini, R., Elansary, H. O., & Shakil, N. A. (2023). Bio-Intensive Tactics for the Management of Invasive Fall Armyworm for Organic Maize Production. *Plants*, 12(3). <https://doi.org/10.3390/plants12030685>

14. Nagoshi, R. N., Nagoshi, B. Y., Cañarte, E., Navarrete, B., Solórzano, R., & Garcés-Carrera, S. (2019). Genetic characterization of fall armyworm (*Spodoptera frugiperda*) in Ecuador and comparisons with regional populations identify likely migratory relationships. *PLoS ONE*, 14(9), 1–17. <https://doi.org/10.1371/journal.pone.0222332>
15. Pérez, C. J., Alvarado, P., Narváez, C., Miranda, F., Hernández, L., Vanegas, H., Hruska, A., & Shelton, A. M. (2000). Assessment of insecticide resistance in five insect pests attacking field and vegetable crops in Nicaragua. *Journal of Economic Entomology*, 93(6), 1779–1787. <https://doi.org/10.1603/0022-0493-93.6.1779>
16. Phambala, K., Tembo, Y., Kasambala, T., Kabambe, V. H., Stevenson, P. C., & Belmain, S. R. (2020). Bioactivity of common pesticidal plants on fall Armyworm Larvae (*Spodoptera frugiperda*). *Plants*, 9(1), 1–10. <https://doi.org/10.3390/plants9010112>
17. Rioba, N. B., & Stevenson, P. C. (2020). Opportunities and scope for botanical extracts and products for the management of fall armyworm (*Spodoptera frugiperda*) for smallholders in Africa. *Plants*, 9(2), 1–17. <https://doi.org/10.3390/plants9020207>
18. Sisay, B., Tefera, T., Wakgari, M., Ayalew, G., & Mendesil, E. (2019). The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *spodoptera frugiperda*, in maize. *Insects*, 10(2). <https://doi.org/10.3390/insects10020045>
19. Tambo, J. A., Kansime, M. K., Mugambi, I., Rwomushana, I., Kenis, M., Day, R. K., & Lamontagne-Godwin, J. (2020). Understanding smallholders' responses to fall armyworm (*Spodoptera frugiperda*) invasion: Evidence from five African countries. *Science of the Total Environment*, 740, 140015. <https://doi.org/10.1016/j.scitotenv.2020.140015>
20. Tambo, J. A., Kansime, M. K., Rwomushana, I., Mugambi, I., Nunda, W., Mloza Banda, C., Nyamutukwa, S., Makale, F., & Day, R. (2021). Impact of fall armyworm invasion on household income and food security in Zimbabwe. *Food and Energy Security*, 10(2), 299–312. <https://doi.org/10.1002/fes3.281>
21. Tulashie, S. K., Adjei, F., Abraham, J., & Addo, E. (2021). Potential of neem extracts as natural insecticide against fall armyworm (*Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae). *Case Studies in Chemical and Environmental Engineering*, 4. <https://doi.org/10.1016/j.csee.2021.100130>
22. Varshney, R., Poornesha, B., Raghavendra, A., Lalitha, Y., Apoorva, V., Ramanujam, B., Rangeshwaran, R., Subaharan, K., Shylesha, A. N., Bakthavatsalam, N., Chaudhary, M., & Pandit, V. (2021). Biocontrol-based management of fall armyworm, *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae) on Indian Maize. *Journal of Plant Diseases and Protection*, 128(1), 87–95. <https://doi.org/10.1007/s41348-020-00357-3>
23. Wahedi, J. A., Zakariya, R., Elkanah, O. S., Ishuwa, M. N., Vincent, V. M., & Enoch, T. G. (2017). Activities of neem and wood ash as biopesticides in the control of insect pests on vegetable crops in Mubi. *GSC Biological and Pharmaceutical Sciences*, 1(1), 006–010. <https://doi.org/10.30574/gscbps.2017.1.1.0006>