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Biopesticides for the Control of Fall Army Worms in Nigeria: Current Status, Challenges, and Prospects

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Abstract

The fall armyworm (FAW), *Spodoptera frugiperda*, originated from tropical and subtropical regions of the Americas. In 2016, Nigeria reported its first FAW outbreak, which later spread across West Africa, predominantly affecting cereal crops, mainly maize—staple crop of great importance in Nigeria. Since its emergence in Africa, FAW has posed a significant threat. In Nigeria, approximately 395.05 hectares and $52.7 million were lost in some states due to FAW, resulting in over a 50% reduction in maize production. While chemical pesticides are promoted and used for FAW control, their application is limited due to toxicity concerns and high costs. Due to their affordability, availability, and environmentally friendly characteristics, research has shifted towards biopesticides, including microbial, microbial extracts, and plant-based solutions. Integrating biopesticides with effective crop management practices can help control pest populations and reduce the reliance on conventional pesticides. This review explores the current status, challenges, and prospects of using biopesticides to control FAW in Nigeria. It highlights the low utilization of biopesticides due to factors such as unskilled labour, inconsistent field performance, inadequate infrastructure, and weak government policies. Addressing these challenges could significantly enhance Nigeria's crop protection, to ensure food security, and sustainable agriculture.

Keywords: Agriculture, Biopesticides, Fall armyworms (*Spodoptera frugiperda*), Food security, Maize protection.

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Introduction

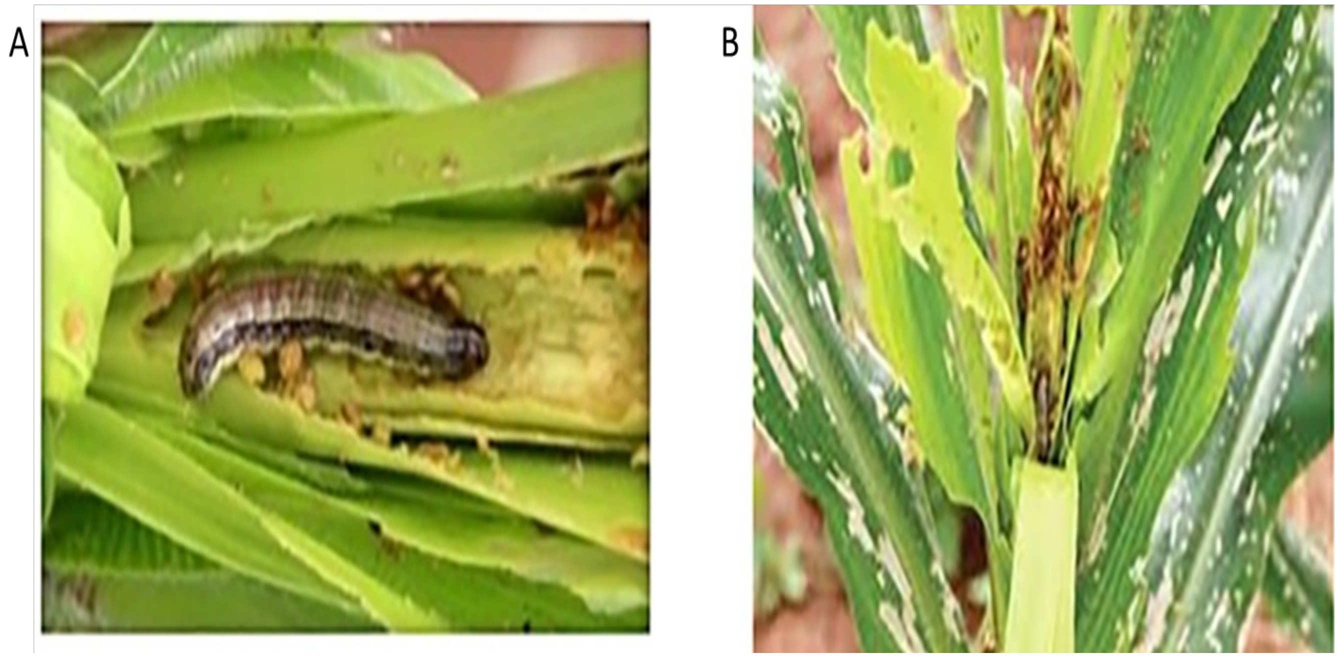
Fall armyworm (FAW) *Spodoptera frugiperda* J.E. Smith is a lepidopterous, highly destructive insect pest from Noctuidae. The discovery of the insect pest was dated more than 200 years ago but was first acknowledged as a terrible economic pest about 93 years ago (Ajiboye et al., 2021). The pest is polyphagous and can be found across different families of crop plants such as Poaceae (maize, rice, sorghum, sugarcane), Curcurbitaceae (cucumber), Brassicaceae (cabbage), Solanaceae (potato), including peanuts and cotton. FAW is highly economically significant, directly and indirectly affecting crops. The larva of FAW predominantly causes damage to the seedlings of crops, notably cereals like maize, and destroys the leaves of the plant, thus reducing its yield (Groote et al., 2020). Low farm income, poor food quality, malnutrition, food insecurity as well as poor economic well-being could be attributed to the deleterious impacts of FAW in crop production (FAO, 2020).

Sustainable food production in Nigeria is highly of great necessity due to the high demand of the ever-increasing population. Therefore, there is a high need to proffer a solution to the invasion of FAW, which has posed a significant risk to achieving quality food production in many African countries, including Nigeria. In Africa, fall armyworm was reported in the South Western part of Nigeria for the first time in the year 2016 (Goergen et al*.,* 2016; Paudel et al., 2022) before its spread to other parts of the globe (Day *et al.,* 2017) (Table 1). It has rapidly spread to about 22 out of the 36 States in Nigeria (Odeyemi et al., 2020). In many African countries, particularly Nigeria, maize is one of the staple foods and is of great economic importance, providing a source of income for small- and large-scale farmers. However, the problems of poor soil fertility, drought, and biotic stress, such as pests and diseases, have generated many concerns, which have increased recently due to the emergence of FAW (Sokame et al*.,* 2021).

Cereals, which belong to the Poaceae family, play a central role in the nutrition of humans and animals. Fall armyworms attack maize at virtually every developmental stage causing severe losses (Goergen et al*.,* 2016; Kalyebi et al., 2023). The larva of FAW commonly causes damage to the seedlings of maize and destroys the leaves of the plant. During cases of high infestation, the growing tip of the plant is destroyed and cob formation of the maize can also be prevented. The cobs can also be infected by microorganisms such as mycotoxins-producing fungi leading to total loss of such cobs (Goergen et al*.,* 2016; Abrahams et al*.,* 2017). Mycotoxins have also posed a serious threat to global trade and food security, particularly when it comes to the export of crops that are host plants for FAW from nations like Nigeria where FAW cases have been confirmed. As a result, these crops undergo scrutiny more closely by importing nations that are pest-free (FAO, 2020).

An increasing number of African farmers are losing their crops each year as a result of the attack launched by FAW. According to Rwomushana et al. (2018), Baudron et al. (2019), and the FAO (2019), for instance, output losses of maize resulting from FAW infestations have been reported to vary from 50% to 100%. Kumela et al. (2019) further revealed that FAW is responsible for yield losses ranging from 32-47% annually due to inadequate control efforts. Although reports of the use of chemical pesticides and technologies to control FAW have been made, these approaches have not been able to provide a single strategy for successfully reducing this threat (Burtet et al., 2017; FAO, 2018; Oliveira et al., 2018).

To manage this pest, maize farmers have traditionally relied on synthetic chemical pesticides, particularly organophosphates, pyrethroids, and neonicotinoids. However, concerns over their toxic effects, non-target specificity, and the accumulation of residues in the food chain have led to restrictions on their use, highlighting their unsuitability for sustainable pest control (Mweke et al., 2019; Pathak et al., 2022). Using integrated pest management (IPM) techniques, which rely less on pesticides and hence have a greater influence on sustainable maize production and consumption, has also been the focus of some study (Day et al., 2017). Fascinatingly, recent studies demonstrate that ecologically friendly techniques, such as entomopathogenic fungi-based biopesticides, offer a viable alternative for controlling fall armyworm (FAW) populations, a major threat to maize productivity by achieving up to 95% larval mortality and significantly reducing feeding damage under laboratory conditions (Akutse et al., 2020; Idrees et al., 2021). Insect pest management in the field and retail settings has drawn a lot of attention lately to biopesticides. Because it is easily accessible, reasonably priced, lowers production costs, and is environmentally beneficial, this is thought to be an environmentally friendly choice. Consequently, in order to identify workable options that would greatly improve crop protection, food security, and sustainable agriculture in Nigeria, this review highlights the status, prospects, and difficulties of employing biopesticides in the country to combat FAW.



Pictures of (A)African armyworm; and (B) fall armyworm damage on maize crop adapted from Groote et al., 2020

Table 1: Distribution of Fall Armyworm

Countries	Year of First Report
Nigeria	2016
Benin	2016
Angola	2017
India	2018
Thailand	2018
Pakistan	2019
China	2019
Nepal	2019
Srilanka	2019
Australia	2020
Papua New Guinea	2020

Source: (FAO, 2020)

Strategies for Controlling Fall Armyworm Infestation in Nigeria

Before the 2016 farming season in Nigeria, the fall armyworm (FAW) was not considered a major threat to maize compared to other pests such as grasshoppers (*Zonocerus variegatus*) and stem borers (*Busseola fusca*) (Ofor et al., 2009). Consequently, the widespread damage caused by FAW was unexpected and took farmers and agricultural stakeholders by surprise. Climate change has played a significant role in altering the pest status of FAW. As noted by Phiri (2017), FAW outbreaks are closely linked to seasonal wind and rainfall patterns, and shifts in these weather conditions across Africa could either escalate or reduce the frequency of these infestations. In response, farmers turned to widespread use of available synthetic pesticides for FAW control. Although these chemicals initially seemed to suppress the pest, FAW populations quickly resurged, returning to feed aggressively on the crops and causing severe damage.

Even though the application of chemical insecticides initially reduces the number of plants affected by this pest, resulting in higher grain output (Ajiboye et al*.,* 2021), farmers used a higher dose of this insecticide than the recommended rate and repeated spraying method to manage the pest. When sprayed wrongly, synthetic pesticides are ineffective and hazardous to the environment (Oliveira et al*.,* 2018). In addition to the negative environmental and human health consequences, pesticide resistance may develop (Pathak et al*.,* 2022; Tudi et al., 2021; Ahmad and Arif, 2010). In certain circumstances, management techniques are unreliable and unsatisfactory because the larvae tend to relocate to the whorl, where they are shielded from pesticide treatments (Bessin, 2017). These concerns triggered a quest for long-term, cost-effective, eco-friendly pest management and control. These criteria are met by biopesticides since they are highly host-specific, generally effective, and have not been shown to have any appreciable negative impacts on non-target organisms or beneficial insects. Consequently, microorganism-based biopesticides have been suggested as a potential substitute for traditional chemical pesticides in a variety of agricultural operations since they are beneficial to agriculture and offer less of a risk to public health (Gupta & Dikshit, 2010)

Biopesticides

Biopesticides are pest control techniques that utilize natural materials such as animals, plants, microbes, and minerals/enzymes for long-term crop protection. They also use bioactive extracts obtained from plants and animals. Three types of biopesticides are categorized as: plant-incorporated, which are biopesticides generated by plants; microbiological, which comprises microorganisms such as bacteria, fungi, and viruses; and biochemical, which are naturally occurring compounds that suppress pests through non-toxic means (USEPA, 2021). Mazid et al. (2011) assert that biopesticides are a sustainable agricultural technique that have minimal, mostly non-toxic impacts on harvested food crops and the environment, hence increasing demand for them on the global market. Nevertheless, the potential of biopesticides for managing and controlling pests has not yet been completely realised. Commonly utilised biopesticides include plant extracts, insect sex pheromones, diseases, and natural enemies of pests (parasites and predators).

Microbiological Pesticides

Pathogens, such as fungi, bacteria, and viruses, are crucial in controlling FAW larvae that cause colour changes. The FAW passes away following a time of attachment. For instance, baculovirus is known to kill FAW larvae, and certain entomopathogenic fungi, such as Metarhizium rileyi, have been shown to kill 95% of FAW larvae in their third instar (Sartiami et al., 2020). This is an important finding that may be used to start the development of a bio-pesticide made of entomopathogenic fungi and persuade farmers to use it to reduce damage. Additionally connected to FAW larvae dying are the granolusis and nucleopolyhedrosis viruses (OECD 2021; FAO and CABI, 2019).

Bacillus thuringiensis (*Bt*) is the most widely employed group of bacteria for biocontrol since it has proven to be an effective biopesticide. Strategic reduction of FAW populations can be achieved by producing biopesticide spray and *Bacillus thuringiensis* maize. The spore-forming bacterium (*Bt*), which occurs naturally in soils, is known to harm a wide range of insect and pest species. Several pesticidal strains have been isolated from soil samples and are effectively utilized by small-scale farmers as bacterial insecticides (Bala, 2016). Research by Akeme et al. (2021) has shown that various strains, including *Bacillus thuringiensis* var. alesti, *Bacillus thuringiensis* var. darmstadiensis, *Bacillus thuringiensis* var. thuringiensis, and *Bacillus thuringiensis* var. kurstaki, are capable of killing fall armyworm (FAW) larvae.

The use of pathogens, including bacteria, viruses, and entomopathogenic fungi, shows promise in the management of FAW. Though they may be too slow to prevent financial loss and are also impacted by weather conditions, they have not been demonstrated to be successful in the absence of additional control measures.

Use of Predators and Parasitoids

While biopesticides derived from bacteria, fungi, and viruses offer sustainable pest control, the introduction of predators and parasitoids provides a complementary biocontrol strategy for managing fall armyworm (FAW, *Spodoptera frugiperda*) populations. Key predators include earwigs (*Forficula auricularia*), ground beetles (Carabidae), predatory bugs (Reduviidae), lady beetles (Coccinellidae), and *Chelonus* spp., while parasitoids such as *Telenomus remus*, *Campoletisflavicinta*, *Trichogramma* spp., *Winthemia trinitatis*, and Tachinid flies (Tachinidae) have shown efficacy in targeting FAW life stages in both laboratory and field settings (Akeme et al., 2021; Kenis et al., 2019; Abang et al., 2021).

In maize ecosystems, predators like the earwig *Doru luteipes* (Scudder) significantly reduce FAW larval populations by preying on eggs and larvae within the maize whorl a critical site for both FAW infestation and predator activity. Laboratory and field studies report that *D. luteipes* nymphs consume 8–12 FAW larvae per day, while adults consume 10–21 larvae daily during the maize growth cycle (Akeme et al., 2021). Similarly, parasitoids such as *Archytas*, *Campoletis*, *Cotesia*, *Euplectrus*, *Gly ptapanteles*, *Microchelonus*,and *Trichogramma* s pecies minimize crop damage by parasitizing FAW eggs and larvae, thereby reducing leaf defoliation without harming maize plants directly. For example, *Telenomus remus*, an egg parasitoid, has been documented to suppress FAW infestations by up to 70% in African maize fields, demonstrating its potential for large-scale biocontrol (Kenis et al., 2019)

Plant derived pesticides

These insecticides, made from plants or plant extracts, are highly effective in controlling the FAW population. The liquid formed from plants, known as plant-based or botanical pesticides, is not only safe for the environment but also for natural adversaries. Neem, *Aglaia cordata* (Hiern), *Annona mucosa* (Jacquin), *Vernonia holosenicea*, long pepper (*Pepper hispidinervum*), *Jatropha gossypifolia*, Castor (*Ricinus communis*), *Chromolae odorata*, *Cedrela salvadorensis*, *Cedrela dugessi*, Chinaberry (*Melia azedarach*) are some of the plants used as biopesticides. The secondary metabolites of these plants, including isobutyl amides, piperine, and natural lipophilic amides, which have deterrent, neurotoxic, and antifeedant properties, are most likely responsible for the botanical efficacy (Dyer et al., 2001; 2004). To manage FAW and stem borer, some Nigerian farmers utilized wood ash made from burned wood, combined with either mocap (*Ethoprophos*) or counter (*Terbufos*). This biopesticide has nutritive, fungicidal, and insecticidal qualities and the capacity to liming soil.

Table 2: Control of FAW using natural enemies

S/No	Natural enemy	Organism type	Life stage	Host plant
1.	*Archytus incertus*	Parasitoid	Larva	Maize
2.	*Archytus marmoratus*	Parasitoid	Larva/pupae	Maize/sorghum
3.	*Chelonus curvimaculatus*	Parasitoid	Eggs/larva	Maize
4.	*Euplectrus platypenae*	Parasitoid	Larva	Maize
5.	*Lespesia archippivora*	Parasitoid	Larva	Maize
6.	*Microchelonus heliopae*	Parasitoid	Eggs/larva	Maize
7.	*Telonomus remus*	Parasitoid	Eggs	Maize/vegetable
8.	*Trichogramma achaeae*	Parasitoid	Egggs	Maize
9.	*Bacillus cereus*	Pathogen	Larvae	Maize
10.	*Bacillus thuringiensis*	Pathogen	Larvae	Maize
11.	*Bacillus thuringiensis alesti*	Pathogen	Larvae	Maize
12.	*Bacillus thuringiensis darmstadiensis*	Pathogen	Larvae	Maize
13.	*Bacillus thuringiensis thuringiensis*	Pathogen	Larvae	Maize
14.	*Beauveria bassiana*	Pathogen	Eggs/larva	Maize
15.	*Granulosis virus*	Pathogen	Larvae	Maize
16.	*Calleida decora*	Predator	Larva	Maize
17.	*Calosoma alternans*	Predator	Larva	Maize
18.	*Calosoma sayi*	Predator	Larva	Maize
19.	*Carabidae*	Predator	Larva/Pupa	Maize

Source: (CABI, 2019)

According to Wahedi et al. (2017), potash is the insecticidal component of wood ash that kills FAW. In contrast to the common belief that applying potash will enhance fruit production and size. To control FAW, some farmers also fill the maize whorl with rhizosphere-derived dirt. A few farmers combined mocap with soil. According to research by Wahedi et al. (2017), wood ash worked better in Nigeria to control pests than neem leaf extract. To be recommended to organic farmers, these studies may need to undergo additional testing under field condition as the majority of them have only been conducted in laboratories. The efficiency of plant-based products with insecticidal qualities is typically restricted, hence in order for them to be used as a control strategy, they must be used in conjunction with other strategies (Akinyemi, 2021). However, more investigation is required to identify the active pesticidal ingredient that provides protection.

The use of Pheromones as Biopesticides

Pheromones, chemical substances produced by an organism to influence the behavior of others within the same species, have shown significant potential in pest management for various insects (Witzgall et al., 2010; Sampson & Kirk, 2013; Kabaluk et al., 2015; Akinyemi et al., 2021). In the case of fall armyworm (FAW), females release sex pheromones such as (Z)-9-tetradecyl acetate, (Z)-7-dodecyl acetate (Z7–12: Ac), and (Z)-9-dodecyl acetate (Z9–12: Ac) (Haenniger et al., 2020). Furthermore, two highly effective entomopathogenic fungi, *Beauveria bassiana* ICIPE 261 and *Metarhizium anisopliae* ICIPE 7, are compatible with FAW pheromones, offering a promising approach to pest control through auto-dissemination (Akutse et al., 2020). Recognizing this potential, the European Commission (EC) approved the use of pheromones in traps or dispensers, either as attractants or disruptors of sexual behavior, for managing key pests (European Commission, 2008). Field trials are currently testing FAW sex pheromones' ability to disrupt mating and reduce populations. However, further field testing is needed to fully assess their effectiveness as a control method or monitoring tool (Bateman et al., 2018).

Current Status of Control of FAW Using Biopesticides in Nigeria

Despite the widely publicized benefits of biopesticides for controlling fall armyworm (FAW) in other countries, their use in Nigeria remains limited. Research on the potential of various plant-based pesticides in Nigeria has been relatively scarce (Akhigbe et al., 2021; Ekwenwosu et al., 2021). Several plants contain bioactive compounds effective against fall armyworm (FAW, *Spodoptera frugiperda*), including wood ash, Christmas melon (*Adenopus breviflorus*), neem (*Azadirachta indica*), and chili peppers (*Capsicum annuum*). It has also been observed that a combination of neem tree, Mexican sunflower (*Tithonia diversifolia*), siam weed (*Chromolaena odorata*), and ejirin (*Momordica charantia*) is beneficial in controlling FAW in Nigeria (Timothy, 2022). Neem extracts have been proposed by Akhigbe et al. (2021) as a means of controlling FAW infection.

Because they are derived from natural materials like microbes, biopesticides are typically safe for the environment. But compared to other African nations like South Africa, comparatively few biopesticides appropriate for the management of FAW have been registered and commercialised in Nigeria, despite their enormous potential and documented success (Bateman et al., 2018). This could be explained by the need for thorough screening and field testing protocols, insufficient risk assessment methods, and poor public knowledge (Ashaolu et al., 2022).

Few studies have documented the use of natural enemies to manage FAW in Nigeria. According to Ogunfunmilayo et al. (2021) those species that were identified as potentially useful in managing FAW infestation were *Telenomus remus* (Hymenoptera: Platygastridae), *Euplectrus laphygmae* (Hymenoptera: Eulophidae), *Trombidium sp*. (Acari.: Trombidiidae), *Cotesia sp*., and *Stictopisthus sp.* (Hym.: Ichneumonidae).

Challenges in Control of FAW Using Biopesticides in Nigeria

The development of biopesticides has many obstacles in developing countries like Nigeria, including low acceptance, confidence, and awareness. A few other things that impair marketability, product quality, and durability are the absence of data-driven standards and field performance monitoring. The effectiveness of biopesticides in controlling FAW has been limited compared to synthetic chemical pesticides due to the absence of a robust regulatory framework, inadequate ecological risk assessments, and health considerations. Due to their accessibility and lower cost, the majority of the local farmers resort to using mechanical methods to combat the threat posed by FAW. However, these difficulties also offer Nigeria a wealth of prospects for the development of biopesticides.

Expectations for the effectiveness of microbial biopesticides have been high because of some of the early achievements and the market's ongoing growth. But there are going to be a lot of obstacles to massively adopt biopesticides in future. Research patents have imposed restrictions on the application of patented technologies for humanitarian purposes, as well as on the conduct of research and the accessibility of data from publicly sponsored studies (Boettiger & Bennett 2006; Gonzalez, 2006). Furthermore, national and international intervention would be essential for the implementation of local production schemes in emerging nations like Nigeria.

As described by Ashaolu et al. (2022), extended field testing, a deficiency of bridging risk assessments, and technical checklists were also found to be major obstacles to the study and advancement of biopesticides in Nigeria. Numerous botanical pesticides have been developed but they are not available for adoption due to various challenges. These challenges include the difficulty of producing plant materials on a large scale, the standardization of chemically complex extracts, stringent regulatory approval processes, the slow action of some botanical pesticides, the lack of residual effects, and the availability of more affordable competing products (Khater, 2012; Ndolo et al., 2019)

The use of synthetic insecticide was prioritised over biopesticides by the government when FAW first emerged (Togola et al., 2018; Ogunfunmilayo et al., 2021). Furthermore, Nigeria has no set policies for the production, use, or regulation of biopesticides. Moreover, this has impeded investments in biopesticide accessibility, marketability, and awareness in Nigeria. Furthermore, farmers in Nigeria have been discouraged from using biopesticides to control FAW and other pests due to the government's lack of promotion and support for these products. As a result, advances in pest management techniques and technologies have been appallingly little.

Even though there has not been much research done to pinpoint the natural adversaries that FAW in Nigeria faces, accurately identifying the target species can be difficult. For example, in their study on the occurrence of natural enemies of FAW in Nigeria, Ogunfunmilayo et al. (2021) reported the detection of species of predators that have not yet been described in distinct niches of maize plants.

Future Prospects in Control of FAW Using Biopesticides in Nigeria

Several field investigations, laboratory experiments, and follow-up testing are still being conducted on various biopesticides, particularly botanical pesticides. If the study in this area is successful, it is anticipated that a plethora of plant-derived pesticide or botanical will be developed to control FAW in Nigeria (Ekefan and Eche 2013; Amadi et al., 2024). This could lead to a significant reduction in FAW infestations and a more sustainable approach to pest management in Nigeria.

The majority of the research on the use of biopesticides to control FAW was laboratory-based. To effectively manage FAW and keep its population below economically damaging levels, it is crucial to conduct field trials to confirm the laboratory results and to consider the mass production and release of these biological control agents. The urgency and necessity of this approach are underscored by the potential to reduce the usage of synthetic pesticides, which are hazardous to the environment and human health.

While it is established that biopesticides alone cannot fully replace chemical pesticides, it is essential to focus on integrating biopesticides into pest control strategies. Nigerian farmers need to understand the importance of biopesticides as a long-term FAW control strategy that can mitigate the negative impacts of synthetic chemical pesticides (Ndolo et al., 2019). Moreover, it is crucial that indigenous Nigerian farmers have access to biopesticides at an affordable price, underscoring the importance of this issue.

CONCLUSION

Fall armyworm infestations are a widespread issue that Nigerian farmers, particularly those who grow maize, have to deal with nationwide.

Complete management of FAW has proven to be extremely difficult because of its quick spreading capacity, and the FAO has warned that it may cause a 100% production decrease in maize. Most farmers use an integrated pest management strategy that includes physical, chemical, botanical, and biological methods. However, it employs a variety of parasitoids, diseases, and predators to eradicate the pest, because the biological method of pest control is environmental friendly. Biopesticides are in high demand for controlling FAW because chemical methods are often not selected because they are not cost effective and toxic. On the other hand, Nigeria is among the nations in Africa with the least amount of information regarding biopesticides that have been approved for controlling FAW. Finding novel active components that may eradicate the pest is the reason for the demand to boost research on biopesticides as a means of controlling it**.**

References

Abang, A. F., Nanga, S. N., Fotso Kuate, A., Kouebou, C., Suh, C., Masso, C., Saethre, M., & Fiaboe, K. K. (2021). Natural Enemies of Fall Armyworm Spodoptera frugiperda (Lepidoptera: Noctuidae) in Different Agro-Eco. *Insec. 12*(6), 509. https://doi.org/10.3390/insects12060509

Abrahams, P., Bateman, M., Beale, T., Clottey V., Cock M., Colmenarez Y., Corniani N., Day R., Early R., Godwin J.L., Gomez J., Gonzalez-Moreno P., Murphy S.T., Oppong-Mensah B., Phiri N., Pratt C., Richards G., Silvestri S. & Witt A. (2017). Fall Armyworm: Impacts and implications for Africa (September 2017), CABI, UK. *Outlooks on Pest Mangt.* 28 (5), 196–201.

Ahmad, M. & Arif, M. I. (2010). Resistance of beet armyworm *Spodoptera exigua* (Lepidoptera: Noctuidae) to endosulfan, organophosphorus and pyrethroid insecticides in Pakistan. *Crop Protec.* 29 (12), 1428–1433.

Ajiboye, T. O., Aladele, S. E., Ogunbiyi, M., Olubiyi, M. R., Michael, C., Oduoye, O. T., Olajire, O. & Oyewole, O. (2021). Review of Fall Armyworm (*Spodoptera frugiperda*) invasion in Nigeria and lessons learned for sustainable food production. *Greener J of Agric. Sci.* 11(1), 48-56.

Akeme, C. N., Ngosong, C., Sumbele, S. L., Aslan, A., Tening, A. S., Krah, C. Y., Kamanga, B. M., Denih, A. & Nambangia, O. J. (2021). Different controlling methods of fall armyworm (*Spodoptera frugiperda*) in maize farms of small-scale producers in Cameroon. *IOP Conf. Ser.: Earth Environ. Sci.,* 911, 012053.

Akhigbe, C. I., Oyerinde, A. A., Asala, S. W. & Anjorin, T. S. (2021). Evaluation of fall armyworm (*Spodoptera frugiperda* J.E. SMITH) infestation and efficacy of neem extracts in maize (*Zea mays*). *Nigerian Agric. J.* 52(1), 77-82.

Akinyemi A. O. (2021). Exploring integrated pest management strategies in the control of the fall armyworm in smallholder organic agriculture farms in Africa. *Agro-Sci.* 20(3), 65-70. DOI: https://dx.doi.org/10.4314/as.v20i3.9

Akutse, K. S., Khamis, F. M., Ambele, F. C., Kimemia, J. W., Ekesi, S. & Subramanian, S. (2020). Combining insect pathogenic fungi and a pheromone trap for sustainable management of the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *J. Invertebr. Pathol.,* 177, 107477. https://doi.org/10.1016/j.jip.2020.107477

Amadi, G. I., Ukoroije, R. B., & Dimkpa, S. O. (2024). Efficacy of Five Botanicals in the Management of Fall Armyworm Spodoptera frugiperda JE Smith (1993) (Lepidoptera: Noctuidae) Larvae on Some Maize Varieties in Port Harcourt, Rivers State, Nigeria. *Intern J. of Entom. and Nemat. Res. 8* (1), 1-15.

Ashaolu, C. A., Okonkwo, C. O., Njuguna, E. & Ndolo, D. (2022). Recommendations for Effective and Sustainable Regulation of Biopesticides in Nigeria. *Sustain.* 14, 2846. https://doi.org/10.3390/su14052846

Bala S. N. (2016). Fundamentals of biological control of pests Wolbachia mediated species View project Effects of Entomopathogenic Nematodes for Bio-Control of *Brontispa longissima* (Gastro) and *Octodon tanipae* (Maulik) View project. August, 0–11.

Bateman, M. L., Day, R. K., Luke, B., Edgington, S., Kuhlmann, U. & Cock, M. J. W. (2018). Assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa. *J. Appl. Entomol.,* 142(9), 805–811.

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 Protec.* 120, 141-150. doi: 10.1016/j.cropro.2019.01.028

Bessin, G. (2017). Fall Armyworm in Corn. Kentuky: Univ. of Kentuky, 2017. Available in:. Access on: 22 sep. 2017.

Boettiger, S. & Bennett, A. B. (2006). Bayh-Dole: if we knew then what we know now. *Nat. Biotech.* 24(3), 320-323.

Burtet, L. M., Bernardi, O., Melo, A. A., Pes, M. P., Strahl, T. T. & Guedes, J. V. C. (2017). Managing fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), with Bt maize and insecticides in Southern Brazil. *Pest Manag. Sci.* 73, 2569-2577. doi: 10.1002/ps.4660.

CABI, F. (2019). Community-Based Fall Armyworm (*Spodoptera frugiperda*) Monitoring, Early warning and Managemen. Training of Trainers Manual, p. 21.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., Godwin, J., Gomez, J., Moreno, P.G. & Murphy, S.T. (2017). Fall armyworm: impacts and implications for Africa. *Outlooks Pest Manag.,* 28, 196–201. https://doi.org/10.1564/v28

Dyer, L. A., Dodson, C. D., Beihoffer, J. & Letourneau, D. K. (2001). Trade-offs in antiherbivore defenses in Piper cenocladum: Ant mutualists versus plant secondary metabolites. *Journ. of Chem. Eco.* 27(3), 581–592. https://doi.org/10.1023/A:1010345123670

Dyer, L. A., Richards, J. & Dodson, C. D. (2004). Isolation, synthesis, and evolutionary ecology of Piper amides. In *Piper: A model genus for studies of phytochemistry, ecology, and evolution* (pp. 117-139). Springer, Boston, MA.

Ekefan, E. & Eche, C. (2013). Indigenous biopesticides use and biodiversity management. In: Proceedings of the 9th National Conference on Organic Agriculture in Nigeria. Nigeria: NCOAN.

European Commission, EC (2008). European Commission Regulation No. 889/2008 of 5 Sep. 2008 laying down detailed rules for the implementation of council regulation (EC) No 834/2007 on organic production and labeling of organic products with regard to organic production, labelling and control. *Official J. Europ. Union L.,* 250, 1-84.

FAO & CABI (2019). Community-Based Fall Armyworm monitoring, early warning and management: Training of Trainers Manual.

FAO (2019). Regional workshop for Asia sustainable management of fall armyworm. Department of Agriculture Kunming City, Yunnan Province, China, 11–15 November 2019

FAO (2020). Global Monitoring for Fall Armyworm Control. Available online: http://www.fao.org/fall-armyworm/monitoring-tools/faw-map/en/. Accessed on 20 June 2020

Food and Agriculture Organization of the United Nations (FAO) (2018). Integrated management of the fall armyworm on maize: a guide for farmer field schools in Africa. Rome, Italy: FAO. Retrieved from http://www.fao.org/3/I8665EN/i8665en.pdf

Goergen, G., Kumar, P., Sankung, S., Togola, A. & Tamò, M. (2016). First Report of Outbreaks of the Fall Armyworm Spodoptera frugiperda (J E Smith) (Lépidoptère, Noctuidae), a New Alien Invasive Pest in West and Central Africa. *PLoS ONE,* 11(10), e0165632. https://doi.org/10.1371/journal. pone.0165632

Gonzalez, A. G. (2006). Open science: open source licenses in scientific research. *North Carolina J. of Law Tech.,* 7, 321-366.

Groote, H. D., Kimenju, S. C., Munyua, B., Palmas, S., Kassie, M., & Bruce, A. (2020). Spread and impact of fall armyworm (Spodoptera frugiperda J.E. Smith) in maize production areas of Kenya. *Agric. Ecosyst. & Environ. 292*. https://doi.org/10.1016/j.agee.2019.106804

Gupta, S. & Dikshit, A. K. (2010). Biopesticides: an ecofriendly approach for pest control. *J. of Biopest.* 3, 186–188.

Haenniger, S., Goergen, G., Akinbuluma, M. D., Kunert, M., Heckel, D. G. & Unbehend, M. (2020). Sexual communication of *Spodoptera frugiperda* from West Africa: Adaptation of an invasive species and implications for pest management. *Scientific Rep.* 10(1), 1-9.

Idrees, A., Qadir, Z. A., Akutse, K. S., Afzal, A., Hussain, M., Islam, W., Waqas, M. S., Bamisile, B. S. & Li, J. (2021). Effectiveness of entomopathogenic fungi on immature stages and feeding performance of Fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) Larvae. *Insects,* 12, 1–16.

Kabaluk, J. T., Lafontaine, J. P. & Borden, J. H. (2015). An attract and kill tactic for click beetles based on Metarhiziumbrunneum and a new formulation of sex pheromone. *J. Pest Sci.,* 88 (4), 707-716.

Kalyebi, A., Otim, M.H., Walsh, T. *et al.* Farmer perception of impacts of fall armyworm (*Spodoptera frugiperda* J.E. Smith) and transferability of its management practices in Uganda. *CABI Agric Biosci* 4, 9 (2023). https://doi.org/10.1186/s43170-023-00150-w

Kenis, M., et al. (2019). *Telenomus remus*, a candidate parasitoid for the biological control of *Spodoptera frugiperda* in Africa, is already present on the continent. *Insects*, 10(4), 92. https://doi.org/10.3390/insects10040092

Khater, H. F. (2012) Prospects of botanical biopesticides in insect pest management. *Pharmacologia,* 3(12), 641–656.

Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L. & Tefera, T. (2019). Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (Spodoptera frugiperda) in Ethiopia and Kenya. *Int. J. Pest Manag.,* 65, 1– 9. https://doi.org/10.1080/09670874.2017.1423129

Mazid, S., Kalita, J. C. & Rajkhowa, R. C. (2011). A review on the use of biopesticides in insect pest management. *Intern. J. of Sci. and Adv. Tech.* 1(7), 169–178.

Mweke, A., Akutse, K. S., Ulrichs, C., Fiaboe, K. K. M., Maniania, N. K. & Ekesi, S. (2019). Efficacy of aqueous and oil formulations of a specific *Metarhizium anisopliae* isolate against *Aphis craccivora* Koch, 1854 (Hemiptera: Aphididae) under field conditions. *J. Appl. Entomol.,* 143, 1182–1192. https://doi.org/10.1111/jen.12705

Ndolo, D., Njugunaa E., Adetunji, C. O., Harbor, C., Rowea, A., Breeyend, A. D., Sangeethae, J., Singhf, G., Szewczykg, B., Anjorinh, T. S., Thangaduraii, D. & Hospeti, R. (2019). Research and development of biopesticides: challenges and prospects. *Outlooks on Pest Managt.* 30, 267-276.

Odeyemi, Oluwakemi & Lawal, Bosede & O.F.Owolade, & Olasoji, Julius & O.A.Egbetokun, & T.Omodele, & Anjorin, Folake. (2020). Fall Armyworm Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae): Threat to maize production in Nigeria. Nig. Agric. J. 51. 101-108.

OECD (Organisation for Economic Cooperation and Development) (2021). Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology. Working Document on the Evaluation of Microbials for Pest Control JT03257921. 2008. Available online: https://www.oecd.org/env/ehs/pesticides-biocides/41946259.pdf (accessed on 24 September 2021).

Ofor, M. O., Ibeawuchi, I. I. & Oparaeke, A. M. (2009). Crop Protection Problems in Production of Maize and Guinea Corn in Northern Guinea Savanna of Nigeria and Control Measures. *Nat. and Sci.* 7(11), 45-51.

Ogunfunmilayo, A. O., Kazeem, S. A., Idoko, J. E., Adebayo, R. A., Fayemi, E. Y., Adedibu, O. B., et al. (2021). Occurrence of natural enemies of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Nigeria. *PLoS ONE,* 16(7), e0254328. https://doi. org/10.1371/journal.pone.0254328

Oliveira, M. A., Iost Filho, F. H. & Thuler, R. T. (2018). Efficiency of *Bacillus thuringiensis* in controlling the corn fall armyworm in lab conditions. *Revista Inova Ciência & Tecnologia/Innov. Sci. & Tech. J.* 14-19.

Pathak, V. M., Verma, V. K., Rawat, B. S., Kaur, B., Babu, N., Sharma, A., Dewali, S., Yadav, M., Kumari, R., Singh, S., Mohapatra, A., Pandey, V., Rana, N., & Cunill, J. M. (2022). Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review. Front. in Microb. 13. https://doi.org/10.3389/fmicb.2022.962619

Paudel Timilsena, B., Niassy, S., Kimathi, E. *et al.* Potential distribution of fall armyworm in Africa and beyond, considering climate change and irrigation patterns. *Sci Rep* 12, 539 (2022). https://doi.org/10.1038/s41598-021-04369-3

Phiri, F. (2017). Sambia's Armyworm Outbreaks: Is Climate Change to Blame. Inter Press Service. http://www.ipsnews.net/2017/01/zambias-armyworm-outbreak-isclimate-change-to-blame/

Rwomushana, I., Bateman, M., Beale, T., Beseh, P., Cameron, K., Chiluba, M., Clottey, V., Davis, T., Day, R., Early, R., Godwin, J., Gonzalez-Moreno, P., Kansiime, M., Kenis, M., Makale, F., Mugambi, I., Murphy, S., Nunda, W., Phiri, N., Pratt, C. & Tambo, J. (2018). Fall armyworm: impacts and implications for Africa. *Evidence Note Update,* 1–53.

Sampson, C. & Kirk, W. (2013). Can mass trapping reduce thrips damage and is it economically viable? Management of the western flower thrips in strawberry. *PLoS One,* 8(11), e80787.

Sartiami, D., Harahap, I. S., Kusumah, Y. M. & Anwar, R. (2020, March). First record of fall armyworm (Spodoptera frugiperda) in Indonesia and its occurence in three provinces. In *IOP Conference Series: Earth and Env. Sci.* 468(1), 012021).

Sokame, M., Musyoka, B., Obonyo, J., Rebaudo, F., Abdel-rahman, E.M., Subramanian, S., Kilalo, D.C., Juma, G. & Calatayud, P. (2021). Impact of an exotic invasive pest, *Spodoptera frugiperda* (Lepidoptera : Noctuidae), on resident communities of pest and natural enemies in maize fields in Kenya. *Agron.* 11, 1074.

Timothy, O. A. (2022). Management of fall armyworm (*Spodoptera frugiperda*) in Nigeria: theoretical and practical approach. Retrieved on Oct 10, 2022 from: https://tribuneonline.com/management-of-fall-armyworm-spodoptera-frugiperda-in-nigeria-theoretical -and-practical-approach.

Togola, A., Meseka, S., Menkir, A., Badu-Apraku, B., Bouka, O., Tamò, M. et al. (2018). Measurement of Pesticide Residues from Chemical Control of the Invasive *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in a Maize Experimental Field in Mokwa, Nigeria. *Int. J. Environ. Res. Public Health,* 15, 849–860. https://doi.org/10.3390/ijerph15050849

Tudi M, Daniel Ruan H, Wang L, Lyu J, Sadler R, Connell D, Chu C, Phung DT. Agriculture Development, Pesticide Application and Its Impact on the Environment. Int J Environ Res Public Health. 2021 Jan 27;18(3):1112. doi: 10.3390/ijerph18031112. PMID: 33513796; PMCID: PMC7908628.

USEPA (United States Environmental Protection Authority), (2021). What Are Biopesticides? Available online: https://www.epa.gov/ ingredients-used-pesticide-products/what-are-biopesticides (accessed on 24 September 2021).

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 Biol. and Pharm. Sci.* 1(1), 006–010.

Witzgall, P., Kirsch, P. & Cork, A. (2010). Sex pheromones and their impact on pest management. *J. Chem. Ecol.,* 36(1), 80-100.