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A REVIEW OF BIOPESTICIDE PRODUCTS AS ECOLOGICAL ALTERNATIVE AGAINST FALL ARMYWORM (*SPODOPTERA FRUGIPERDA*) IN AFRICA

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ABSTRACT

Spodoptera frugiperda, Fall Armyworm (FAW), poses an existential threat to farmers in Africa given their destructive effect on crops. This is essentially the case in south-eastern Nigeria where major crops such as cassava and maize are highly vulnerable to the adverse effects of the pest. This paper reviewed published work on the availability of biopesticides that can control FAW without compromising environmental sustainability. Altogether, 50 active ingredients have been identified as potential biopesticides to control fall armyworm globally, out of which 29 were described in Africa. Although there are reports of remarkable successes in the application of these organic pesticides, there is a need to identify more biopesticides and also establishing the most effective modes of application for managing the pest. This review examines possible biopesticides that may be used in controlling FAW in Africa and also provides insight for further research.

Keywords: *Biopesticide, Active Ingredient, Environmental Sustainability, Pesticide*

INTRODUCTION

The emergence of FAW in Africa is worrisome given its destructive effect on food crops such as maize. As FAW continues to destroy economic crops, managing the pest often necessitates the usage of large quantities of chemical insecticides even when they are normally associated with environmental risks and health hazards. Though FAW originated from the Western Hemisphere, it has now become a pest of economic importance in Africa (Kalleshwaraswamy *et al*., 2019; Chen *et al*., 2019; Nagoshi *et al*., 2018; Otim *et al*., 2018; Brevault *et al*., 2018; Nagoshi *et al*., 2017). However, Goergen *et al.,* (2016) reported the first case of FAW invasion in Nigeria**.** Maize is one of the staple foods in many African countries and it provides a source of income to both small and large-scale farmers. Although there have been concerns of low soil fertility, drought, and biotic stress such as pests and diseases, the arrival of FAW tends to increase these present concerns. Farmers in Africa are losing their crops to its attack at quite an alarming rate. For example, maize production loss estimates caused as a result of FAW infestations range from 50% to 100% (Baudron *et al*., 2019; Rwomushana *et al*., 2018). Though there have been reports on the use of technology and chemical pesticides in the control of FAW however, these reports have failed to provide a single strategy to effectively manage the pest (Oliveira *et al*., 2018; FOA, 2018; Burtet *et al*., 2017).

Maize crops are attacked by FAW at larval stages as seen in Plate 1. This is the most destructive phase in their lifecycle as they attack mostly the young leaves (Obok *et al.,* 2020). Though the larva could also feed on maize silk and tassel tissues, their major feeding site preference is the succulent and tender leaf tissues, especially at whorl stages (CABI, 2018). Perhaps mature leaves are classified as unsuitable sites for the growth and development of the pest due to their preference for tender leaf tissues (Pannuti *et al*., 2016). The mouthpart of FAW larvae encourages rapid defoliation which often increases with the age of the larvae (CABI, 2018). Meanwhile, the first to third larval instar causes injuries ranging from perforations to defoliations of maize plant leaf while ribs and leaf stalks are less likely affected (CABI, 2018). However, the adult (males and females) is not destructive to host crops.

Plate 1: Larvae of fall armyworm on a maize cob
*Source***:** Centre for Agriculture and Bioscience International (CABI)

Since the invasion of FAW in Africa, the pest has undoubtedly proven to be an existential threat to smallholders as it has continued to ravage economic crops (CABI, 2018). Despite this apparent threat to livelihood, controlling the pest using chemical pesticides cannot be reasonably justified due to environmental concerns such as heavy mental deposit on the terrestrial soil ecosystem (Misra *et al.,* 2015). As of September 2018, FAW had invaded 44 African countries causing massive loss of crop yield (Cock *et al.,* 2017). The projection that FAW would give rise to an annual crop yield loss of between 4.3 to 17.7 million tons of maize in Africa is frightening (Rwomushana *et al.,* 2018). A recent evidence notes from CABI revealed that farmers in Ghana could lose 45% of maize production annually due to FAW infestation (Abrahams *et al.,* 2017; Day *et al.,* 2017). Similar study showed that Namibia could lose 57% of total maize production annually due to FAW infestation (FAO, 2018). This forecast is indeed a challenge and calls for immediate action.

TAXONOMY OF FALL ARMYWORM

Fall Armyworm (FAW) is a lepidopteran pest that feeds in large numbers on the leaves, stems, and reproductive parts of more than 350 plant species causing significant damage to economic crops such as maize, rice, sorghum, sugarcane, and wheat (CABI, 2018).

TAXONOMIC TREE
Domain: Eukaryota
Kingdom: Metazoa
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Lepidoptera
Family: Noctuidae
Genus: *Spodoptera*
Species: *Spodoptera frugiperda*

BIOLOGY AND ECOLOGY OF FALL ARMYWORM

Eggs are laid at night on the leaves of the host plant stuck to the lower surface of the leaves in tight clusters of 100-300 and sometimes in two layers usually covered with a protective layer of abdominal bristles (CABI, 2018). Hatching requires 2-10 days (usually 3-5) (FAO, 2018). The mortality rate following emergence may be high in some cases due to climatic factors and attacks by predators, parasitoids, and pathogens (CABI, 2018). During the first instar stage, young larvae move to the whorl and feed on the underside of the young leaves causing a characteristic 'windowing' effect (CABI, 2018). However, in the second and third instar stages, larvae are usually cannibalistic, and thus one or two larvae per whorl (Obok *et al.,* 2020). The rate of larval development through the six instars is controlled by a combination of diet and temperature conditions and usually takes 14-21 days. Larger larvae are nocturnal unless they enter the armyworm phase when they swarm and disperse, seeking other food sources. Pupation takes place inside a loose cocoon in an earthen cell but has also been observed in the kernels of the maize cob or rarely between leaves on the host plant and a period of 9-13 days are required for development. Adults emerge at night, and they typically use their natural pre-oviposition period of 3-4 days to fly for many kilometres before they settle to oviposit, sometimes migrating for long distances. In the migratory habit, moths can migrate over 500 km (300 miles) before oviposition.

The female normally deposits most of her eggs during the first 4-5 days of life, but some oviposition continues to occur for up to 3 weeks (CABI, 2018). On average, adults live for 12-14 days (CABI, 2018; FAO, 2018). Fig 1 shows the developmental stages of FAW.
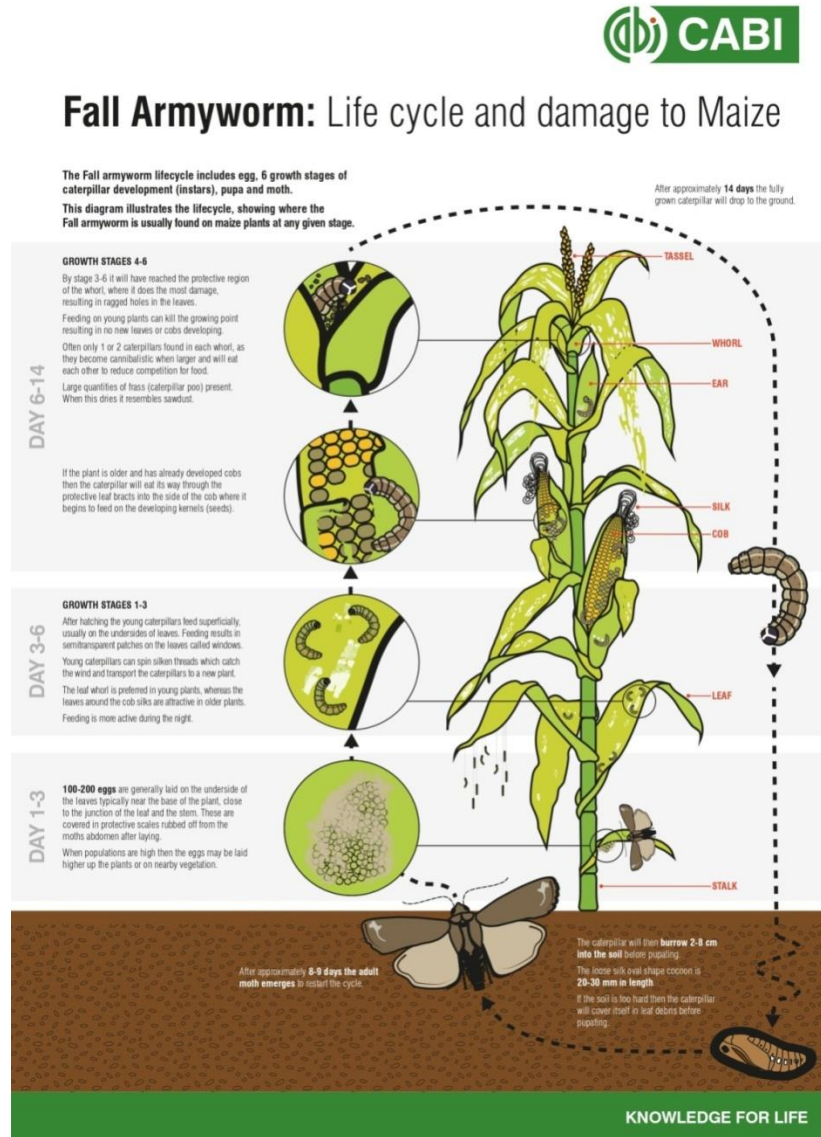

Figure 1: FAW life cycle
Source: Centre for Agriculture and Bioscience International (CABI)

BIOPESTICIDES FOR PEST MANAGEMENT

The use of plant-derived pesticides (commonly called "botanicals") in pest management is a cultural practice of most African farmers. It could provide a potential arsenal against FAW in Africa. The mode of action of botanical pesticides is broad and ranges from repellency, knock-down, larvicidal to anti-feedant, moulting inhibitors, and growth regulation. They have a broad-spectrum activity with very little or no mammalian toxicity. However, some botanicals like tobacco extracts are highly toxic to pests and humans (Ashishie and Ashishie (2018). Smallholders normally use

water to extract bioactive ingredients as a concoction after grinding plant materials. Essential oils are also used at times. A review of literature in search of biopesticides that are effective against FAW showed that a total of 29 active ingredients (AI) have so far been identified in Africa of which Tunisia, Kenya, and South Africa have the highest number of registered biopesticide products as well as active ingredients (Fig 2) (Bateman *et al.,* 2018). Tunisia has 70 products and 11 AI, Kenya has 85 products and 20 AI, while South Africa has 61 products and 18 AI (Bateman *et al.,* 2018).
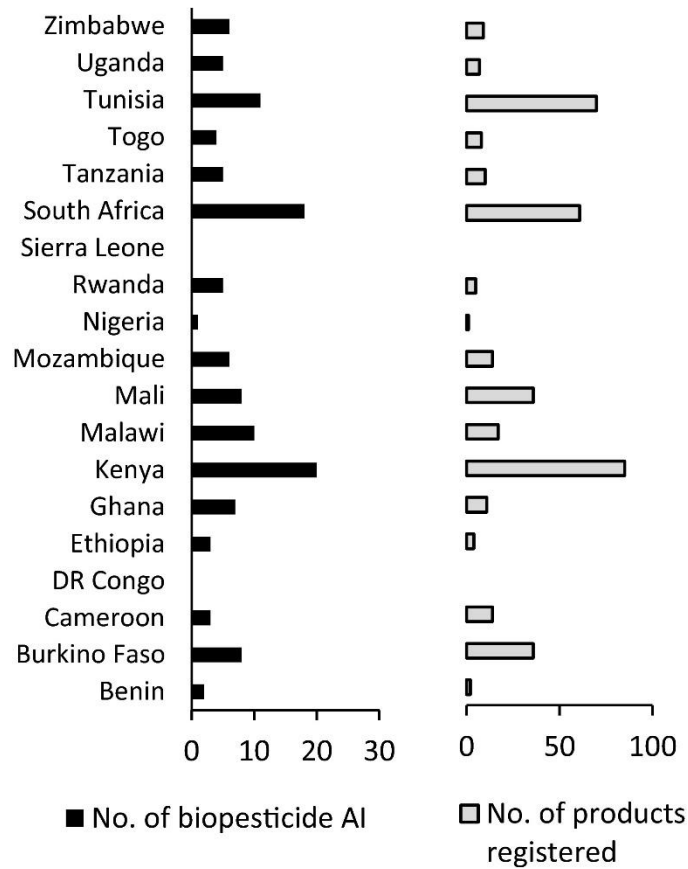
Figure 2: Registered biopesticide active ingredients (left, dark) and corresponding products (right, pale) in 19 countries in Africa.

Source: Bateman *et al.,* 2018

Registered for field use against FAW or other Lepidoptera in our survey	Reported effective against FAW in field trials in native range; field trials and evaluation needed in Africa	Reported effective against FAW in lab bioassays; field trials needed in Africa	Reported effective against related pests; bioassays needed for FAW followed by field trials if justified	Not recommended for follow-up on available information (at this time)
Not registered				Ethyl pulmitate
Registered outside sub-Saharan Africa	*Spodoptera frugiperda* NPV	Dysphana *ambrosiodes*	Garlic oil Allyl isothiolyanate Sucrose octanoate	2-phenylethyl-propanoate Anagrapha-fallipera NPV *Chromobacterium subtsugae.* Cinnamaldehyde Cryolite d-glucitol, octanoate GS-omega/kappa-Hxtx-Hv1a Helicoverpa zea NPV *Isaria fumosorosea* Beet armyworm NPV Potassium salts of fatty acids S-methroprene Soybean oil
Registered within sub-Saharan Africa	Azadirachtin (neem products) *Bacillus thuringiensis* Lufenuron Methoxy fenozide Oxymaytine Pyrethrins Sex pheromones Silicon dioxide Spinetoram Spinosad *Trichogramma* spp	*Beauveria bassiana* Matrine	Capsaicin Kaolin clay Maltodextrin *Metarhizium anisopliae* Orange oil	Borax Canola oil Citric acid Emamectin benzoate Eugenol *Steinernema* spp Sulphur

Source: Bateman *et al.,* (2018)

An overview of biopesticide active ingredients (Table 1) revealed that orange oil which is an active ingredient extracted from (Orange plant) *Citrus sinensis,* has been reported effective against pests and that bioassay is needed for FAW control to be followed by field trial (Bateman *et al.,* 2018). Altogether, a total of 50 biopesticide active ingredients have been identified and registered worldwide in the management of FAW (Bateman *et al.,* 2018). This

clarification becomes necessary because the list of registered biopesticides and their active ingredients in FAW management is regularly updated. Among the registered 50 active ingredients are products from 417 botanicals, 274 microbials, 271 microbial extracts, one parasitoid (*Trichogramma pretiosum* Riley), and two entomopathogenic nematodes *Steinernema carpocapsae* (Weiser) and *Steinernema feltiae* (Filipjev) (Bateman *et al.,* 2018). One of the microbial biopesticides identified as a priority by Bateman *et al.,* (2018) was baculoviruses, which are highly host-specific, non-pathogenic to beneficial insects and other non-target organisms, and are attractive candidates for integrated pest management. Littovir (RAVAGEX), a baculovirus based product, initially developed for control of African cotton leafworm, has been tested and registered against FAW in Cameroon by Andermatt Biocontrol (CABI, 2018). Work on entomopathogenic nematodes of FAW is in progress at the University of Neuchatel (CABI, 2018). *Azadirachtin* (neem) has been reported to be effective against FAW in the Americas and Ghana (CABI, 2018). In Ghana, for example, three products based on *Azadirachtin* are already registered for use against FAW. *Oxymatrine* and *Matrine* (found in *Sophora* spp) are reported effective against FAW in the field and laboratory bioassays respectively in the Americas (Bateman *et al.,* 2018). Pyrethrins (from *Chrysanthemum cinerariaefolium*, formerly *Pyrethrum*) are effective against FAW and registered in Africa, but have non-target risks that require mitigation (Bateman *et al.,* 2018). Also, extracts from *Synedrella nodiflora* and *Lupinus stipulatus* have shown to have biological effects on mature insects of FAW (FAO, 2018). Researchers from Brazil have also demonstrated that the application of a 5% extract concentration of pequi fruit decreased the amount of damage caused by the FAW caterpillars (Souza *et al.*, 2018).

To optimize the use of botanical extracts for FAW control, Kelita *et al.,* (2020) screened some commonly used plant pesticides in laboratory trials to determine their toxicity against the pest. They discovered that highest larval mortality was obtained from *Nicotiana tabacum* (66%) and *Lippia javanica* (66%) during contact toxicity tests. Similarly, in a feeding bioassay, the authors observed that *L. javanica* (62%) and *N. tabacum* (60%) exhibited high larval mortality. Further field investigation where maize plants infested with FAW larvae were treated with plant extracts revealed that *N. tabacum* and *L. javanica* were effective at reducing foliar damage compared to the untreated control whilst the synthetic pesticide chlorpyrifos was the most effective in reducing FAW foliar damage. While investigating the efficacy of some plant extracts as storage protectants against *Callosobruchus maculatus*, Mojisola *et al.,* (2016) produced a biopesticide for preserving beans and grains. They investigated and developed a plant-based biopesticide formulation using lemongrass leaves to control *Callosobruchus maculatus* that attack food crops in storage facilities especially maize and beans weevils. Extract from lemongrass is normally used by locals in Nigeria for treatment of malaria because of its medicinal properties (Mojisola *et al.,* 2016).

CONCLUSION

Since the invasion of FAW in Africa, the pest has proven to be a source of concern to smallholders. The projection by Rwomushana *et al.,* (2018) that fall armyworm would give rise to an annual crop yield loss of between 4.3 to 17.7 million tons of maize in Africa calls for immediate action to forestall this downturn as farmers livelihood is being threatened. An aggressive approach that would easily manage the invasive pest and prevent this economic forecast from transiting from the realm of theory to reality is required. While some farmers have resort to the use of chemical

pesticides to manage FAW, environmentalists have raised concern about the negative implication of the continuous use of chemical pesticides on the terrestrial soil ecosystem. Interestingly, in an assessment of potential biopesticide options for managing fall armyworm in Africa, FAO (2018) suggested the use of plant and microbial extracts in the fight against the pest at the continental level as possible alternatives to chemical pesticides. Thus since Nigeria is one of those countries with very little data on approved biological products for the management and control of FAW in Africa, the call to intensify investigation on biopesticide to manage the pest is a call to either discover new active ingredients that can potentially get rid of it or at most variants or strains of active ingredients already registered. Although scientific treatise has highlighted the numbers of biological products and their active ingredients approved for FAW control in Africa, there is a need for an extensive search of more potential biopesticides that could control the pest. This would provide smallholders with an easy and cost-effective means of managing FAW without compromising environmental sustainability.

CONFLICT OF INTEREST

The authors declare there is no conflict of interest regarding this publication

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