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Review of Fall Armyworm (*Spodoptera frugiperda*) invasion in Nigeria and lessons learned for sustainable food production

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ABSTRACT

Fall armyworm (*Spodoptera frugiperda*) is a lepidopterous insect pest belonging to the family noctuidae. This insect pest was first discovered more than 200 years ago but was first recognized as a serious economic pest about 93 years ago (Luginbill 1928). The study of review of Fall Armyworm in Nigeria was carried out to know the present status, and various methods of control being used by farmers. The methodology used is to search the available literature on the status and the methods of control being employed by farmers. It was discovered that in the states in Nigeria where Fall Armyworm (FAW) was reported, an average of 395.05 hectares were affected per state. Average of $52.7m was lost per state so far since 2016 in state affected by FAW in Nigeria. Despite that there have been concerted efforts by various stakeholders in controlling FAW, many farmers have abandoned maize farming while sale of green maize during harvest has reduced drastically. It was also discovered that farmers employed various materials both conventional and unconventional for the control of Fall Armyworm (FAW). This discovery is very important in FAW and environmental management and policy briefs.

INTRODUCTION

Fall armyworm (*Spodoptera frugiperda*) has suddenly become a major pest of Cereals in Africa.

However, in 2016, there was an outbreak of insect pest called Fall Armyworm (*Spodoptera frugiperda*) in Nigeria, later Benin, Togo, Ghana and other West African countries. The worse hit cereals were maize (*Zea mays*) and sorghum (Sorghum *bicolor*) (Koffi et al., 2020). *Spodoptera frugiperda* is native to Tropical and Sub-tropical regions of America (Wiseman 1987, Odeyemi, 2018). It was first recognized as a serious economic pest over 200 years ago (Luginbill, 1928; Wiseman, 1987). It is one of only few pests that periodically disperse and breed throughout the United States of America (Wiseman, 1987). The Fall Armyworm constitutes pests and causes serious damage and destruction to many crops in various areas of South Eastern United States, Mexico and Central and South America (Wiseman and Davis, 1979; Wiseman, 1987). It is a long distance and migratory transboundary pest. It is a harmful insect that has been rapidly spreading out African continent (2016), South- East Asia (2018) and Southern part of China (2019). Fall Armyworm is polyphagous and is found not only on poaceae (maize, sorghum, sugarcane, rice, etc.) but it is also found on peanuts, cotton, Brassicaceae, (Cabbage: *Brassica oleracea var capitata*), Curcurbitaceae (Cucumber: *Cucumis sativus*) and Solanaceae (Potato: *Solanum tuberosum*). It is also reported to have been causing extensive damage to oil palm nurseries in Cote d'Ivoire since 2016 (N'guessan, 2019). *Spodoptera frugiperda* belong to the family Noctuidae.

Distribution

Fall armyworm is an important pest of sorghum in tropical America. It is found in sorghum fields in Southeastern USA. It is one of the biotic constrains to sorghum production in Tropical America. Sorghum production in much of Central and South America have also been reported to be affected by Fall Armyworm (ICRISAT, 1989; Ajiboye 2019; Kofi et al.2020). There was severe outbreak of Fall Armyworm in Southeastern, USA in 1975, 1976 and 1977. The estimated losses in US dollars was $61.2 million in 1975 and $31.9 million in 1976, while in 1977 losses in Georgia alone were estimated at $137.5 million (Sparks, 1979; ICRISAT, 1989; Ajiboye 2019). Fall Armyworm is also known to stray North from Southeastern, USA to South central and South eastern Canada (Bland and Jacques, 1978). Recently, Fall Armyworm has now spread to African continent, South East Asia and Southern part of China and Australia in 2020.

Other Species of *Spodoptera* in Africa

Before the outbreak of the *frugiperda* species of *Spodoptera,* some species of *Spodoptera* found in Africa include cotton leafworm called *Spodoptera littoralis*. This is called Egyptian cotton leafworm. The host range include cereals like *Zea mays* (maize), *Oryza* sp., and other crops such as groundnut (*Arachis hypogea*), cowpea (*Vigna unguiculata*), tomato (*Lycopersicon esculentus*), onion (*Allium cepa*), cabbage(*Brassica oleracea var capitata*), okra (*Abelmoschus spp*), cotton (*Gossypium* sp.), vegetables and fruits (NRI 1996; Koffi et al. 2020).

Spodoptera littoralis constitute pest to cotton by the damage it causes to foliage of tobacco. This results in the reduction of yield of tobacco and death of young tobacco plants. The larva also attack stem, foliage and green pods of cowpea (*Vigna unguiculata*). The larva of *Spodoptera littoralis* also attacks leaves of cocoa (*Theobroma cacao*) and likewise the leaves of okra, tomato, cabbage, onion, eggplant and sesame (*Sesamum indicum*).

Another species of *Spodoptera* that is common in Africa before the invasion of *frugiperda* is *Spodoptera exempta* (Odeyemi 2016). It is usually referred to as Africa armyworm. The larva attack leaves of maize (*Zea mays*), millet (*Pennisetum glaucum*), rice (*Oryza glaberrima*; *Oryza sativa*) and sorghum (*Sorghum* sp.)

Biology of *Spodoptera frugiperda*(Fall Armyworm)

Fall armyworm has complete metamorphosis. Adult lays eggs on immature plants and hatch in about 3-5days. The larvae which emerge in 14- 28 days may tunnel directly into the maize ear. Pupation takes place in the soil for about 7-14days after development. The pupae then changes to adult. The adult moth lives for about 11-14days. The cycle repeats in warmer climates. Fall armyworm is highly migratory and can migrate as far as 100s of kilometer and can move from one country to another by migration. Life cycle of the fall armyworm takes about 30 -40 days (Prasanna et al., 2018).

Host Plants of Fall Armyworm (*Spodoptera frugiperda)*

Fall armyworm has over 80 host plants but known to prefer grasses (Dively, 2018; Chidege et al., 2019). Among the plants in the world that serve as host plants for fall armyworm include – maize (sweet maize and field maize), Sorghum, Bermuda grass, grass weeds (crab grass), Alfafa, barley, buckwheat, cotton, clover, oat, millet, peanut (groundnut), rice, ryegrass, sugarbeet, Sudan grass, soybean, sugarcane, tobacco, wheat, sweetpotato, turnip, tomato, cabbage, cucumber, apple, grape, orange, papaya (pawpaw), strawberry, oil palm and some flowers (Dively, 2018).

Agricultural Crops infestation of Fall Armyworm (FAW).

Fall armyworm normally attack the seedlings of cereal crops like maize, sorghum, etc and turn the leaves of the plant to rag looking mass. The larva normally damages

the whorl of the plants. High infestation can destroy the growing tip of maize or sorghum and can prevent ear formation in maize. Fall armyworm normally attacks the ears or cobs of maize formed as well.

Cereals belong to the family Poaceae. They play vital role in the nourishment of both humans and animals. They store longer and are easily transported. Therefore, cereals movement for the purpose of trade and as germplasm is sacrosanct. Cereals are very rich in energy, protein, mineral elements such as potassium and calcium, vitamin A, vitamin C and essential amino acids. Cereals are consumed in different forms: pastes, noodles, cakes, breads, drinks, etc. the major cereal crops in Nigeria are maize, rice, sorghum, wheat, pearl millet, sugar cane and fonio millet.

According to Dively (2018), the damage is estimated at $13.3 billion and is a major threat to food security.

Case study of Agricultural crops infestation of Fall Armyworm in Nigeria

In Nigeria, fall armyworm is a threat to agro and agro-allied industries. In the areas affected by fall armyworm in Nigeria, average of 395.05 hectares of land is affected per state. Average crop loss of 68.2 % (in maize production) has been recorded per state affected by fall armyworm. Average of $52.7m was lost per state so far since 2016 in states affected by fall armyworm. Despite that there have been efforts in 12 states in Nigeria as at 2018, many farmers have abandoned maize planting in those parts of the country while sale of green maize during time of harvest have reduced drastically (Odeyemi, 2018; Ajiboye, 2019).

Control of Fall Armyworm

Various control approach have been employed in the control of fall armyworm in Nigeria. However, the control option that will give quick “knock down” is the first line of action that a typical African farmer will think of. But the environment is as important as control of fall armyworm. Both old and new classes of pesticides are being used for the control of fall armyworm in Nigeria. However, the best control option is the Integrated Pest Management (IPM) that integrates both the use of insecticides, cultural and biological control in economic and environmental balanced approach.

The thresholds recommended for farmers in Africa include when 10-30% of the maize are infested with early whorl stage of Fall armyworm or when 30-50% of the maize field are infested with late whorl and pretassel stages of Fall armyworm or when 10-30% maize fields are infested with tassel silking and ear stages for commercial farmers.

The cultural methods employed by the farmers include intercropping of susceptible crops (e.g. maize, sorghum) with crops not susceptible (like yam, cassava, etc.). Also, early planting or the use of early maturing varieties of maize has been found effective. The practice of closed season, which is, burning of residue of maize stubbles and stem after the harvest to kill pupae or diapausing larvae of Fall armyworm or other Lepidoptera species (Adesiyun 1983). Thus the heat generated can kill the pupae in the soil. Deep tillage that destroys pupae in the soil may also be effective.

Table 1: Foliar Treatments- Higher Risk Insecticides for FAW in the US

Product Name	Active Ingredients	Other Comments
Lannate	Methomyl*	Available in Africa
Lorsban	Chlorpyrifos*	Pyrinex (+ SP)
Asana	Esfenvalerate*	Available in Africa
Perm-UP	Permethrin*	Available in Africa
Baythroid	Beta- cyfluthrin*	Thunder (+ neo)
Declare	Gamma cyhalothrin*	
Bifenture, capture, sniper	Bifenthrin	Available in Africa
Hero	Zeta- cypermethrin* + bifenthrin*	
Warrior, capture, generics	Lambda- cyhalothrin*	Super top (+neo)
Mustang Maxx	Zeta- cypermethrin*	Chemaprid
Tombstone	Cyfluthrin*	Available in Africa
Avaunt	Indoxacard	Avata, viper (+SP)
Besiege	Lambda- cyhalothrin* + chlorantraniliprole	

Restricted use products have 12-48hours re-entry and 1-7 days harvest interval. All classified highly hazardous or require mitigation measures to reduce risks.

(Author: Professor Galen Dively, Emeritus Professor, Department of Entomology, University of Maryland: Management of Fall Armyworm (*Spodoptera frugiperda*) with emphasis on Bt Transgenic Technology)

Table 2: Foliar Treatment- soft insecticides for FAW control in the US

Product Name	Active Ingredients	Other Comments
Coragen, Premio	Chorantraniliprole	Available in Africa
Volian Targo	Chorantraniliprole + abamectin	Available in Africa
Minecto Pro	Cyantraniliprole	Available in Africa
Belt	Flubendiamide	Available in Africa
Blackhawk, Entrust	Spinosad	Available in Africa
Radiant, Exalt	Spinetoram	
Match	Lufenuron	Available in Africa
Intrepid	Methoxyfenozide	
Rimon	Novaluron	
Dimilin	Diflubenzuron	Available in Africa
Neemix, many others	Azadiractin	Available in Africa
Able, Agree	*Bacillus thuringiensis*	Bypel, Agoo

(Author: Professor Galen Dively, Emeritus Professor, Department of Entomology, University of Maryland: Management of Fall Armyworm (*Spodoptera frugiperda*) with emphasis on Bt Transgenic Technology).

Table 3: List of insecticides used for FAW control in Nigeria

Product Name	Active Ingredients	Other Comments
Ampligo	Chlorantroniliprole+ lambda – cyhalothrin	Used in Nigeria
Magicforce	Lambda – cyhalothrin + dimethroate	Used in Nigeria
Ematrex	Emamectin benzoate	Used in Nigeria
Best action	Cypermethrin + dimethroate	Used in Nigeria
Tihan	Spirotetiamat 75g/l + flubenbiamide	Used in Nigeria
Caterpillar force	Dichlorvos (DDVP) 100g/l	Used in Nigeria
Strongforce	Methomyl 90% Sp family carbamate	Used in Nigeria
Goldmax	Trade secret*	Used in Nigeria
Relambda	Lambda- cyhalothrin	Used in Nigeria
Picco	Fatty acid methylester	Used in Nigeria

(Compilation by Ajiboye, T.O 2020)
*****Active ingredient- not known.

Biological Control

The use of entomopathogenic fungi, bacteria and virus are promising. However, they have not been found sufficient without the addition of other control methods because they may be too slow to prevent economic damage and also they are influenced by weather conditions. Though, there is prospect for development of biopesticide of viruses, bacteria and fungi, the use of predators and parasitoids also has prospects. Among the predators are Earwig spp. (skirt and blouse) (*Forficula auricularia*), ground beetles, predacious bugs, various types of lady beetle, *Telenomus* spp., *Campoletis flavicinta, Chelonus* spp. Parasites and parasitoids include tachinid fly, *Winthemia trinitatis* and *Trichogramma*.

Use of Resistant Varieties

The use of host plant resistance combined with carefully timed minimum insecticide application (that will not disrupt the natural enemy balance) and appropriate cultural practices have been advocated as the appropriate integrated management for managing insect pests (Jackai and Singh, 1983; Pitan and Odebiyi, 2002; Ajiboye, 2018). This is particularly true of Fall armyworm. However, all efforts to get maize with complete resistance to Fall armyworm have not yielded complete success. Africa maize germplasms have not shown promising level of resistance to Fall armyworm (Dively 2018). Host plant resistance is particularly good for resource constrain African farmers with low level of application knowledge of other control methods and inadequate financial resources for purchase of inputs such as pesticides (Ajiboye, 2018; Dively, 2018).

Other control methods

However, there are various types of local control employed by farmers. These include the use of detergent soaked in water, use of battery carbide (dry cell); others include the use of wood ash, soap, neem

extract, and other botanicals. Some farmers in Tanzania, just like Nigeria also used wood ash and soap (Chidege et al., 2019)

Research Gaps

There is need to research into the use of host plant resistance for the control of fall armyworm in Africa. This is especially true for African farmers who will find it safer and cheaper than other control methods. Also, this will be equally good for African farmers who prefer to use open pollinated varieties (OPV) and select seeds for the next planting season from the current year harvest.

Other possible research questions (even though strains of maize and rice fall armyworm have been found (Pashley 1986; Nagashi and Meagher 2004), include whether there have been interspecific hybridization between *Spodoptera littoralis*, *Spodoptera frugiperda* and also between *S. exempta* X *S. frugiperda.* Even there is possibility of cross between *Spodoptera frugiperda X Spodoptera exigua ,* likewise, there is possibility of cross between *Spodoptera frugiperda X Spodoptera ornithogali .* Also, there is need to find out possibility of intergeneric hybridization between *Spodoptera* spp and other Lepidoptera (stem borer) affecting maize in Africa. Although, Ajiboye, 2018 found out that after sequencing maize stem borers, possible options in the process of identification with BLAST was *Spodoptera litura* which showed 75% resemblance to the samples to be identified though they were identified as *Eldana saccharina*. Likewise, another sample identified as *Eldana saccharina* shows 79% resemblance to *Spodoptera litura* (Ajiboye, 2018). There is also need to show whether there have been three-way cross between *Spodoptera littoralis* X *Spodoptera exempta* X *Spodoptera frugiperda*. If this occurs, a virulent strain may be produced. This has occurred in the case of plant parasite, *Striga hermonthica* and *Striga aspera* though a reciprocal cross. (Berner *et al.,* 1997; Ajiboye *et al.,* 2011).

CONCLUSION

Fall armyworm (*Spodoptera frugiperda*) has joined the arrays of Lepidoptera pests ravaging crops in Africa especially Nigeria and has become part of cohorts of pests constituting biological constraints to cereals especially maize production and other crop production. This is threatening food security in Africa. Nigeria population will be 400 million by year 2050 (Ibrahim, 2019; Ajiboye *et al.,* 2019). This necessitates the importance of pest control to increase food production needed to feed the expanding population.

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SECTION II: Comments on the sections of Manuscript below.

Title:	The title is not complete. Please, include place of armyworm invasion. You have not presented how this pest has constituted a major threat to the food security situation in Africa especially in Nigeria. You may need to x-ray the hunger and food security situation in Africa and especially Nigeria to really find the place of crop pests in this discourse. you may find some important information about these issues in these links: https://doi.org/10.1016/j.gfs.2019.08.001 https://premierpublishers.org/ajaerd/19120820382
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Introduction:	Author(s) needs to present more robust background information in this section. Please, can you provide historical background of armyworm before becoming a major pest of cereals in Africa? You need to give robust background information about armyworm and sustantiate the need to link it to the major crops. You may need to include the names of some crops belonging to these families (please,

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Tables, Figures, Graphs and additional files:	
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Is the title of the manuscript befitting for the manuscript? If no, please suggest in section II.	Yes
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