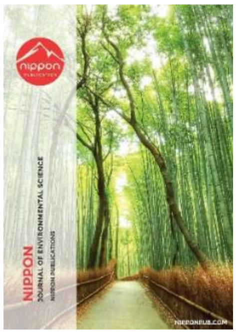

Nippon Journal of Environmental Science
ISSN: 2435-6786
1(4): 1010
https://doi.org/10.46266/njes.1010

Review Paper

An introduction of fall armyworm (*Spodoptera frugiperda)* with management strategies: a review paper

G.C. Sagar*, Bhusal Aastha, Khatri Laxman

Local Initiatives for Biodiversity, Research and Development, Pokhara, Nepal

*Corresponding Author: Email: gcsagar92@gmail.com

Received 29 May 2020; Accepted 28 June 2020

Abstract. Fall armyworm (FAW) (*Spodoptera frugiperda)* is a polyphagous crop pest native to America and later reported in West Africa in 2016. The larval stage is the most devastating in nature affecting the production of 353 species of crops with 70 percent yield loss in the overall economy. The pests are found to thrive in the temperature above 10 degree Celsius and the wings of moths are deformed above 30 degree Celsius. The cultural method are most effective method which contribute 56 percent of the pest management where push and pull method control 82.6 percent larvae per plant. Seed powder of *Azadirachta indica,* was found to control 70 percent larval mortality in lab whereas *Nicotiana tobacum* and *Lippia javanica* controlled the larvae by 66 percent in contact toxicity. *Metarhizium anisopliae,* a bio-control agent control the egg and neonate larvae by 87 percent and 96.5 percent. Chloropyrifos mixed with saw dust controls 20 percent of the pest and spinosad has effect with 90 percent larval mortality. An agro-advisory at large scale can play an indispensable role to minimize the incidence of the fall armyworm and help smallholder farmers to take the precautions on time reducing the possible crop loss. Integrated pest management is best for the management strategy of the fall armyworm.

Keywords: fall armyworm, incidence, integrated pest management, species, strategies

1. INTRODUCTION

The fall armyworm (FAW) *(Spodoptera frugiperda)* is one of the devastating insect pest belonging to the family Noctuidae and falls in the Lepidoptera order. It is a polyphagous pest (Baudron et al., 2019) causing damage to economically important cultivated cereal crops such as maize, rice, sorghum, cotton and various vegetable crops and eventually impacts on food security (FAO, 2017; CABI, 2018a; Bateman et al., 2018). The FAW feeds on leaves, stem and reproductive parts of plant species (Tefera et al., 2019). It is native to tropical and subtropical regions of the America. FAW, which was first found in America, is one of the common pests of maize in South and North America. In Africa, it was first reported in 2016 (Sisay et al., 2018) and has become one of the major invasive pests reaching over 30 countries across tropical and southern Africa including Madagascar, Seychelles and Cabo Verde at the end of 2017 (Bateman et al., 2018) which later reached over 44 countries (Sisay et al., 2019). There are 353 plants reported as a host for this pest (Kansiime et al., 2019).

Symptoms start with the larval stage making different sizes of papery windows in leaves leading to extensive defoliation of plants, occurrence of faecal materials and in later stage growth and development of plants is affected (Reddy, 2019). This insect has marching behaviour similar to that of the army causing havoc loss to the crops that come in its path (FAO, 2019; CABI, 2019). The FAW is devastating in nature and CABI (2017a) has predicted that the pest causes a possible loss of 6.1 billion US dollar only in African countries when control measures are not applied. The awareness programmes regarding the symptoms, early detection and control measures of the pest along with the recommendation of effective pesticide and bio-pesticide can be effective to minimize the loss. Assessing suitable crop varieties that can tolerate the FAW needs to be initiated and in a longer run national policies should promote lower risk control options through short term subsidies and rapid assessment and registration of bio-pesticides and biological control products (CABI, 2017a).

This paper highlights the necessary information on the introduction and identification of the fall armyworm with its possible control measures.

2. TAXONOMY OF THE INSECT

Two strains of fall armyworm such as rice strain and corn strain are found (Nagoshi et al., 2007). Rice strain feeds on rice and other pasture grasses whereas the corn strain feeds on maize, cotton and sorghum (CABI, 2020). These strains are morphologically similar but can be differentiated at the molecular level. The fall armyworm invaded in Africa has a greater diversity than that found in America which contains both the strains (Jacobs et al., 2018; CABI, 2020). Table 1 shows the classification of fall armyworm (*S. frugiperda*.

Table 1. Detail classification of fall armyworm (*S. frugiperda*)

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

(CABI, 2020)

3. DISTRIBUTION OF THE INSECT

An adult fall armyworm does have a capacity to fly over longer distances. The distance covered by one generation is estimated 300 miles. This fast migration rate may be due to the movement of air in weather fronts (Sparks, 1979). Fall armyworm is the major insect pests of tropical regions of the Americas and a native to tropical and subtropical regions of the Americas. In late 2016, it was reported for the first time in West Africa and rapidly spread throughout Sub-Saharan Africa (SSA) and later confirmed in forty four African countries (Sisay et al., 2019). The report suggests that the entry of both the strains of FAW from Americas to Africa was through commercial aircrafts, cargo containers or aeroplane holds and which later spread through the dispersal of wind (Day et al., 2018). Fall armyworm has been reported in many Asian countries. In Indian continent, it was first reported in 2018 in Karnataka. Later, it spread in different places like Bihar, Chhattisgarh, Gujrat, Maharashtra, Odisha, West Bengal etc (CABI, 2020). The insect pest has existed in Asian countries like China, Japan, Bangladesh, Cambodia, Indonesia, Myanmar, Korea, Thailand, Srilanka and Vietnam (FAO, 2019). Fall armyworm is yet to be recorded in some continent but the threat of its spreading is very high in a short time. In Nepal, it was first recorded in Nawalparasi district on 9th May 2019 (Bhusal and Bhattarai, 2019) and declaration of the invasion of FAW was made in the 19th meeting of Nepal Plant Protection Organization (NPPO) of Nepal (GoN, 2019). This pest has now been observed in fifteen districts of Nepal (Bajracharya and Bhatt, 2019).

4. ECONOMIC IMPORTANCE OF FAW

The larval stage of the fall armyworm is the most devastating in nature and detrimental to crops. In infected maize plants, the larvae of FAW can be observed on the different plant parts viz., young leaves, leaf whorls, tassels and cob depending on the growth stages of the plant (Goergen et al., 2016). To determine the loss due to FAW, many variables needs to be considered. In general, crop infestation due to the pest depends on the number of pest, time of infestation, natural enemies and pathogens of the pest available at that time and health (nutritional and moisture) status of the plant (CABI, 2019). Buadron et al. (2019) reported that when there is 26.4% to 55.9 % of pest incidence in maize then there is yield reduction of 11.57%. Chimweta et al. (2019) revealed that the 25-50% damage of leaf, silk and tassel results in 58% of yield reduction while 55-100 % of severity at the period of mid to late whorl stage caused up to 73% of yield loss (Huska and Gould, 1997; CABI, 2019). Kiprop (2017) reported 12.5 to 30% loss in country's economy in Malawi.

There was a yield loss of 3.2 million tonnes in Tanzania, 13.91 million tonnes in Uganda and 30.54 million tons in Ethopia during the reporting period (Kiprop, 2017). In Kenya, FAW affected 250,000 ha of agricultural land that accounts 11 percent of the country's total maize cultivated area (Kiprop, 2017). Similarly, production loss of maize estimated by FAW in Ghana and Zambia were 45% and 40%, respectively. In Africa, losses from FAW in twelve countries including Ghana and Zambia were estimated at 8.5 to 21 million tonnes worth about 250-630 million US dollars if no control measures were applied (Bateman et al., 2018).

A total of 170,000 ha of maize crops was estimated to be affected by FAW in India spreading in 10 states of the country (Sangomla and Kukreti, 2019). In China, Yunnan province is mostly affected area by this pest where 80,000 hectare of land has been found to be affected by this pest damaging the crops like maize, sorghum, sugarcane and ginger crops (Gu and Woo, 2019). The total area of 11,1992.17 ha has been affected in China and 98.6 percent of the total area is covered with maize (FAO, 2019). Likewise, more than 10,000 ha of maize was affected in four provinces of Cambodia (Cambodia News, 2019). FAW was detected in 8 regions, 22 districts and 71 administrative regions with the infestation rate of 0.5 to 32 % in Bangladesh. Similarly, almost 10,000 ha of land in Indonesia, 16,200 ha of land in Myanmar and 46,000 ha of land in Vietnam was reported to be infested by this worm. In Thailand, yield loss predicted by FAW was reported to be 25 to 40% that results in 130 million to 260 million dollar loss (FAO, 2019). Beshir et al. (2019) reported that the deadly pest having voracious appetite for the crops like maize and others can hugely affect the Nepalese farmers and economy. Since Nepalese climatic condition is suitable for the establishment of the populations of this pest, the potential crop loss up to 100 % is predicted in maize if this pest is not managed properly.

5. FAVOURABLE ENVIRONMENT FOR THE PEST

Fall armyworm are affected by climatic factors and changes in the climate may affect its distribution in various geographical regions. It has been reported that growth, abundance, survival, mortality, number of generations and other characteristics are highly affected by environmental condition (Ramirez-cabral et al., 2017).The pest overwintering mechanism governs the greater invasion of FAW. It thrives in cool, wet weather and severe outbreaks after heavy rainfall and humid weather (Westbrook and Sparks, 1986). A warm and humid growing season with heavy rainfall is favorable for the survival and reproduction of the pest. The development of the pests ceases below the temperature of 10 degree Celsius (Assefa and Ayalew, 2019). For the efficient reproduction, tropical and subtropical areas are favored where more than ten generations of the fall armyworm per year are reported compared to just two generations in temperate areas (Assefa and Ayalew, 2019). A warm temperature accelerates the development of insects with probability of increasing the multiple generations of fall armyworm (Westbrook and Sparks, 1986)

The varied temperatures at the different stages are required to complete the life cycle of fall armyworm. The minimum threshold temperature required is 10.9 degree Celsius with sandy clay or clay sand soils which is suitable for pupation and adult emergence (CABI, 2019). Eggs hatch within two to four days at temperatures of 21-27 °C (Assefa and Ayalew, 2019). The optimum temperature required for the development of larvae is 28 degree Celsius whereas pupation requires a bit lower temperature than for larval development with threshold temperature of 14.6 degree Celsius. The wings of the pest are deformed at temperature above 30 degree Celsius (CABI, 2019).

6. SYMPTOMS OF PEST DAMAGE IN MAIZE

Symptoms of FAW infestation in maize starts after the eggs are hatched. The typical symptoms caused by FAW is the papery windows of variable sizes and ragged edges with oblong to round appearance on the leaves leading to become loose and detach from the plants. At the severe stage, extensive defoliation can be observed with the excessive faecal material left over on the plant due to voracious feeding nature of larval instars. Eventually, growth and development of crops are stopped that results in no cob or tassel formation (Reddy, 2019). The windows pane of translucent patches are observed at 1st and 2nd instar infestation while larger elongated holes are visible at 3rd to 6th instars. At the end, the faecal of the FAW looks as sawdust-like materials in the maize funnel or on the leaves (CABI, 2018b).The leaf damage assessment of the crop can be done as follows as presented in the Table 2 (Sisay et al., 2019).

Table 2. Scale for the leaf damage assessment of the crop through fall armyworm (*S. frugiperda*)

Scale	Description
0	No visible leaf damage
1	Only pinhole damage on leaves
2	Pinhole and shot hole damage to leaf
3	Small elongated lesions (5-10 mm) on 1-3 leaves
4	Mid-sized lesions (10-30 mm) on 4-7 leaves
5	Large elongated lesions (>30 mm) or small portions eaten on 3-5 leaves
6	Elongated lesions (>30 mm) and large portions eaten on 3-5 leaves
7	Elongated lesions (>30 cm) and 50% of leaf eaten
8	Elongated lesions (30 cm) and large portions eaten on 70 % of leaves
9	Most leaves with long lesions and complete defoliation observed

7. Life Cycle of the insect

The lifecycle of the insect can be classified into four stages. The fall armyworm can be identified either by using morphological characters or through characteristic injury symptoms on susceptible crops or molecular characterizations (FAO and CABI, 2019).

Egg: The egg of fall armyworm is dome-shaped with a flattened base with 0.4 mm in diameter and 0.3 mm in length (Prasanna et al., 2018). Bajracharya and Bhat (2019) reported that eggs of the fall armyworm are creamy white in color with reticulate ribs covered with abdominal hairs. The female lays 100 to 200 eggs at a time in mass (Prasanna et al., 2018) on the upper, lower sides of the leaf, the stalk and the funnel of the maize plant (CABI, 2018b).

Larvae: The newly hatched caterpillars at first and second instar are green in colour which turns into brown to black colour at the third to sixth instars (CABI, 2018b). The mature larva has a white inverted "Y" shaped mark on the front and its epidermis is rough or granular in texture (Prasanna et al., 2018) with four dark raised spots in the form of square (CABI, 2018b). The newly hatched larvae is observed to be burrowing in nature (CABI, 2017c). Capinera (2000) reported that the 1–6 instar have head capsule with 0.35, 0.45, 0.75, 1.3, 2.0, and 2.6 mm wide, and body lengths are about 1.7, 3.5, 6.4, 10.0, 17.2, and 34.2 mm, respectively.

Figure 1. Larvae of fall armyworm (Bajracharya and Bhat, 2019)

Pupa: Pupae are oval in shape, reddish brown in colour and form a cocoon of 20-30 mm in length which are usually found at the depth of 2-8 cm in soil (CABI, 2018b). According to Silva et al. (2017), pupae are usually 15 mm long and are found in the soil in cocoons (20–30 mm across).

Adult: The adults of FAW are nocturnal in behaviour (CABI, 2017b). The adult moths vary in colour and wingspan (32 to 40 mm). The male moths have shaded grey and brown forewing with triangular white spots at the tip and near the centre of the wing (Assef and Ayalew, 2019) which is absent in female moth. The moths are migratory in nature and can fly over long distance through travel (CABI, 2018m).

Figure 2. Adult female

Figure 3. Adult male (Ibrahim and Jimma, 2018)

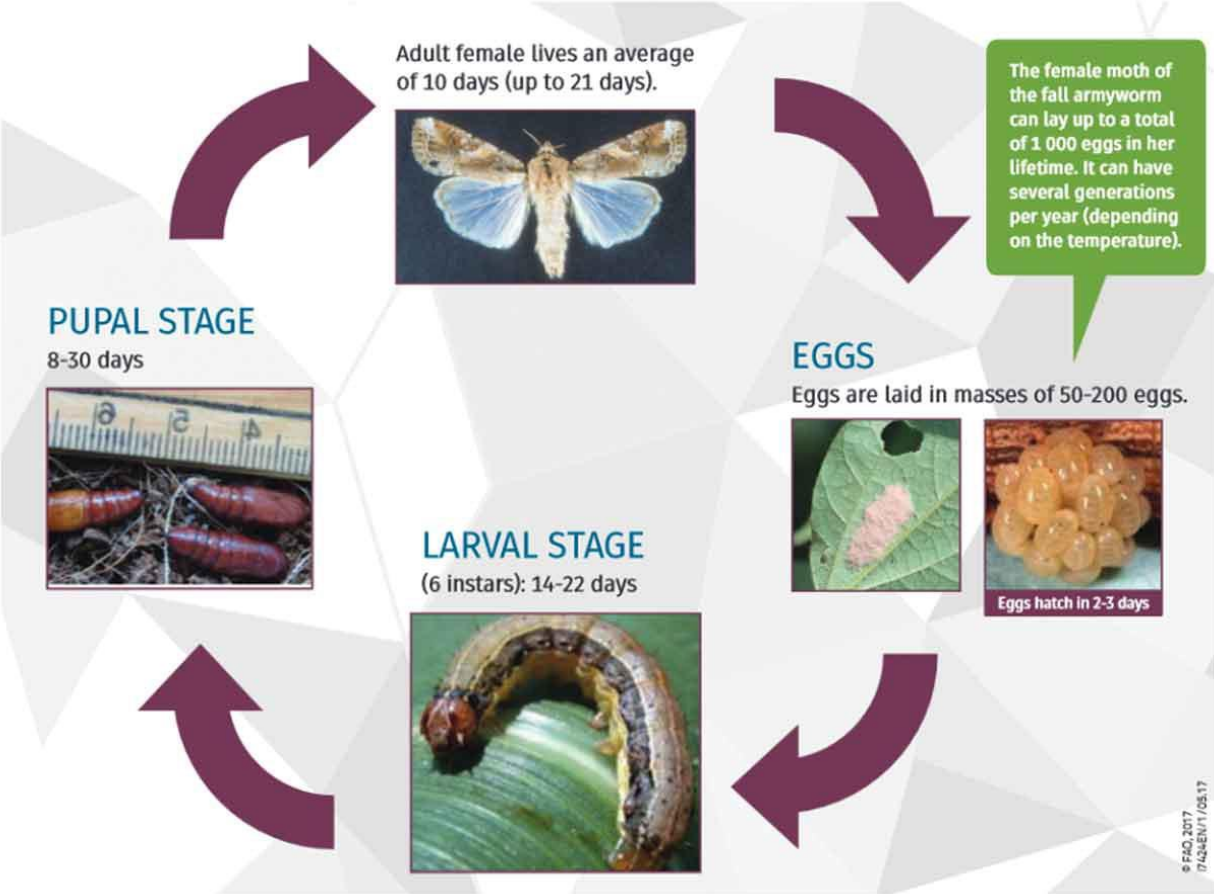

Figure 4. The lifecycle of fall armyworm, FAO (2017)

8. Integrated Management of Fall Armyworm

The detection of fall armyworm is utmost important before the pets causes economic damage. Fernandez (2002) reported that it is recommended to use the control measures in the maize, only when the 5% of seedlings are cut or 20% of whorls of small plants (during the first 30 days) are infested with fall armyworm. Assefa and Ayalew (2019) revealed that larval stage of fall armyworm is the effective time for the proper management of the pest with timing (morning, afternoon or evening) when the management activity is done is indispensable.

8.1. Advisory Services

A combination of communication methods (in public and private sectors) is required taking into account the information to be communicated and the control methods being promoted (Day et al., 2017). This is the first and the most important step for the management of the fall armyworm. The Asian countries like China, Bangladesh, Indonesia, Japan, Myanmar, and Srilanka are adopting this method to bring awareness among the people regarding the management of the devastating pest (FAO, 2019).

8.2. Physical and Mechanical Method

Firake (2019) reported that hand picking and destruction of egg masses, and neonate larvae in mass by crushing or immersing in kerosene water as one of the control measures of fall armyworm. The application of dry sand into the whorl of affected maize plants soon after observation of FAW incidence in the field has been reported as the another control measure. The number of eggs or caterpillars of fall armyworm are few so handpicking and crushing them can act as a practical measure for small gardens or few affected plants. 54 % of the pest control has been found through the adoption of mechanical control of management (Assefa, 2018). Installation of pheromone traps @ 5/acre at the potential area of spreading in crop season and off-season helps to control the incidence of fall armyworm (Firake, 2019). FAO (2017) reported that the pheromone traps that attract the male armyworm moths are recommended for scaling as this method is simple to use. The standard bucket trap with a green canopy, yellow funnel, and white bucket has been the most effective for capturing the moths of the fall armyworm (Meagher, 2001; Hardke et al., 2015).

8.3. Cultural Method

The fall Armyworm is often controlled through the use of synthetic/chemical insecticides (Blanco et al., 2014, 2010; Hruska and Gould, 1997). However, application of different cultural methods might help to minimize the crop loss by FAW. Firake (2019) demonstrated that intercropping of maize with legume crops (eg. Maize + pigeon pea/black gram /green gram) can be effective to control fall armyworm. Similarly, clean cultivation and balanced use of fertilizers along with cultivation of maize hybrids with tight husk cover reduces ear damage by FAW and other insects. Kumela et al. (2019) illustrated that the dry mixture of sand with trichlorfon and formulated as granules or powder when applied into the whorls has been effective and widely used by smallholder farmers in Ethiopia and Kenya. Van Huis (1981) has reported that the amount of pesticide use has been reduced by 20% by the application of the mixture of chlorpyrifos with sawdust. Prasanna et al. (2018) reported that the early plantation or the use of early maturing varieties (higher armyworm densities occur later in the season) are found to be effective to control FAW. The concept of "Push-Pull" companion cropping showed some potential to control the spread of the FAW, however, this attempt requires an investment of labor and extra cost viz., intercropping maize with a pest-repellent ("push") plant (*Desmodium* spp.) surrounded by a border with pest-attractive trap ("pull") plant such as napier grass (*Pennisetum purpureum* or *Brachiaria* spp.) has been found to be effective in FAW management (Pradhan et al., 2019). A research reported that 82.7 percent reduction in the average number of larvae per plant and 86.7 percent plant damage per plot were observed in climate adapted with push pull in comparison to maize grown in a plot as a sole crop along with 2.7 times higher maize grain yield (Midega et al., 2018). Early crop plantation to avoid the higher densities of pest, intercropping of maize with non-host plant like sunflower and bean (FAO, 2018), crop rotation and varietal choice, good soil tilth, regular monitoring of the field and burning of the crop residues can destroy egg, larvae, pupa and adult left in the field (Assefa, 2018). Frequent weeding significantly reduce the damage from FAW as graminaceous weeds which are found dominantly in the maize fields are considered as the major host of the fall armyworm. Similarly, the pest damage was significantly low in the maize plots that are established adopting minimum/zero tillage in which the natural enemies are found in higher densities (Buadron et al., 2019). In Kenya, 39 percent of the farmers were reported to follow the cultural control method such as adding soil to the plant whorl, drenching tobacco extract to the damage plants for controlling the FAW (Kumela et al., 2019). A study reported that 56 percent of pest management through cultural method (Assefa and Ayalew, 2019).

Advantages

1. It is cost effective method of pest management.
2. This method is safe and do not poses the undesirable residual effects on food, human health and environment.

Disadvantages

1. Requires long term planning for greatest effectiveness.
2. The percentage of pest control is lower as compared with other methods of management.

8.4. Biocontrol Method/Biological Method

Certain bio-control agents have been found to be effective to control the FAW. The in-situ protection of natural enemies through habitat management along with increasing the plant diversity by intercropping with pulses and ornamental flowering plants has been reported as building-up of various natural enemies (Firake, 2019). The application of *Bacillus thuringiensis* var kurstaki formulations @ 2g/litre (or) 400g/acre is effective to control FAW. The application of *Metarhizium anisopliae* talc formulation (1x108 cfu/g) @ 5g/litre whorl application at 15-25 days after sowing is good. Similarly, 1-2 sprays at the interval of 10 days depending on pest damage has been reported effective to control the extension of the pest infection. FAO (2018) reported that the biopesticides especially based on the bacteria *Bacillus thuringiensis* (Bt), fungi (such as *Beauveria bassiana*) and Baculo viruses have been effectively used for the control of FAW. These biotic agents also have a contribution to reduce leaf defoliation in crops (Molina-Ochoa et al., 2003). Pilkington et al. (2010) highlighted that various microbial pathogens and arthropod bio-control agents have been successfully used to control the FAW. Globally, there are fifty three species of parasites that represent forty three genera and ten families which are effective to control fall armyworm (Ashley, 1979; Sparks, 1986; Assefa, 2018). Aktuse et al. (2019) in his study to evaluate the efficacy of entomo-pathogenic fungi against eggs and second instar larvae revealed that 30 percent mortality of second instar larvae by the *Beauveria* isolate whereas *Metarhizium* isolate provided the 87% and 96.5% of egg and neonate larvae mortality respectively. There are many natural enemies which are effective to control many lepidopteran insects of the noctuidae family. Tefera et al. (2019) suggested that these natural enemies could be potential for the biological control of many insect pests. *Cotesia icipe* a larval parasitoid was found effective to control fall armyworm infestation in Ethiopia, whereas in Kenya *Plaexorista zonata* was found to control the pest (Sisay et al., 2018). Various parasitoid species belonging to *Trichogramma* and *Telenomus*, which are easy to rear in a laboratory (Cave and Acosta, 1999; Cave, 2000; Ferrer, 2001; Nagaraja, 2013; Tefera, 2019), are widely used for the management of fall armyworm (Mihm, 1987; Cave, 2000; Gutierrez-Martinez et al., 2012; Tefera, 2019). The biological control agents reported for the management of FAW are *Telenomus remus* (Platygastridae), *Chelonus insularis, Cotesia marginiventris, Trichogramma* spps (Braconidae), *Archytas*, *Winthemia* and *Lespesia* (Tachinidae), earwigs (Dermaptera), Ladybird beetles (Coccinellidae), Assassin and flower bugs like *Zelus* (Reduviidae), *Podisus* (Pentatomidae), *Nabis* (Nabidae), *Geocoris* (Lygaeidae), *Orius, Anthocoris* (Anthocoridae), ants, birds and bats (FAO, 2018).

Advantages

1. No problem of development of resistance by the pest.
2. It is safe to use and has no adverse effect on human health and environment.
3. It is a very specific strategy, hence possess no danger to non-target pest.
4. It is cost effective method of pest management in a longer run.

Disadvantages

1. Initial management cost is high.
2. This management method is a slow process.
3. The pest control percentage with the use of biological control agent is lower as compared to chemical method of pest control.

8.5. Botanical Method

Different locally available resources and botanical methods are used to control fall armyworm in the world through local botanical extract, soil, sand, wood ash, lime, oils and soaps (Hruska, 2019). Souza et al. (2010) reported that plant oils obtained from *Corymbia citriodora, Eucalyptus urograndis* and *Eucalyptus urograndis* had positive effects for protecting maize plants from FAW larvae. The neem seed powder has been reported to be effective in killing over 70% of larvae of FAW in the laboratory (Maredia, 1992). A significant mortality of larvae of FAW has been reported from the use of aqueous seed extract obtained from *Carica papaya* which is similar to the mortality caused by Malathion (Figueroa-Brito et al., 2013). Similarly, the plant oils obtained from the turmeric, clove, palmarosa and neem have significant effects in controlling first and second instar of FAW larvae (Barbosa et al., 2018). Jirnmci, (2013) and Schmutterer (1985) reported that various botanicals extracts obtained from plants such as *Azadirachta indica, Millettia ferruginea, Croton macrostachyus, Phytolacca docendra, Jatropha curcas, Nicotiana tabacum* and *Chrysanthemum cinerariifolium* have been successfully used to control the FAW. The seed cake extract of *Azadirachta indica* (Silva et al., 2015) and ethanolic extracts of *Argemone ochroleuca* (Martinez et al., 2017) cause high mortality of FAW larva due to reduction of food intake by larvae resulting slower growth. As the botanical pesticides have lesser effect on the non-target organisms and have an ability to add in growth promotion some of the pesticidal plants, they are found effective with reduce in use of synthetic insecticides (Abudulai et al., 2001; Mkindi et al., 2020; Rioba et al., 2020). *Ageratum conyzoides* (Lima et al., 2010; Rioba and Stevenson, 2017), *Chenopodium ambrosioides* has been evaluated for their efficacy against fall armyworm (Sisay et al., 2019; Rioba et al., 2020). *Cymbopogon citratus, Malva sylvestris, Ruta graveolens, Petiveria alliacea, Zingiber officinale, Bacharis genistelloides, Artemisia verlotiorum (*Tagliari et al., 2010), extracts of castor plant, *Carica papaya* (Figueoroa et al., 2002) and *Moringa* (Rioba et al., 2020) has been reported to have insecticidal properties against fall armyworm. The larval mortality was found highest 66 percent from both *Nicotiana tobacum* and *Lippia javanica* in contact toxicity test and in a feeding bioassay *L. javanica* and *N. tabacum* reported the highest larval mortality of 62 percent and 60 percent respectively at the concentration of 10 percent w/v. At the same time while evaluating the feeding differences, *Cymbopogon citratus* and *Azadirachta indica* were found to be the most potential feeding deterrents with 36 percent and 20 percent respectively (Phambala et al., 2020).

Advantages

1. The raw materials such as botanicals are easily available within the locality of farmers.
2. It is one of the cheapest method of pest management as compared with other methods.
3. This is safe and environmentally friendly method.

Disadvantages

1. The pest control percentage with the use of botanical method is lower as compared to chemical method of pest control.

8.6. Chemical Method

The appropriate time for the chemical application is utmost important for the management of the fall armyworm. An individual should have knowledge on the life cycle and timing when to apply the pesticide i.e. there is no effectiveness in spraying when the larvae are deeply embedded inside the whorls and ears of maize and in the day time because larvae only come out to feed on plants during night dawn or dusk (Day et al., 2017). Various chemicals have been recommended to control the fall armyworm. The insecticides of different groups such as Methomyl, Pyrethroids, Cyfluthrin and organophosphate insecticide, methyl parathion can be used for the control of fall armyworm (Tumma and Chandrika, 2018). The seed treatment with chlorantraniliprole and cyantraniliprole was found to be effective and reduced the need for foliar sprays against fall armyworm in soya (Thrash et al., 2013). Van Huis (1981) reported that when chlorpyrifos was mixed with the saw dust and used as a treatment, 20% control of the fall armyworm was found. Chemicals like chlorpyrifos, carbosulfan, emamectin benzoate, cartap hydrochloride and beta cypermethrin have been widely used for the control of the fall armyworm in Africa. Among them, emamectin benzoate, cartap hydrochloride and beta cypermethrin are also recommended to use for vegetables (IRAC South Africa, 2018). Cruz et al. (2012) and Bhusal & Bhattarai (2019) reported that over 90% of larval mortality through the use of Spinosad and new insecticide Chlorantraniliprole, flubendiamide, and spinetoram was found to perform better than traditional insecticide lambda-cyhalothrin and novaluron (Hardke et al., 2015).

Advantages

1. The percentage control through this method is higher than other method of pest control.
2. This method act very fast if selected in proper concentration and proper quantity.

Disadvantages

1. This method has residual effect and have detrimental effect on human health and environment.
2. Along with the harmful insects, it also kills the beneficial insects.

9. CONCLUSION

The fall armyworm (*Spodoptera frugiperda)* has been one of the most devastating pests worldwide. This pest has a higher probability of spreading all over the world causing massive reduction in agricultural production and productivity. The control of fall armyworm requires an integrated management strategy where the field inspection at the early pest attack and identification of the controlling mechanism is important. An awareness programme through advisory services regarding the pest identification, its damage symptoms, and control measures with appropriate measures can reduce the incidence of the pest. Locally available resources and methods could play a vital role for the smallholder farmers across the world so there's an urgent need to sensitize the smallholder farmers against the control measures of fall armyworm. The measures can help to lower down the incidence and loss from the pests invasion and contribute to global stability. A collective action could be recommended that can play a vital role for the management of the fall armyworm.

Acknowledgement: The authors acknowledge all the helping hands during the time of this manuscript preparation.
Conflict of Interest: The author(s) declare(s) that there is no any conflict of interest regarding the publication of this paper.

REFERENCES

Abudulai, M., Shepard, B.M., Mitchell, P.L. (2001). Parasitism and predation on eggs of Leptoglossus phyllopus (L.)(Hemiptera: Coreidae) in cowpea: impact of endosulfan sprays. J. Agric. Urban Entomol, 18(2), 105-115.

Akutse, K.S., Kimemia, J.W., Ekesi, S., Khamis, F.M., Ombura, O.L., Subramanian, S. (2019). Ovicidal effects of entomopathogenic fungal isolates on the invasive Fall armyworm Spodoptera frugiperda (Lepidoptera: Noctuidae). Journal of Applied Entomology, 143(6), 626-634.

Ashley, T.R. (1979). Classification and distribution of fall armyworm parasites. Florida Entomologist, 114-123.

Assefa, F. (2018). Status of Fall Armyworm (Spodoptera frugiperda), Biology and Control Measures on Maize Crop in Ethiopia: A Review. International Journal of Entomological Research, 6(2), 75-85.

Assefa, F., Ayalew, D. (2019). Status and control measures of fall armyworm (Spodoptera frugiperda) infestations in maize fields in Ethiopia: A review. Cogent Food & Agriculture, 5(1), 1641902.

Bajracharya, A.R., Bhat, B. (2019). The first record of Fall Armyworm Spodoptera frugiperda in Nepal. Khumaltar, Nepal, 2019 NARC http://narc.gov.np/the-first-record-of-fall-armyworm-spodoptera-frugiperdain-nepal/

Barbosa, M.S., Dias, B.B., Guerra, M.S., Haralampidou da Costa Vieira, G., (2018). Applying plant oils to control fall armyworm (Spodoptera frugiperda) in corn. Australian Journal Crop Science 12(04):557–62.

Baudron, F., Zaman-Allah, M.A., Chaipa, I., Chari, N., Chinwada, P. (2019). Understanding the factors influencing fall armyworm (Spodoptera frugiperda JE Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. Crop Protection, 120, 141-150.

Baudron, F., Zaman-Allah, M.A., Chaipa, I., Chari, N., Chinwada, P. (2019). Understanding the factors influencing fall armyworm (Spodoptera frugiperda JE Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. Crop Protection, 120, 141-150.

Beshir, A.R., Shrestha, H.K. Pradhan, B. (2019). Destructive Pest Alert: Fall Armyworm (FAW) is paving its way to Nepal. Retrived from: https://maize.org/destructive-pest-alert-fall-armyworm-faw-is-paving-its-way-to-nepal/

Bhusal, K., Bhattarai, K. (2019). A review on fall armyworm (Spodoptera frugiperda) and its possible management options in Nepal. Journal of Entomology and Zoology Studies, 7(4), 1289-1292

Blanco, C.A., Chiaravalle, W., Dalla-Rizza, M., Farias, J. R., García-Degano, M.F., Gastaminza, G., Rodríguez, J. (2016). Current situation of pests targeted by Bt crops in Latin America. Current opinion in insect science, 15, 131-138.

Blanco, C.A., Portilla, M., Jurat-Fuentes, J.L., Sánchez, J.F., Viteri, D., Vega-Aquino, P Terán-Vargas, A.P., Azuara-Domínguez, A., López Jr, J.D., Arias, R. Zhu, Y.C. (2010). Susceptibility of isofamilies of Spodoptera frugiperda (Lepidoptera: Noctuidae) to Cry1Ac and Cry1Fa proteins of Bacillus thuringiensis. Southwestern Entomologist, 35(3), 409–416.

Brito, R.F., Ayala, P.V., Olguín, J.F.L., de la Peña, A.H., Aguilar, J.R.P., López, M.A.R. (2013). Nitrogen fertilization sources and insecticidal activity of aqueous seeds extract of Carica papaya against Spodoptera frugiperda in maize. Ciencia e investigación agraria: revista latinoamericana de ciencias de la agricultura, 40(3), 578-580.

CABI. (2017a). New report reveals cost of Fall Armyworm to farmers in Africa, provides recommendations for control. Retrived from: https://www.cabi.org/news-article/new-report-reveals-cost-of-fall-armyworm-to-farmers-in-africa-provides-recommendations-for-control/

CABI. (2017b). Fall Armyworm Status Impacts and control options in Africa: Preliminary Evidence Note (April 2017) P. Abrahams, T. Beale, M. Cock, N. Corniani, R.Day*, J.Godwin, S. Murphy, G. Richards & J. Vos. Retrived from: https://www.cabi.org/ISC/abstract/20187200430

CABI. (2017c). Spodoptera frugiperda (fall armyworm) invasive species compendium. Retrieved from: http://www.cabi.org/isc/datasheet/29810

CABI. (2018a). Crop Protection Compendium. Retrived from: https://www.cabi.org/cpc/

CABI. (2018b).Fall armyworm Technical Brief with reference to Maize production in Uganda. Retrived from: https://www.cabi.org/ISC/FullTextPDF/2018/20187200504

CABI. (2020). Spodoptera frugiperda (fall armyworm). Invasive Species Compendium. Retrived from: https://www.cabi.org/isc/datasheet/29810

Cambodia News, (2019).Worm epidemic destroys 10,000 hectares of corn. Retrived from: https://cambodiaexpatsonline.com/the-barnyard/worm-from-south-america-theatens-cambodian-corn-crops-t29646.html

Capinera, J.L. (2000). Fall armyworm, Spodoptera frugiperda (JE Smith)(Insecta: Lepidoptera: Noctuidae). University of Florida IFAS Extension.

Cave, R.D. (2000). Biology, ecology and use in pest management of Telenomus remus. Biocontrol News and Information, 21(1), 21N-26N.

Cave, R.D., Acosta, N.M. (1999). Telenomus remus Nixon: un parasitoide en el control biológico del gusano cogollero, Spodoptera frugiperda (Smith).

Chimweta, M., Nyakudya, I.W., Jimu, L., Bray Mashingaidze, A. (2019). Fall armyworm [Spodoptera frugiperda (JE Smith)] damage in maize: management options for flood-recession cropping smallholder farmers. International Journal of Pest Management, 1-13.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Gomez, J. (2017). Fall armyworm: impacts and implications for Africa. Outlooks on Pest Management, 28(5), 196-201.

FAO, CABI. (2019). Community-Based Fall Armyworm (Spodoptera frugiperda) Monitoring, Early warning and Management, Training of Trainers Manual, First Edition. 112. Retrived from http://www.fao.org/3/CA2924EN/ca2924en

FAO. (2017). FAO Advisory Note on Fall Armyworm (FAW) in Africa. Food and agriculture Organization of the United Nations, 7

FAO. (2018). Integrated management of the Fall Armyworm on maize: A guide for Farmer Field Schools in Africa. Retrived frm http://www.fao.org/family-farming/detail/en/c/1112643/

FAO. (2019). Regional Workshop for Asia Sustainable Management of Fall Armyworm. Retrived from: http://www.fao.org/3/ca7615en/ca7615en

Fernández, J.L. (2002). Nota corta: Estimación de umbrales económicos para Spodoptera frugiperda (JE Smith)(Lepidoptera: Noctuidae) en el cultivo del maíz. Invest. Agric. Prod. Prot. Veg, 17, 467-474.

Ferrer, F. (2001). Biological control of agricultural insect pests in Venezuela; advances, achievements, and future perspectives. Biocontrol News and Information, 22(3), 67N-74N.

Figueroa, R., Camino, M., Pérez-Amador, M.C., Muñoz, V., Bratoeff, E., Labastida, C. (2002). Fatty acid composition and toxic activity of the acetonic extract of Carica papaya L. (Caricaceae) seeds (with 2 tables). Phyton, 97-99.

Firake, D.M., Behere, G.T., Babu, S., Prakash, N. (2019). Fall Armyworm: Diagnosis and Management (An extension pocket book). ICAR Research Complex for NEH Region, Umiam-793 103, Meghalaya, India. 48

Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A., Tamo, M. (2016). First report of outbreaks of the fall armyworm Spodoptera frugiperda (JE Smith)(Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PloS One, 11(10).

Govt. Nepal, (2019). NPPO Nepal Declares the Invasion of American Fall Armyworm (Spodoptera frugiperda) in Nepal. Retrived from: https://reliefweb.int/report/nepal/nppo-nepal-declares-invasion-american-fall-armyworm-spodoptera-frugiperda-nepal

Gu, H., Woo, R. (2019).Crop invaders: China's small farmers struggle to defeat armyworm. Environment. Retrived from: https://www.reuters.com/article/us-crops-armyworm-china-idUSKCN1UZ0LL

Gutierrez-Martinez, A., Tolon-Becerra, A., Lastra-Bravo, X.B. (2012). Biological control of spodoptera frugiperda eggs using Telenomus remus Nixon in maize-bean-squash polyculture. American Journal of Agricultural and Biological Sciences, 7(3), 285-292.

Hardke, J.T., Lorenz III, G.M., Leonard, B.R. (2015). Fall armyworm (Lepidoptera: Noctuidae) ecology in southeastern cotton. Journal of Integrated Pest Management, 6(1), 10.

Hruska, A.J., Gould, F. (1997). Fall armyworm (Lepidoptera: Noctuidae) and Diatraea lineolata (Lepidoptera: Pyralidae): Impact of larval population level and temporal occurrence on maize yield in Nicaragua. Journal of Economic Entomology, 90(2), 611–622.

Hruska, A.J., Gould, F. (1997). Fall armyworm (Lepidoptera: Noctuidae) and Diatraea lineolata (Lepidoptera: Pyralidae): Impact of larval population level and temporal occurrence on maize yield in Nicaragua. Journal of Economic Entomology, 90(2), 611-622.

Ibrahim, E.S., Jimma, E. (2018). Review on Effect of American Fall Army Worm and Its Management on Maize as the World.

IRAC South Africa. (2018). Integrated Pest Management (IPM) & Insect Resistance Management (IRM) for Fall Armyworm in South African Maize. Retrieved from: https://www.irac-online.org/documents/ipm-irm-for-fall-armyworm-in-s-african-maize/

Jacobs, A., van Vuuren, A., Rong, I.H. (2018). Characterisation of the fall armyworm (Spodoptera frugiperda JE Smith) (Lepidoptera: Noctuidae) from South Africa. African Entomology, 26(1), 45-49.

Kansiime, M. K., Mugambi, I., Rwomushana, I., Nunda, W., Lamontagne-Godwin, J., Rware, H., Day, R. (2019). Farmer perception of fall armyworm (Spodoptera frugiderda JE Smith) and farm-level management practices in Zambia. Pest management science, 75(10), 2840-2850.

Kiprop, V. (2017). Fall armyworm to cost more than $2bn in losses. Retrived from: https://www.theeastafrican.co.ke/business/Fall-armyworm-to-cost-more-than-billions-in-losses-/2560-4106436-ndlcjlz/index.html

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. International Journal of Pest Management, 65(1), 1-9.

Lima, R.K., Cardoso, M.D.G., Moraes, J.C., Andrade, M.A., Melo, B.A., Rodrigues, V.G. (2010). Chemical characterization and inseticidal activity of the essential oil leaves of Ageratum conyzoides L. On fall armyworm Spodoptera frugiperda (Smith, 1797) (Lepidoptera: Noctuidae). Bioscience Journal, 26(1), 1-5.

Martínez, A.M., Aguado-Pedraza, A.J., Viñuela, E., Rodríguez-Enríquez, C.L., Lobit, P., Gómez, B., Pineda, S. (2017). Effects of ethanolic extracts of Argemone ochroleuca (Papaveraceae) on the food consumption and development of Spodoptera frugiperda (Lepidoptera: Noctuidae). Florida Entomologist, 100(2), 339-345.

Meagher Jr, R.L. (2001). Collection of fall armyworm (Lepidoptera: Noctuidae) adults and nontarget Hymenoptera in different colored unitraps. Florida Entomologist, 77-82.

Midega, C.A., Pittchar, J.O., Pickett, J.A., Hailu, G.W., Khan, Z.R. (2018). A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (JE Smith), in maize in East Africa. Crop protection, 105, 10-15.

Mkindi, A.G., Tembo, Y.L., Mbega, E.R., Smith, A.K., Farrell, I.W., Ndakidemi, P.A., Belmain, S.R. (2020). Extracts of common pesticidal plants increase plant growth and yield in common bean plants. Plants, 9(2), 149.

Molina-Ochoa, J., Lezama-Gutierrez, R., Gonzalez-Ramirez, M., Lopez-Edwards, M., Rodriguez-Vega, M. A., & Arceo-Palacios, F. (2003). Pathogens and parasitic nematodes associated with populations of fall armyworm (Lepidoptera: Noctuidae) larvae in Mexico. Florida Entomologist, 86(3), 244-253.

Nagaraja, H. (2013). Mass production of trichogrammatid parasitoids. In Biological control of insect pests using egg parasitoids (pp. 175-189). Springer, New Delhi.

Nagoshi, R.N., Silvie, P., Meagher, R.L., Lopez, J., Machado, V. (2007). Identification and comparison of fall armyworm (Lepidoptera: Noctuidae) host strains in Brazil, Texas, and Florida. Annals of the Entomological Society of America, 100(3), 394-402.

Phambala, K., Tembo, Y., Kabambe, V.H., Stevenson, P. C., Belmain, S.R. (2020). Bioactivity of Common Pesticidal Plants on Fall Armyworm Larvae (Spodoptera frugiperda). Plants, 9(1), 112.

Pilkington, L.J., Messelink, G., van Lenteren, J.C., Le Mottee, K. (2010). "Protected Biological Control"–Biological pest management in the greenhouse industry. Biological Control, 52(3), 216-220.

Pradhan, B., Rusinamhodzi, L., Subedi, R. (2019). System uses plants to lure fall armyworm away from maize fields. Retrived from https://www.cimmyt.org/news/system-uses-plants-to-lure-fall-armyworm-away-from-maize-fields/

Prasanna, B.M., Huesing, J.E., Eddy, R., Peschke, V.M. (2018). Fall armyworm in Africa: a guide for integrated pest management.

Ramirez-cabral, N. Y. Z., Kumar, L., Shabani, F. (2017). Future climate scenarios project a decrease in the risk of fall armyworm outbreaks. The Journal of Agricultural Science, 155(8), 1219-1238.

Reddy, J. (2019). Fall Armyworm control methods and symptoms. Agrifarming. Retrived from https://www.agrifarming.in/fall-armyworm-control-methods-and-symptoms

Rioba, N.B., Stevenson, P.C. (2017). Ageratum conyzoides L. for the management of pests and diseases by small holder farmers. Industrial crops and products, 110, 22-29.

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), 207.

Sangomla, A., Kukreti, I. (2019).Fall Armyworm attack: The damage done. https://www.downtoearth.org.in/coverage/agriculture/fall-armyworm-attack-the-damage-done-63445

Silva, D.M.D., Bueno, A.D.F., Andrade, K., Stecca, C.D.S., Neves, P. M.O.J., Oliveira, M.C.N.D. (2017). Biology and nutrition of Spodoptera frugiperda (Lepidoptera: Noctuidae) fed on different food sources. Scientia Agricola, 74(1), 18-31.

Silva, M.S., Broglio, S.M.F., Trindade, R.C.P., Ferreira, E.S., Gomes, I.B., Micheletti, L.B. (2015). Toxicity and application of neem in fall armyworm. Comunicata Scientiae, 6(3), 359-364.

Sisay, B., Simiyu, J., Malusi, P., Likhayo, P., Mendesil, E., Elibariki, N., Tefera, T. (2018). First report of the fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae), natural enemies from Africa. Journal of Applied Entomology, 142(8), 800-804.

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), 45.

Souza, T.F., Fevero, S., Conte, C.D.O. (2010). Bioatividade de óleos essenciais de espécies de eucalipto para o controle de Spodoptera frugiperda (JE Smith, 1797)(Lepidoptera: Noctuidae). Revista Brasileira de Agroecologia, 5(2), 157-164.

Sparks, A.N. (1979). A review of the biology of the fall armyworm. Florida Entomologist, 82-87

Sparks, A.N. (1986). Fall armyworm (Lepidoptera: Noctuidae): potential for area-wide management. Florida Entomologist, 603-614.

Tagliari, M.S., Knaak, N., Fiuza, L.M. (2010). Efeito de extratos de plantas na mortalidade de lagartas de Spodoptera frugiperda (j. E. Smith) (Lepidoptera: Noctuidae). Arquivos do Instituto Biológico, São Paulo, 77, 259-264.

Tefera, T., Goftishu, M., Ba, M., Muniappan, R.M. (2019). A Guide to Biological Control of Fall Armyworm in Africa Using Egg Parasitoids.

Tefera, T., Goftishu, M., Ba, M., Muniappan, R.M. (2019). A Guide to Biological Control of Fall Armyworm in Africa Using Egg Parasitoids.

Thrash, B., Adamczyk, J.J., Lorenz, G., Scott, A.W., Armstrong, J.S., Pfannenstiel, R., Taillon, N. (2013). Laboratory evaluations of lepidopteran-active soybean seed treatments on survivorship of fall armyworm (Lepidoptera: Noctuidae) larvae. Florida Entomologist, 96(3), 724-728.

Tumma, M., Chandrika, K. (2018). Fall Armyworm. Retrieved from http://vikaspedia.in/agriculture/crop-production/integrated-pest-managment/fallarmyworm-faw.

Van Huis, A. (1981). Integrated pest management in the small farmer's maize crop in Nicaragua (Doctoral dissertation, van Huis).

Westbrook, J.K., Sparks, A.N. (1986). The role of atmospheric transport in the economic fall armyworm (Lepidoptera: Noctuidae) infestations in the southeastern United States in 1977. Florida Entomologist, 492-502.