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Invasion of Fall armyworm [*Spodoptera frugiperda* (JE Smith, 1797) (Lepidoptera: Noctuidae)] (JE Smith ,1797) (Lepidoptera: Noctuidanead) Management Strategies in Maize Fields of Nepal

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A R T I C L E   I N F O

Review Article

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A B S T R A C T

The fall armyworm [*Spodoptera frugiperda,* (JE Smith, 1797) (Lepidoptera: Noctuidae)] is a polyphagous pest native to tropical and subtropical regions of America. After it was detected for the first time in Nepal in the Nawalpur area on 9th May 2019, it has become a major threat in maize fields even though it has over 80 host species to proceed its life cycle. Due to its migratory nature, FAW moth can travel up to 500 km before oviposition, and infestation of its larva has resulted in vast devastation of the vegetative as well as reproductive parts of plants causing significant yield loss in maize. A mature larva possesses a dark head with an upside-down pale Y-shaped marking on the head area and black four spots that are arranged in a square on the second last body segment. This paper audits the executive choices (avoidance, observing, push-pull, cultural, biological, organic, chemical, and integrated techniques to incorporate in FAW susceptible areas) that apply to smallholder farmers who do not have the monetary asset to buy compound pesticides and other costly control instruments. For the majority of Nepalese farmers with low resources and small landholding, push-pull technology is beneficial and applicable. Botanicals that have bioactive chemical compounds, insecticidal, pest repellent properties are environment-friendly and degradable, readily available in tropical and subtropical regions of Nepal. The assessment of the efficacy of implemented management practices against FAW has revealed that implementation of more than one method of management practices showed the least percentage of infestation as compared to the individual method.

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Introduction

The fall armyworm (FAw) [*Spodoptera frugiperda* (JE Smith, 1797) (Lepidoptera: Noctuidae)], is a migratory, polyphagous pest, native to Florida and the Caribbeans. A voracious insect, FAW feeds on plants from a very diverse range of families having more than 80 host species such as maize, rice, sorghum, and sugarcane, as well as cabbage, beet, groundnut, soybean, alfalfa, onion, cotton, pasture grasses, millet, tomato, potato cotton, etc. (Day et al., 2017). Its ability to travel long distances (up to 500 km) before oviposition and to feed on a wide variety of plant species, make it a particularly dangerous pest even far away from its native area (Prasanna et al., 2018).

Outside the USA and Caribbeans, the FAW was first reported in late January 2016 in maize plants of central and western African countries (Goergen et al., 2016): the moist climate of Ghana, Benin, Togo, and Nigeria especially favored this pest (Chapman et al., 2017) and the area became the epicenter of the invasion in Africa (Early et al., 2016). FAW was then recorded in Nepal in the Nawalpur district on the 9th May 2019 (Shree et al., 2019) where it attacked the local plantations of maize.

Maize is the second most important crop produced in Nepal, where it is second only to rice. About 956,447 hectares of land in Nepal is cultivated to produce maize with a productivity rate of 2.84 Mt./Ha. As a means of comparison, rice 1,491,744 hectare of land are cultivated with rice, with a productivity rate of 3.76 Mt./Ha (MOALD, 2020).

The invasion of FAW in Nepal is causing devastating damage: in 2020, 56% of winter maize was reported to be infested with FAW in the Dhanusha district only (A.S.R. Bajracharya et al., 2020). Given the scale of the invasion, it is essential for farmers to devise methods to control and eradicate the pest to be able to protect their crops. At the same time, it is necessary to devise methods that are financially viable and can be smoothly integrated in the traditional farming system of Nepal.

A possible approach to the problem is the application of integrated pest management (IPM) strategies within which push-pull technologies offer a convenient trade-off between financial viability, eco-sustainability and integration with traditional farming systems. This review article focuses on the identification of FAW, damage characteristics, life cycle, and appropriate management strategies of this pest.

Methodology

This audit article is arranged dependent on optional wellsprings of data. This paper depends on important data, research papers from various diaries, and reports from various associations. All through composing this article conversations were made with the educators, researchers, seniors, and among us. Bits of writing were gathered from various diary articles, government foundations, and other significant reports were examined lastly, significant discoveries were assessed and summed up.

Results and Discussion

Origin, Global Distribution, and Incidence of Fall Armyworm in Nepal

Fall armyworm (*Spodoptera frugiperda*) a devastating pest is native to tropical and subtropical regions of America. The inability to survive in any stage of life to pass winter in the tropical life zone of the United States indicates the fall armyworm is tropical in origin. The redistribution and migration of the moths result in the occurrence of the general outbreak in 1899 and again in 1922 which invades the transitional zone of the Austral region. The large outbreak of fall armyworm during 1922 provides evidence of the origin of this pest in the Eastern United region (Luginbill, 1928). The fall armyworm moth can travel up to 500km distance before oviposition as it is a strong flier with migratory and localized dispersion habits (Prasanna et al., 2018). The longer period of drought followed by the wet season causes the outbreak of this invasive pest out of the American continent. Before 2016 *S. frugiperda* was confined only to American Continent for centuries. Fall armyworm records for the first time in late January 2016 in maize plants of South –Western Nigeria, Benin, Tago, and Sao Tome and Principe of Africa (Goergen et al., 2016). About 28 Sub- Saharan African Countries also get outbreak by fall armyworm with further nine more countries till August 2017 (Day, Abrahams, Bateman, Beale, Clottey, Cock, Colmenarez, Corniani, Early, Godwin, Gomez, Moreno, Murphy, et al., 2017). The regions Ghana, Benin, Togo, and Nigeria with moist climates favor the origin of flight (Chapman et al., 2017) and acts as an epicenter for invasion of this devastating pest in Africa (Early et al., 2016).

The ideal climatic condition and the availability of host plants in different regions of Africa and Asia favor the rapid spread of the fall armyworm. India was the first country to be infested by fall armyworms from Asia. *S.frugiperda* first detected from Shivamogga district in Karnataka, India, and further spread to its districts such as Shivamogga, Bellary, Belgaum, and Hasson (Sharanabasappa et al., 2018). The pest spreads quickly in different Indian states like Bihar, Chattisgarh, Gujrat, Andhra Pradesh, Odisha, Tamil Nadu, Madhya Pradesh, Telangana, Maharashtra, and West Bengal (Singh, 2019). Subsequently, FAW spreads rapidly into China, Bangladesh, Indonesia, Japan, Korea, the Republic of Laos, Malaysia, Myanmar, Nepal, Srilanka, Thailand, Vietnam, and Yemen (*Spodoptera Frugiperda (Fall Armyworm)*, n.d.).

Table 1. FAW Distribution in different Countries with first reported date (*Spodoptera Frugiperda (Fall Armyworm)*, n.d.)

SN.	Country /Region	First Reported
1.	Benin	2016
2.	Angola	2017
3.	Ghana	2017
4.	Kenya	2017
5.	Nigeria	2016
6.	South Africa	2017
7.	Tago	2016
8.	India	2018
9.	Karnataka	2018
10.	Maharastra	2018
11.	Tamil Nadu	2018
12.	Pakistan	2019
13.	Nepal	2019

Source: Rwomushana (2020)

The infestation of FAW in the tropical region of India indicates a high chance for its outbreak in the terai region of Nepal as there is an open border between Nepal and India. Due to the favorable climatic condition and availability of host plants, Nepal also can't be out of the attack by FAW like other Asian countries. FAW records for the first time in Nepal from Nawalpur district on 9th May 2019 but the official declaration of invasion is on 12th August 2019 by NPPO Nepal (Ajaya Shree Ratna Bajracharya et al., 2019; NPPO, 2019). After the first record, within a short period, the pest spreads over different regions from east to west in the country. FAW was detected from 165 meter above sea level (masl) to 1471 masl and also from 1700 masl at Mainapokheri area of Dolakha district already. (A.S.R. Bajracharya et al., 2020)confirmed the occurrence of *Spodoptera frugiperda* from varied locations of six districts (Kavrepalanchowk, Sindhupalchowk, Sindhuli, Lalitpur, Chitwan, Nawalpur) in summer maize and 18 districts (Jhapa, Morang, Sunsari, Saptari, Siraha, Dhanusha, Mahottari, Sindhuli, Sarlahi, Rau tahat, Bara, Parsa, Makwanpur, Chitwan, Nawalpur, Dang, Banke, and Bardiya) in winter and summer season maize showing damaging effect at V_3(third leaf collar stage), V5(Fifth leaf collar is visible , Growing point of nitrogen uptake and uptake and kernel rowa are determined), V6(sixth collar leaf is visible), V_7(seventh collar leaf visible), V_8(eighth collar leaf visible), V_9(ninth collar leaf visible), Vegetatitive Emergence (VE) and Grain Filling(GF) maize growth stages.

Pest Identification

Some of the major pests observed in the maize fields of Nepal are *Helicoverpa, Sesamia, Chilo partellus,* Armyworm (*Mythimna separata),* cutworm(*Agrotis sp*., tiger beetles(*Cocindela sp.*), red ant(Dorylus sp), grasshopper(*Schistocera sp*), termites(*Cryptocercus sp*.), field cricket(*Gryllus sp*), white grub (*Holotrich.ia sp*), and many other pest species (Bhandari et al., 2015). These insect data are collected based on two years of research carried out in Kaski district of Nepal on the types of pests that are attracted to blacklight trap and maize crops. Eggs of FAW can be recognized based on their spherical shape lying beneath the leaves, near the base of the plant, close to the junction of the leaf, and stem in clusters ranging from few to hundreds in number (Sharanabasappa, Kalleshwaraswamy, Maruthi, et al., 2018). Expertisation and skill are required for the identification of larvae in the maize field as FAW can be easily confused with species like African armyworm (*Spodoptera exempta*), cotton leafworm (*Spodoptera littoralis*), and the species of other nocturnal genera. The first instar larvae are greenish with a blackhead capsule which turns into greenish-brown later in the second instar. Third instar larvae are brownish with three dorsal and lateral white lines. Similarly, the fourth to sixth instar larva are brownish-black and had three white dorsal lines and a light lateral line (Sharanabasappa, Kalleshwaraswamy, Maruthi, et al., 2018). A mature larva (Figure 1) possesses a dark head with an upside-down pale Y-shaped marking in the head area and black four spots that are arranged in a square shape on the second last body segment (Benson, 2017). Adult FAW (Figure 2) can be identified by its forewing. The forewing of the male moth is generally shaded grey and brown along with triangular white spots at the tip and near the center of the wing. In contrast, the forewing of female moths is less distinctly marked, ranging from a uniform greyish brown to a fine mottling of grey and brown (Prasanna et al., 2018).

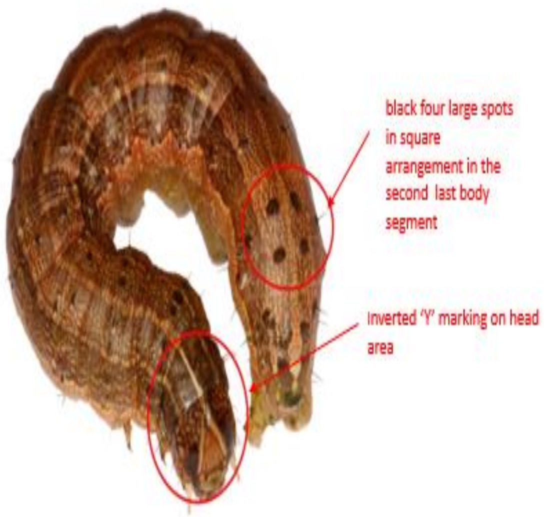

Figure 1. Mature FAW larvae
(image source: (Benson, 2017))

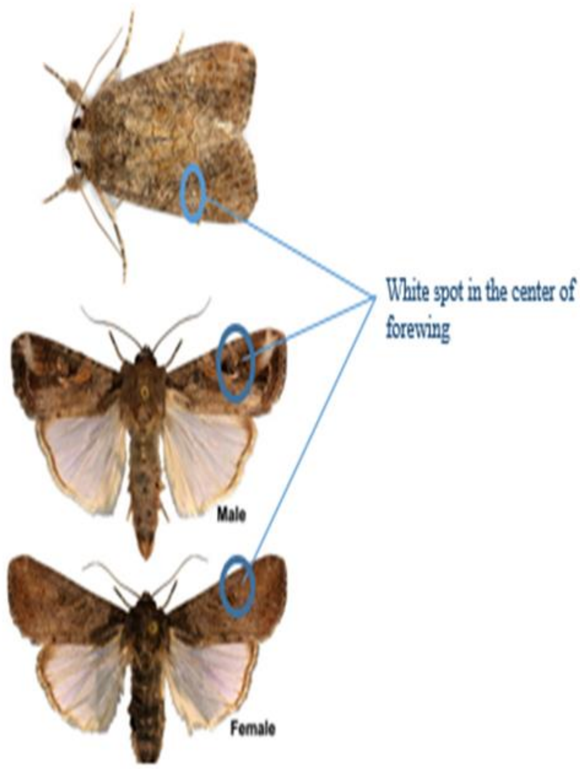

Figure 2. Adult moth of FAW
(image modified from (Benson, 2017))

Biology of the Pest

As FAW is a Lepidopteran pest, it completes its life cycle in 4 stages namely egg, larva, pupa, and adult among which there are 6 larval instars (Prasanna et al., 2018). The duration of the life cycle varies with the season i.e., it is completed in 30 days during summer, 60 days during autumn, and spring. But when the temperature drops down, it can be prolonged up to 90 days during winter (*Spodoptera Frugiperda (Fall Armyworm)*, n.d.). The different biological stages of FAW can be briefly described as below:

Egg: Eggs are dome-shaped that measures 0.4 mm in diameter and 0.3 mm in height with a flattened base. The eggs are pale yellow or creamy white in color at the time of oviposition which changes into light brown during hatching (Prasanna et al., 2018). Eggs are laid on the underside of leaves mainly near the base junction of stem and leaves in a cluster of 50-150 (Hardke et al., 2015). A layer of scales that are grey to pink in color called the setae is bored by the abdomen of the female moth that covers the egg masses and protects them. On average, about 1500 eggs can be laid by a female which may rise over to 2000 (Igyuve et al., 2018). The favorable temperature for maturing of eggs within 2-3 days is 20-30°C.

Larvae: Larvae are considered to be the destructive stage in the life cycle of FAW (Figure 3). 28-30°C is favorable for the development of larva. During the summer and winter, the duration of the larval stage tends to be almost 14 days and 30 days respectively. They have a biting type of mouthpart that causes damage to the crops. The larval stage completes in six instar stages. In their first instar stage, larvae are greenish in color but during the second instar stage, color changes to orange. The third instars are brownish with three dorsal and lateral white lines. From 1 mm in length at its first instar stage, it grows up to 45 mm when they reach six instar stages (Prasanna et al., 2018). The head is reddish-brown mottled with white lateral lines in its fourth and sixth instars (Igyuve et al., 2018). On the dorsal body surface, black tubercles were found bearing spines (Sharanabasappa, Kalleshwaraswamy, Maruthi, et al., 2018). The back of the larvae contains 3 yellow strips followed by a black and again yellow stripe on the side. Four dark spots are seen forming a square on the second to last segment (FAO & ASARECA, 2018).

Pupae: The caterpillar falls to the ground after about 14 days. Loose, oval, and 20-30 mm long cocoon is formed by binding of the soil particles together inside which a reddish-brown pupa of 14-18 mm in length and 4.5 mm in width resides (Igyuve et al., 2018). Under a suitable temperature of 13-16℃, FAW pupates in underground soil up to 2-8 cm deep with the formation of a cocoon. But, if the surface of the soil is hard, the leaf debris along with other materials are webbed together on the soil surface. The duration of the pupal stage completes in 8 to 9 days in summer and 20 to 30 days in winter. Male pupae have shorter distance and females have more distance between the genital opening for pupal sexing (Sharanabasappa, Kalleshwaraswamy, Maruthi, et al., 2018).

Adult: Adults are generally active during warm and humid evenings because of their nocturnal behavior (*Spodoptera Frugiperda (Fall Armyworm)*, n.d.). The adult female is bigger having a body length of 1.7 cm and wingspan of 3.8 cm than the adult male having 1.6 cm of body length and a wingspan of 3.7 cm. The forewing of the male is mottled and contains a discal cell having straw color on three quarters and dark brown color on one-quarter of the area along with a triangular white spot at the tip and near the center of the wing (*Spodoptera Frugiperda (Fall Armyworm)*, n.d.). Similarly, the forewings of the female are less distinctly marked which ranges from uniform greyish brown to a fie mottling of grey and brown. In addition to the forewing, the hindwing is iridescent silver-white containing a narrow dark border in both sexes (Igyuve et al., 2018). The period of adult life is 10 days on average with a range of about 7-21 days (Prasanna et al., 2018). Temperature less than 30℃ is favorable for adults.

Damage Characteristics of Faw in Maize Plant

FAW larval stage damages sequentially on different maize parts like leaves, tassel, ear all over the growing period from seedling to repeoductive stage (Chimweta et al., 2019). Young larvae for the most part feed on epidermal leaf tissue and make openings in leaves, which is the regular harmful side effect of FAW (Sisay et al., 2019). FAW ingest the young plant through the whorl which causes dead heart. Overdue planted maize crops and delay maturing hybrids are probable to be affected by this pest. Major harm is completed through younger larvae. Larvae reasons harm through ingesting foliage and reproductive parts of the plant. Small holes and "windowpane" feeding in the leaves emerging from the whorl are commonly seen. FAW danages leaf, tassel and silk from 25% to 50% but stem is similar and negligible across maize plots (Chimweta et al., 2019). (Noctuidae & Capinera, 2020) documented that second or third instar, larvae began to make holes in leaves, and eat from the edge of the leaves inward. They found larval densities typically decreased to one to two for every plant when instars feed nearness to each other due to cannibalism. Further, they found older larvae causing extensive defoliation, often leaving only the ribs and stalks of corn plants, or a ragged, torn appearance. When the FAW population is high on a plant, the adult larvae might occasionally move to the tassel and the ears, reducing the quality of the produce at harvest (Schools, 201).

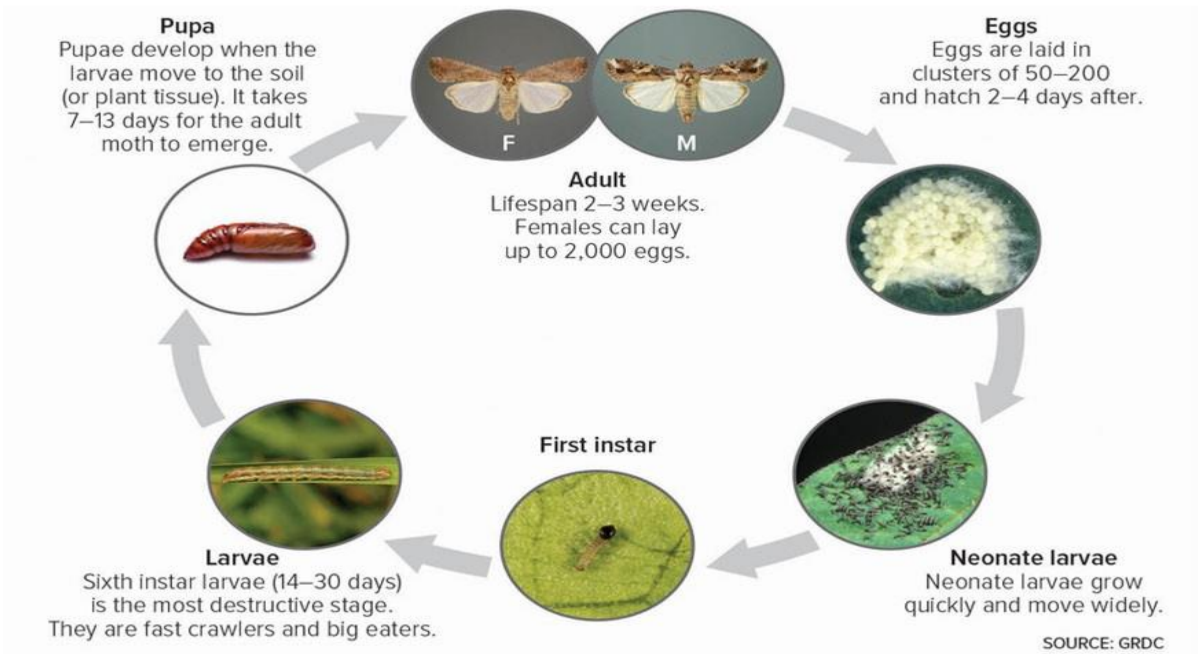

Figure 3. Life cycle of Fall Armyworm. (Shifa et al., 2018)

Figure 4. Infestation of FAW larva at different stages of the maize plant. (Benson, 2017).

Table 2. Record of yield loss of maize found in different countries

Country	Yield loss due to FAW infestation in maize.	Year	References
Ghana	45%	2017	(Day et al., 2017)
Zambia	40%	2017	(Day et al., 2017)
Kenya and Ethiopia	138kg/ha and 934kg/ha respectively.	2017	(Kumela et al., 2019)
Zimbabwe	11.57%	2018	(Baudron et al., 2019)

Impact of Faw Severity in Maize Field

If no controlled measures are used then FAW may cause yield loss from 8.3 to 20.6 million tonnes annually (Day et al., 2017). Yield loss of maize owing to an infestation of FAW (Figure 4) has become a major concern for both farmers and researchers in different countries. If maize plants are infested by FAW in between 1^{st} and 2^{nd} weeks after germination then yield would be reduced by 22.6% (Evans and Stansly., 1990), severe infestation levels of a field can reach 100% (Benson, 2017) due to ballooning (spreading by the wind on a thread of silk) nature of young fall armyworm caterpillars. Fall armyworms can survive in the winter season in various inner Terai and inner Terai districts of Nepal (Bajracharya et al., 2020). No abundant research has been conducted to assess the yield loss due to maize in the context of Nepal. Fall armyworm can destruct maize plants in huge amounts which will affect the food security and feed industry of Nepal (Bajracharya et al., 2019). Fall Armyworms damage 5-56% of maize plants that are cultivated in different locations of Nepal (Bajracharya et al., 2020).

Integrated Pest Management

In a very less time, FAW has rapidly spread throughout the country and has become the most destructive pest threatening maize production in Nepal. We must take adoptive measures to mitigate the damage and prevent further destruction. The prevention and mitigation of FAW cannot be achieved through a single practice. The assessment of the efficacy of implemented management practices against FAW conducted in Kailali district of Nepal reveals that implementation of more than one method of management practices shows the least percentage of infestation as compared to an individual method (Bhandari et al., 2021). There is thus a need for the combination of control methods that are sustainable, cost-effective and causes less risk to human and environment. This can be achieved through the Integrated Pest Management technique(IPM). IPM emphasizes environment-friendly methods with minimum utilization of chemical stuff. The key components of IPM strategy are:

Prevention

Best pest management starts with planting healthy plants so it is necessary to use high-quality seed with high germination viability and that is free of insect pests and diseases (Godoy et al., 2014). By early planting, we can bypass the time of arrival of pests and hence reduce infestation (Bhusal and Chapagain, 2020). Increasing plant diversity is also recommended as it can increase the population of natural enemies that can attack FAW eggs and larvae (Gebreziher, 2020).

Monitoring

Early detection of Fall Armyworm infestation before it causes heavy damage is very important for its management and control. This requires frequent observation and estimation of the pest population. Therefore, Monitoring-based Integrated Pest Management has been proven effective in controlling FAW (Gebreziher, 2020). The efficient methods of monitoring this pest in the field include regular scouting, light traps, and pheromone traps (Bista et al., 2020). Scouting is the precise assessment of the level of infestation of pests in the field performed by trained individuals by the use of science-based protocols. It is done by walking the "W" pattern in the field after leaving 4-5 outer rows (to avoid the border effect) as soon as maize seedlings emerge (MoALD, 2019). If 5% of plants are damaged at seedling to early whorl stage, 10% whorls are damaged in mid whorl stage, 20% are damaged at late whorl stage then it is recommended to apply effective control measures to prevent further damage (Bista et al., 2020; Firake et al., 2019). Since FAW are attracted to light sources we can also use night-time light traps as one of the monitoring mechanisms for FAW (Haftay Gebreyesus Gebreziher, 2020). Pheromone is a chemical usually produced by females to attract a male for mating and it has been found as an effective tool to capture male insects. There is a use of specific pheromone traps involving [(Z)-7-dodecenyl acetate (Z)-7-12: Ac), (Z)-9-dodecenyl acetate (Z)-9-12: Ac), (Z)-9-tetradecenyl acetate (Z)-9-14: Ac), and (Z)-11- hexadecenyl acetate for monitoring in different countries including USA (Sisay, 2018). Pheromone traps are considered more efficient than light traps. However, they can only determine the presence or absence of the pest but not necessarily its density (Sisay, 2018).

Push-pull Technology

Push-pull technology (PPT)is a cropping strategy for controlling agricultural pests developed by the International Centre of Insect Physiology and Ecology (ICIPE) in collaboration with Rothamsted Research (UK), Kenya Agricultural Research Institute (KARI), and other national partners for integrated pest weed and soil management in cereal livestock-based farming system (Khan et al., 2011). It involves intercropping crops with repellant push plants like *Desmodium uncinatum* that repels insect pests and trap pull plants like Napier grass, *Pennisetum purpureum*, which attract pests thereby facilitating pest control (Midega et al., 2006). In the PPT, the push plant release volatile chemicals such as (E)-β-ocimene and (E)-4, 8- dimethyl- 1, 3, 7-nonatriene, that have repellent characteristics to the female moths whereas the pull plant releases semiochemicals that are attractive to the gravid female moths than maize, thus increasing its concentration on pull plants (Neelima et al., 2020). In a field experiment in Ethiopia significant reduction in infestation of maize by FAW was found in PPT treated maize plots as compared to monocropped maize plots (Neelima et al., 2020). Similarly, results from the research conducted in different sub-countries in western Kenya, eastern Uganda, and Northern Tanzania shows a reduction in 82.7% in an average number of larva per plant and 86.7% in plant damage per plot in climate-adapted push-pull plots as compared to maize monocrop plots (Midega et al., 2018). Since the technology is based on locally available plants it is also economical for smallholder farmers. In addition, *Desmodium* and Napier grass also improves soil fertility, control soil erosion, and provide high-value fodder crops increasing milk production and diversifying income sources (Khan et al., 2011) Keeping in view that the majority of Nepalese farmers are low resource smallholders this technology is economical and can also be well integrated with the traditional farming system of Nepal.

Cultural Methods

Several cultural practices such as early planting, deep ploughing, burning stubbles after harvest of infested crops, intercropping, and rotating maize with non -host crops were found to be practiced in African countries for pest management strategy against FAW (Yigezu and Wakgari, 2020). Planting leguminous intercrops like french beans, soybean, groundnut, and other cover crops can be an effective possible cultural method as it diversifies the field environment for beneficial insects and inhibits the movement of larvae among plants (Ramzan et al., 2021). Other cultural practices include ploughing, clean cultivation and proper use of fertilizers, grown of maize hybrids with tight husk cover (Devi, 2020). In addition, plantation of scented and flowering plants like coriander, fennel, rose, marigold, etc. can attract natural pests of FAW and help in reducing the pest population (Bhusal and Chapagain, 2020). The selection of good crop variety is also important for pest control. In the context of Nepal, no evaluation has been done for FAW-resistant varieties. Some GMOs including Bt. maize were reported resistant varieties in Africa (GC et al., 2019).

Biological Control

Biological management is the core component of IPM since it focuses on the natural method of pest control. Biological management is the beneficial action of natural enemies like predatory insects, parasitoids, and entomopathogens like fungi, bacteria, viruses, and nematodes in managing pests and their damage.

Parasitoids

Various insects have been reported parasitizing *S. frugiperda* larvae and eggs. *Apanteles marginiventris (*Hymenoptera, Braconidae*), Campoletisgrioti (*Hymenoptera, Ichneumonidae*), Chelonus insularis (Hymenoptera* Braconidae*), Meteorus autographae (*Hymenoptera, Braconidae*), Ophion spp.* (Hymenoptera, Ichneumonidae), *Eiphosoma vitticolle* (Hymenoptera Ichneumonidae) are some of the important parasitoids that can be used in FAW management (Sisay, 2018). Cotesia icipie is one of the important larval parasitoids which has the potential to kill over 60% of fall armyworms (Khatri et al., 2020). The larvae of parasitoids kill their host as the outcome of their development.

Predators

General predators that attack the larvae of other lepidopterans also attack FAW. The most common predators of FAW include various ground beetles (Coleoptera: Carabidae), the striped earwig, *Labidura riparia* (Dermaptera: Labiduridae), the spined soldier bug, *Podisus maculiventris* (Hemiptera: Pentatomidae), and the insidious flower bug, *Orius insidiosus* (Hemiptera: Anthocoridae) (H Gebreziher, 2020). Birds, skunks, and rodents are the common vertebrates that feed on larvae and pupae of FAW (Sisay, 2018).

Entomopathogens Metarhizium anisopliae and *Beauveria bassiana* are the important fungi used in FAW management. Likewise, viruses such as Spodoptera frugiperda multiple nucleopolyhedrovirus and bacteria such *as Bacillus thuringiensis (*Bt), and others are also known to infect FAW (Sisay, 2018).

Mechanical Control

The mechanical method can be used to prevent further damage soon after observation of FAW incidence. However, it is not suitable in the case of higher infestations. Handpicking and crushing of egg masses and young larva can be performed if any sign of incidence is observed (MoALD, 2019). The application of dry sand and wood ashes into the whorl of affected maize is also considered an effective mechanical method to control pests (Khatri et al., 2020).

Botanicals

Botanical Pesticides are naturally occurring chemicals extracted or derived from plants that repel, inhibit, or kill pests. To overcome the major limitations of chemical control methods such as rising resistance, environmental and health risks, and the adverse effect on non-target organisms IPM focuses on the use of botanical pesticides. Botanical pesticides are environment-friendly, degradable, and easy to use. More than 6000 plant species from at least 235 plant families have been screened for pest control properties (Devi, 2020). Application of 0.25% Neem oil has 80% mortality in larvae, Hexane and ethanol extract of seeds from *Aglaia cordata* shows 100% larvicidal effect, Castor oil and Ricinine (seed extracts) of *Ricinus communis* inhibits growth and development of larva, ethanolic extracts from leaves of *Jatropha gossypifolia* is antifeedant of larva*e* (Prasanna et al., 2018). These botanicals which have insecticidal properties can be collected from tropical and subtropical regions of Nepal and those bioactive chemical compounds could be sprayed in FAW infested zones.

Chemical Control Measures

Pesticides are chemical compounds that are used to kill pests. In IPM the use of pesticides is not considered good as it is a threat to the environment and human health. However, in severe conditions, we can use chemicals under the economic threshold by applying safety measures. Several synthetic pesticides that were reported to be effective against FAW include methomyl, acephate, cyphluthrin, benfuracarb, methyl parathion, carbaryl, carbosulfan, lindane, chlorpyrifos, diazinon, and methyl parathion (GC et al., 2019).

Table 3. Recommended chemical pesticides in Nepal*

S.N	Name of pesticide	Doses
1.	Spinetoram 11.7 SC (Delegate)	0.5 ml/liter of water
2.	Chorantraniliprole 18.5% SC	0.4 ml/liter of water
3.	Spinosad 45% SC	0.3 ml/liter of water
4.	Emamectin benzoate 5% SG	0.4 g/liter of water

*Source: (MoALD, 2019), SC=Suspension Concentrate, SG: Soluble Granules

Conclusion

Fall Armyworm is a major invasive pest of maize plants that completes its life cycle within one month in the monsoon season. It has spread over a large number of countries within a short period and has caused huge yield loss of maize. The FAW species has recently invaded maize fields of Nepal but it spread over Terai, Hilly, and Himalayan districts in a short time. In a country like Nepal where farmers lack awareness about proper crop management practices, an infestation of Fall Armyworm has caused significant damage in maize fields. Integrated pest management is the best preventive option to reduce the pest infestation where regular monitoring of the maize field is compulsory. IPM approach helps to reduce the toxic levels of the pests in the crop field. Among the cultural practices to prevent the infestation of fall armyworm, push and pull technology is most widely used and it should be promoted in Nepal too. Rearing and release of Predators like ground beetles, striped earwing, and spined soldier bugs are effective against larvae and pupae of FAW. Use of botanical pesticides such as Neem oil, bioactive chemical compounds extracted from Castor, *Jatropha gossypifolia*, *Aglaia cordata*, etc that are readily available must be preferred over chemical pesticides in the control of pest infestations for the sound environment and human health. Government should promote research activities, education, and crop insurance to minimize damage from pests. Strict implementation of policies related to pest quarantine in border areas can prevent invasion of FAW as well as other kinds of pests and diseases.

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