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REVIEW ARTICLE

FALL ARMYWORM OUTBREAKS IN ASIA: ANALYZING THE STRATEGIES TO CONTROL

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ABSTRACT

Fall armyworm (*Spodoptera frugiperda)* is a Lepidopteran moth of Noctuidae family. Due to its polyphagous characteristic with a large host range, strong migration ability, high fecundity (average egg production per female is about 1500) and lack of diapause has already contributed to its invasiveness in America and Africa. Recently it has been introduced in Asia in the year 2018. Though it has been only around three years of Fall armyworm (FAW) introduction, it has already spread into many Asian countries and on the way to cause havoc. Though it can infest many crops, its main target and maximum yield loss has occurred in case of Maize. In America and Africa, farmers are already well known to this pest and have adapted themselves to reduce crop loss to some extent by undertaking several management options. As this pest is completely new to Asia, farmers do not know much about its biology, nature of damage and control measures. And their misdiagnosis of the pest leads to panic and increased crop loss. Therefore, it is very important to increase awareness among the farmers to identify its attack on the right time to take suitable control measures as well as preventive measures for upcoming cropping seasons. Some of the cultural, mechanical, biological and chemical control measures those were effective in reducing its infestation outside Asia, has also found to be effective inside Asia. Collaboration of these control measures according to the field condition is main concern for the cultivators. But the integrated pest management option alone can also help to keep FAW population much below economic injury level and prevent its invasiveness as a tool of sustainable management for ensuring food security.

KEYWORDS

Fall armyworm, invasiveness, yield loss, control measures, Integrated Pest Management.

1. INTRODUCTION

Fall Armyworm (FAW) (*Spodoptera frugiperda*) is a Lepidopteran crop pest that has more than 80 host species and causes severe damage to maize cereals. It is native to the tropical and subtropical region of America but has rapidly spread worldwide. The larvae and adults of FAW damage young leaves, leaf whorls, tassels or cobs of maize. Under heavy infestation of FAW cause 50-80% yield loss in maize crop. This pest is capable of rapidly breeding, migrating and feeding on a large variety of host plants, making it very difficult to monitor (Adhikari et al., 2020).

It is considered as a super pest on the basis of its host range, its inherent ability to survive in a wide range of habitats, its strong migration ability, high fecundity, rapid resistance development to insecticides/viruses, no diapauses stage and its gluttonous characteristics. The inherently superior biological characteristics of FAW contribute to its invasiveness (Jing et al., 2021).

Two sympatric host-plant strains of FAW including the "corn-strain" (C-strain) that feed mostly on maize, cotton and sorghum and the "rice-strain" (R-strain) that is mostly associated with rice and various pasture grasseshave been identified (Nagoshi& Meagher, 2004). Among these strains, the maize strain is most widespread and causes serious damage mainly to maize (Adhikari et al., 2020). Damage by FAW was detected in central and western Africa in early 2016 and it spread very quickly across all over within two years to more than 40 African countries due to unscientific, uncontrolled trade and is spreading rapidly in south Asian countries since last two years in spite of scientists deep concern (Chhetri & Acharya, 2019). After causing serious damage of crops in Africa, it was first spotted in Asia from Karnataka, (India) in May 2018. As of March 2020, it has spread to countries beyond South Asia to South East Asia and even found in China (2019), Thailand, Myanmar, Korea, Nepal, Japan, Sri Lanka, Bangladesh (Alam et al., 2018; Jing et al., 2021; Lamsal et al., 2020).

Maize (*Zea mays*) is one of the world's major cereal crops because- it has high importance as a staple food as well as it is also being used as animal feed and fuel (Abebe et al., 2017). But it was observed the productivity of maize is getting lower than its potential in recent years due to many biotic and environmental constraints. The major constraints are pests and disease which reduces the production and yield of the crop. Many pests are directly responsible for the damage and reduction in yield of maize (Adhikari et al., 2020). FAW is considered as the most important and

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devastating insect pest of maize crops causing serious damage in many countries (Ayala et al., 2013). FAW directly affects capital costs due to increased need of manpower and the type of knowledge required to handle the pest, yield losses and higher financial costs of its control (Khan et al., 2018).

While destroying the crops, exotic pest species develop some negative impact on environment and makes the pest management under practice invalid. The Fall armyworm is already considered a major pest of maize in western hemisphere and it is an invasive pest in Asia. Their potential of competing and hybridization with other maize pest may cause devastating consequences disturbing available pest management strategies. Already a pesticide resistant inter strain hybrid was found in China that is an alarming issue for developing successful management techniques as well as a threat to ecosystem (Ayra-Pardo et al., 2021). Since it is practically impossible to eradicate the pest now, it is essential to work on long term management to keep pest population below economically injury level. Reliance on chemical pesticides is only a temporary way of dealing with the pest because FAW is becoming tolerant to many insecticides and difficulty is increasing in finding and surveying field infestation with simple protocols. Educating the farmers about the pest and practicing integrated approach of management compatible and feasible in the region would be more sustainable. Identification and use of native species of natural enemies, such as predators, parasites and parasitoids is the current need of research (Chhetri & Acharya, 2019; Lamsal et al., 2020).

This pest is declared as invasive species in many regions of the world and farmers are facing difficulties to control it as it is new to these regions. If not controlled properly, it may spread all over the world causing severe food insecurity. The objective of this review is to provide an insight of the spread of FAW referring its biology and invasiveness, and the adopted strategies for managing the pest incidence in Asian countries leading to the means of sustainable management.

2. METHODOLOGY

This review article synthesized from secondary data of different literature related with Fall armyworm outbreak and its management techniques. The information was collected from various journals, research papers, books, articles and the findings were summarized and arranged in texts, table along with conclusion.

3. RESULTS AND DISCUSSION

3.1 Outbreak of FAW in different region

FAW was first observed in tropical and subtropical America. First it was recorded in Georgia of the United States in the 1797. Afterwards it spread into Africa in the year 2016, followed by Asia in 2018. If not controlled properly, the consequences can be more devastating. Its occurrence flow from Africa to Asia is given below (Figure 1).

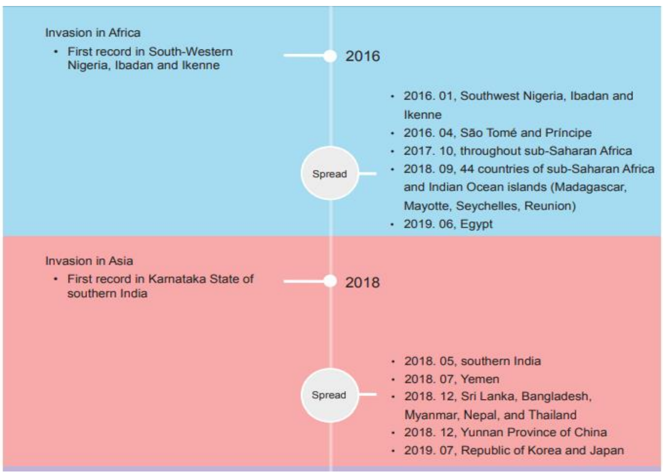

Figure 1: Invasion and outbreak of fall armyworm (FAW) from Africa to AsiabyJing et al., 2021).

After being introduced in Asia, it is spreading rapidly throughout Asian countries. Though the maximum numbers of countries are infested in Africa, Asian countries are in second position (Table 1).

Table 1: Global distribution of Fall Armyworm by Adhikary et al., 2020	
Continent	**Total number of countries per continent**
Africa	54
Asia	48
Europe	44
North America	23
Oceania	14
South America	13

Till now, data from papers indicate that, Pakistan and Afghanistan do not have official report of infestation of FAW but other nearby Asian countries like China, Myanmar, Bangladesh, Thailand, Vietnam, Malaysia, Japan and Indonesia have already confirmed cases of FAW in their country (Figure 2).

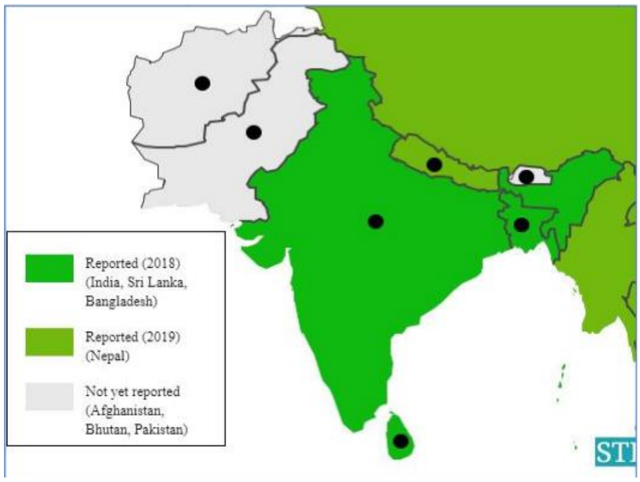

Figure 2: Distribution of FAW in South Asia by Lamsal et al., 2020)

3.2 Biology of FAW

FAW has a wide host range of more than 353 recorded plant species (Jing et al., 2021). FAW has very high migratory ability, over 100 km /hr (Tendeng et al., 2019). Average egg production per female FAW is about 1500 and they don't have the diapausing ability (Prasanna et al., 2018). According to Ashley et al., (1980) FAW is very much similar to the true armyworm. But FAW larvae can be distinguished from armyworm by 4 dark spots in 8th abdominal segment and an inverted 'Y' sign on its head. In case of adults, grayish brown forewing with light and dark splotches can be seen in the males, whereas noticeable spot near the end of forewing and iridescent silver white with thin dark border in hind wing is the identifying characteristic of females (Figure 3 and Figure 4).

Figure 3: FAW larval identification marks (Prasanna et al., 2018)

Figure 4: Adult male (left) and female (right) of FAW (Lamsal et al., 2020)

3.2.1 Suitable environment for FAW

The suitable environment for FAW survival and multiplication includes- warm and humid temperature with heavy rainfall, and temperature below

10^0C inhibits its growth and development. It completes its 4 life cycles- egg, larval instars, pupae and adult stages within 1, 2 and 3 months in summer, spring & autumn, and winter season respectively (Reinert &Engelke, 2010). Its life cycle includes egg (2–3 days), larvae (total six instars, 13–14 days), pupae (7–8 days) and adults (7–21 days). FAW has a generation time of approximately 30–40 days during the warm summer months (daily temperature of ~28ºC), and approximately 55 days in cooler temperatures (Prasanna et al., 2018; Sharanabasappa et al., 2018). So prolonged summer season in Asia helps FAW to develop its population more rapidly.

The number of generations produced in an endemic area depends mainly on environmental conditions, e.g., temperatures and host plants (Prasanna et al., 2018).

3.2.2 Nature of Damage to crops

Primary symptoms of FAW appear as small holes and window pan feeding that is similar to other stem borers. The early stages of instars feed on leaves and late stages on tassel and ears of maize plants. Windowing and saw dust like fecal matter on the base of upper young leaves indicate FAW larval feeding; leaves become skeletonized during vegetative stage of maize. Vigorous feeding by larvae in young plants can kill growing point and lead to "dead heart" symptom and in the reproductive stage of plant, larval feeding cause injury to the growing cob that influences further development of plants and induce yield damage (Bateman et al., 2018; Deole & Paul, 2018; Kumela et al., 2019).

This pest can destroy the crop almost overnight, because the early stages of FAW caterpillar consume very little food, but the later stages require about 50 times more food. As their food consumption changes rapidly, it is difficult to notice the presence of larvae until they have destroyed almost everything within a night (Alam et al., 2018). (Figure 5).

Figure 5: Windowing of leaves (left), ear feeding (middle) and moist frass (right) in the feeding area (Lamsal et al., 2020)

3.3 Control strategies for FAW

Worldwide, several crops are infested by FAW, hence several control measure strategies have been developed in different regions. In Asia, cultural, physiological, biological, chemical control measures are followed by farmers. But approach to Integrated Pest Management (IPM) is also preferred in some countries. Some of the techniques that are used to control FAW in Asia are discussed below:

3.3.1 Cultural control measures against FAW

3.3.1.1 Adjusting planting time

Several studies show that, the infestation during late season can be reduced by planting early maturing variety and avoiding late season planting with staggered planting (planting in same field at different times) (Chhetri & Acharya, 2019).

3.3.1.2 Seed and variety

Seeds contain genetic information of a plant. Growth and development of plant depends mainly on three factors- climate, soil condition and genotype of seed. Some of the plants are naturally genetically resistant to some disease and pests. Development of transgenic variety using gene of *Bacillus thuringiensis* produce crystal like protein (Cry protein) can make the plant resistant against some specific insect species including FAW (Chhetri & Acharya, 2019). It was found through Laboratory bioassay that, insects invading China are resistant to organophosphate and pyrethroid pesticides but are sensitive to genetically modified maize containing the Bt toxin Cry1Ab in field experiments (Zhang et al., 2020).

3.3.1.3 Management of crop residues

Crop residues used as mulching are the clothes of soil that help in maintaining soil temperature, soil biological activity and ultimately humus formation i.e. immune system of soil. Thus, managing the crop residues promote ultimately better plant health, and plants having better health has higher resistibility power that can resist the adverse condition either climatic or biological (Chhetri & Acharya, 2019).

3.3.1.4 Soil health and adequate moisture

Development of resistance power comes genetically and from the humus contain in soil to plant. Mulching is the process that promotes the humus formation, whereas excessive inorganic fertilizer especially nitrogen decreases the resistibility and makes the plant susceptible to pest and disease. Adequate moisture contains promote the physiological activity of plants ultimately plants become strong (Chhetri & Acharya, 2019).

FAW doesn't damage to whole plant causes significant reduction in yield up to only 20% that can be avoided and removed if there is good plant nutrition and moisture (Baudron et al., 2019).

3.3.1.5 Intercropping of maize

Maize intercropping with legume was found to be more effective compared to maize monocropping in combating FAW. If the intercrop is legume, it advances maize by fixing nitrogen in soil thereby increasing compensating capacity against foliar damage (Lamsal et al., 2020). The larvae of FAW usually shift from maize to sugarcane after 40 to 50 days, so intercropping of maize with sugarcane should be avoided for blocking the multiplication of further generations (Chormule et al., 2019). Some of the beneficial intercropping combination of maize with legume has been found to be effective against FAW.

1. Maize + Napier (Border intercrop) (Midega et al., 2018).

2. Maize + Bean (*Phaseolus vulgaris* L.) (Row intercrop) reduces FAW attack up to 40% due to confusion (Midega et al., 2018).

3.3.2 Agroecological approach for controlling FAW

Agro-ecological approaches offer culturally appropriate and low-cost pest control strategies that can be readily integrated into existing efforts to improve smallholder incomes and resilience through sustainable intensification. Three agroecological measures can be taken to reduce FAW in the long run- (i) sustainable soil fertility management to maintain or restore soil organic carbon; (ii) intercropping with appropriately selected companion plants; and (iii) diversification of farm environment through management of (semi)natural habitats at multiple spatial scales (Harrison et al., 2019).

Push-pull is considered a more suitable and cost effective agroecological technology where mainly three approach is used together -1) Use of trap plants (pull) such as Napier grass or Brachiria grass for attracting pests, 2) Using a repellent intercrop (push) such as Desmodium, to drive away the pest from main crop, 3) Attracting parasitoids and predators to the field. Using this method was found to be effective in reducing average number of larvae per plant by 82.7% and plant damage per plot by 86.7% in Africa and thus is well suited for the intensification of agro-ecosystem of smallholder mixed farming systems (Khan et al., 2018; Midega et al., 2018) (Figure 6).

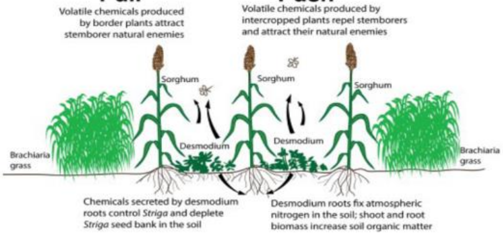

Figure 6: Push-pull technology to control FAW (Khan et al., 2018)

3.3.3 Mechanical control measure for FAW

For smallholder farmers it is feasible to crush young larvae and egg masses before they hatch. Many farmers in Africa have successfully managed FAW by using ash, sand, sawdust and even soil into whorls to desiccate young larvae. Immature leaves are more vulnerable to early infestation and are more likely to be seen with cluster of egg masses. Therefore, finding and destroying these egg masses at the earliest will bring down the active pest population below economic injury levels (Lamsal et al., 2020)

3.3.4 Use of botanicals against FAW

Some botanicalscan be used as plant derived pesticides that display good performance in insecticidal activity. These products show diverse biological activities that result in high mortality, extended larval duration, decreased pupal weight, insecticidal effects, growth inhibition, antifeedant effects, reduced fecundity, as well as sublethal and acute toxicity against several pests (Jing et al., 2021).

The opportunities and scope for botanical extracts and products for the management of FAW in Africa were reviewed by Rioba & Stevenson (2020), and they summarized the efficiency and potential of 69 plant species from 31 families including *Azadirachta indica*, *Phytolacca dodecandra* and *Schinnus molle*. In China, indoor toxicity and control effect of *Azadirachtin* in a maize field for FAW has been estimated and *Azadirachtin* was found to have good toxicity and antifeedant activity on FAW, and the highest control effect was seen at seven days after treatment (Lin et al. 2020). Efficacy of *Nicotiana tabacum* and *Lippia javanica* was reported to cause up to 66% larval mortality in maize (Phambala et al., 2020).

Botanical extracts of pesticidal plants do not produce mortality rates as higher as synthetic pesticides but they can be used as an independent component of sustainable pest management approach.So, there is an immense opportunity to identify and use locally available pesticidal plant species as an alternative to synthetic pesticides (Lamsal et al., 2020).

3.3.5 Biological control

Biological control can reduce environmental contamination and offer an economically and environmentally safer alternative to synthetic insecticides that are currently being used. Natural enemies include parasites/parasitoids, predators and entomopathogens (Jing et al., 2021).

3.3.5.1 Parasitoids

Parasitoids are the organisms that can kill their host and are being used as a natural bio control agent; they lay eggs on the egg masses, larvae or adult of FAW and destroy their host by taking nutrition and multiplying inside them. (Lamsal et al., 2020). Recently some of the parasitoids were found effective in controlling FAW in different regions.

1. *Telenomus remus* (Nixon)- egg parasitoid. Observed parasitism rates ranged up to 69.3%. (Lamsal et al., 2020)

2. *Cotesia icipe* -larval parasitoid. Observed parasitism rates ranged up to 42% (Lamsal et al., 2020).

Studies in southern India recorded five species of larval parasitoids against FAW: *Coccygidium melleum, Campoleti schlorideae, Eriborus sp., Exorista sorbillans,* and *Odontepyris* sp. (Sharanabasappa et al., 2019).

3.3.5.2 Predators

Predator insects usually feed upon different stages of their hosts. (Table 2).

Table 2: Predators of different stages of FAW

Predators	Stages of FAW
Ladybird beetle	Both larvae and adult (Chhetri & Acharya, 2019).
Earwig	Young caterpillar (Chhetri & Acharya, 2019).
Ant	Young caterpillar (Chhetri & Acharya, 2019).
Calosoma granalatum	Young caterpillar (Prasanna et al., 2018).
Picromerus lewisi & *Arma chinensis*	6th instar larvae of FAW (Tang et al., 2019a, b).

3.3.5.3 Entomopathogen

Pathogen like bacteria, fungi and virus affect the yield of the crop but some microorganisms are beneficial to farmers (Chhetri & Acharya, 2019). Different groups of entomopathogens have been identified by researchers that infect FAW (Table 3).

Table 3: Different groups of entomopathogens against FAW by Chhetri & Acharya, 2019

Pathogenic group	Pathogens
Virus	*Nucleo polyhidroxy virus*
Fungi	*Metarhizium anisopilae*
	Metarhizium rileyi
Bacteria	*Bacillus thuringiensis*

3.3.6 Monitoring and scouting to prevent FAW

For migratory invasive insects, monitoring and scouting are very important for timely responses to the pest population dynamics of pest occurrence, development and crop health. This enables the formulation of comprehensive measures for better prevention and control. These actions must be taken based upon cost ratios to keep the FAW population below the economic threshold level (Jing et al., 2021).

Monitoring using vertical-pointing search light traps showed that, in eight provinces of China in 2019, the FAW population was first trapped in June and the observation peaks appeared from August to October (Jiang et al., 2020). The blacklight trap and commercial male traps are recommended to farmers to monitor the field population dynamics of FAW. The recommended height of pheromone traps is- 1.5 m above ground and the interval between two traps should be 50 m (Malo et al., 2013). FAW pheromone trap has been used for pest monitoring, mass-trapping, and interruption in mating in different regions and was recommended in Nepal (Bhusal& Bhattarai, 2019). To record the presence of FAW in Bangladesh, monitoring has already been started in cabbage & maize (Alam et al., 2018).

Farmers are recommended to scout the different plant growth stages and crop damage to determine the optimum stages for spraying insecticides based on action thresholds, which are expressed as percentages of plants with typical FAW damage/injury symptoms. For the early whorl stage, from vegetative emergence (VE) to 6-leaf (V6) stages, the action threshold is 10–30% of the seedlings infested as well as the tassel and silk stages, while it is 30–50% for the late whorl stage (Prasanna et al., 2018).

3.3.7 Chemical control

Synthetic pesticides can only be regarded as an emergency measure to control FAW outbreaks. Three groups of pesticide- emamectin benzoate, spinosad and chlorantraniliprole has been recommended by Indian Institute of Maize Research (ICAR) against FAW. As FAW larvae stays inside the whorl of maize leaves during daytime and comes out only at night, thus it is suggested to use the pesticide at dusk to ensure larval contact with pesticide while coming out and make the pesticidal application more effective. However, using pesticide in the reproductive stage of maize plants will not be effective as damage to tassel cannot affect the yield and in that stage, damage to ear is almost inevitable as larvae keeps hiding inside the ears. But chemical control of FAW in combination with handpicking of larvae by close observation is said to be more effective. On the other hand, in South Asia, farmers mostly apply pesticides in the field without any personal protection, so use of synthetic pesticides against FAW can lead to massive health hazard in farmers. However, it is essential to train and advise farmers about rational use of pesticides to prevent any negative impacts on human health and environment. Another problem is that majority of farmers in South Asia are small holders and chemical control of FAW might not be affordable to all unless governments subsidy. So, it is essential that South Asian farmers do not exclusively rely on synthetic chemicals for long term (Lamsal et al., 2020).

Some other pesticides are also used in different regions of Asia to control FAW (Table 4).

Table 4: Chemical insecticides used against the fall armyworm by Jing et al., 2021

Active ingredient	Active ingredient
Acephate	Fenitrothion
Cartap	Hexaflumuron
Cyfluthrin	Indoxacarb
Cyantraniliprole	Lufenuron
Chlorfenapyr	Lambda-cyhalothrin
Deltamethrin	Tetrachlorantraniliprole

3.3.8 Integrated Pest Management (IPM) approach to control FAW

IPM involves use of several pest management strategies in a combination at a time so as to keep pest population below economic injury level without causing any negative effect on soil health and environment. IPM practices involve not only curative measures, but also prophylactic measures adopted before the occurrence of infestation (Lamsal et al., 2020). For smallholders, IPM acts as a series of low-cost agricultural control measures and is an optimum option to implement as part of an effective control strategy against FAW. IPM approaches use the complex interactions between organisms and their environment to develop techniques to minimize the damage of crops by pests (Jing et al., 2021). Scientists have suggested some IPM approaches to be taken in Asia for successfully minimizing the FAW population. These are given below:

1. Traditional pre-planting, using some measures such as deep ploughing before sowing can decrease the FAW population by exposing pupae to sunlight and predatory birds (Prasanna et al., 2018).

2. Planting transgenic/ Bt insect-resistant maize varieties is also a very effective measure to decrease the damage by FAW and is an alternative method to pesticides (Jing et al., 2021).

3. Use of mechanical methods like hand picking, light traps and pheromone lures could be an option for monitoring and controlling the pest for small scale farmers (Bhusal& Bhattarai, 2019).

4. Use of intercropping of the legumes with maize and use of the "push and pull" strategy should be introduced among the farmers with awareness of controlling the FAW (Bhusal & Bhattarai, 2019; Jing et al., 2021).

5.The synthetic chemical should be avoided as possible but should be used in severe damage more than 50% (Chhetri & Acharya, 2019).

4. Conclusion

The invasiveness of Fall armyworm is already a matter of concern in worldwide. Spread of this pest is occurring quite fast from one country to another despite of taking several control measures. Though it was first introduced within Asia continent in India, it has already spread to a considerable number of Asian countries and FAW has the ability to spread all over the continent. It is clear from the study that the biology of FAW that includes high fecundity, wide host range, lack of diapauses, short generation period and long-distance migration ability etc. are the main contributing factors to its invasiveness. Although different control strategies have been developed, their use should be coordinated with pest occurrence and level of damage. Instead of using cultural, mechanical, chemical or biological approaches alone, IPM approach should be followed by farmers to control FAW population in the long run as it is a complete package for managing any pest to keep the crop loss below economic threshold level. IPM technique will also save the cost of farmer as well as help to maintain sustainable agriculture.

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