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A Review on Management of Invasive Insect Pest Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

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Abstract: Agriculture is the backbone of nation as it provides food to the population and most of the country's economy comes from agriculture. Invasive insect pests, Pathogens, weeds, and other threats to global agriculture are all too frequent, resulting in massive loss to both agricultural productivity and the natural environment. Invasive insect pest like *Spodoptera frugiperda* is a serious problem faced by agriculture and responsible for reduction in crop yield. *Spodoptera frugiperda* is a most destructive nocturnal insect pest endemic to the tropical and subtropical regions of America and spread in Africa and Asia since 2016. Its high migratory behavior leads rapid expansion which reached to India in May 2018 and up to August 2019 it is spread almost in all states of country leading to huge damage to crop thus causing loss of economy of nation. A combination of control methods should be used to reduce fall armyworm (FAW) infestation rather than relying only on pesticide.

Keywords: Fall armyworm, Invasive insect pest, Management, *Spodoptera frugiperda*

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Introduction

Agriculture plays crucial role in the economic status of developing countries as it provides food grains to people and gives most of income from agricultural commodities. The important aspect of agriculture is the food supply hence, agricultural productivity is responsible for health of nation also. Agriculture is continuously affected by numerous insect pests, micro-organisms, weeds etc. leading to reduced crop yield, deprived quality of crops and ultimately national economy.

One of the major reasons for reduction in agricultural production and productivity is invasive alien species (IAS) which leads to billions of dollars loss in agricultural field (Sharanabasappa *et al.*, 2018). Recent report showed that nearly 124 countries facing agricultural yield loss problem due to introduction of about 1300 species of invasive insect pests and pathogens (Paini *et al.*, 2016). On other hand, rapid increasing rate of population leads to

approximate double food demand in 2050 (Tilman *et al.*, 2002). According to FAO estimate, production of grain will be increased more than 140% for future population (Bruinsma, 2009). To serve food to this increased population, it is mandatory to enhance production and yields of grains by using various management practices, the only solution to lower down the pressure of food demand in world (Godfray *et al.*, 2010).

Fall Armyworm (FAW):

The commonly known fall armyworm, *Spodoptera frugiperda* (J.E. Smith) is harmful nocturnal insect pest which belongs to Lepidopteran group of Insects (Montezano *et al.*, 2018). The duration to complete life cycle of fall armyworm may varies seasonally, it requires 30 days in warm summer, 60 days during autumn and spring but may extends in cooler temperatures by 80 to 90 days during winter season (Capinera, 2002). Development of fall armyworm completes in four stages-- First the egg; then larva or caterpillar, which is the stages of pest growth and most injurious to crops; third stage i.e., Pupa or resting stages and finally the adult moth or the mature insect. Female lays eggs in cluster of 150-200 eggs in single layer, sometime two to four layers on different leaf and during its whole life span female can lay about 1500-2000 eggs (CABI, 2020). During larval period fall armyworm goes through six larval instars and lasts for about 14-21 days (Ali *et al.*, 2018). In prepupal phase, fully grown larvae stop feeding and turn a greenish to bright brown colour. Pupation usually takes place at a depth of 2 to 8 cm in the soil (Prasanna *et al.*, 2018). Adult moths live average of 10 days, with a range of 7 to 21 days (Bhusal and Chapagain, 2020). This adult stage of pest is highly migratory, which can travel 100 km in one night while about 2000 km during its adulthood (Venkateswarlu *et al.*, 2018).

Fall armyworm larval stage is voracious feeder causing huge damage to crop, due to its nocturnal habit when there are no disturbances in crop field and hide in funnel during daytime. As fall

armyworm is a polyphagous pest, its larvae can feed on about 353 host plants from 76 different plant families. It prefers the plant from Poaceae (106 taxa), Asteraceae (31 taxa), and Fabaceae (31 taxa) families and cause negative impact on economically significant cultivated crops like wheat, rice, maize, sorghum, sugarcane, cotton, as well as various vegetable crops. Out of this maize is the most important and preferred host, which is damaged severely by FAW in whole world (Montezano *et al.*, 2018).

Maize (*Zea mays* L.) is the “Queen of Cereals”, more than 100,000-hectare maize is cultivated by 70 countries including 53 developing countries like India and its sowing is increasing every year (Kumar *et al.*, 2020). It is attacked by several pests like insects, nematodes, mites, birds and rodents which result in loss of crop grains. Among them, one of the major reasons for the decline in maize productivity is insect pest infestation. Generally maize field infested by cut worms, maize stem borer, white grub and chaffer beetle, gram pod borer, wireworm, hairy caterpillar and many others. In recent years, the most destructive insect pest for maize field is *Spodoptera frugiperda*, which cause crop loss up to 70 per cent, if not manage properly (Raghunandan *et al.*, 2019).

Recent data stated that in India, the production of maize is 28,753 MT (Kharif 20,118 MT and Rabi 8,634 MT) in year 2017-18. However, after the entry of fall armyworm, the production reduced to 27,720 MT (Kharif 19,410 MT and Rabi 8,300) in 2018-19 (Kumar *et al.*, 2020). Almost one thousand metric tonnes of maize yield losses were caused due to the entry of FAW during 2018-19. Likewise, FAW may reduce the yield of other economically important food crops too and its polyphagous nature may put threat to food security in countries like India (Khan *et al.*, 2018).

FAW Global Impact:

Fall armyworm is first reported in Georgia in 1797 after which several outbreaks occurred during 19th century in America (Johnson, 1987). In 2016, the fall armyworm was firstly detected in Central

Fig. 1: Expansion of fall armyworm in different states of India (Modified from Sekhar *et al.*, 2019; Sharma *et al.*, 2020).

and Western Africa (Goergen *et al.*, 2016) and blowout quickly to different part of African continent, by spreading to 44 African countries and damaged crops heavily (Sisay *et al.*, 2019). Thereafter, it spread very quickly and is found in many other countries like India and Yemen (July, 2018), Bangladesh, Thailand, Sri Lanka (December, 2018), China, Malaysia, Myanmar, Indonesia, Egypt, Laos, Viet Nam, Republic of Korea (June, 2019) and Japan (July, 2019). Recently in February 2020, it is recorded in Australia and Mauritania and in Timor-Leste in March 2020 (CABI, 2020).

FAW in India:

The rapid global expansion of FAW in short period is because of its migratory behaviour, high dispersal capacity, significant flying ability and high fecundity (Khatri *et al.*, 2020). Moreover, in Africa and Asia, the climatic conditions for fall armyworm are ideal, allowing it to develop many generations in a single season, resulting in the pest

becoming endemic to this region. In India, first report of fall armyworm was from College of Agriculture, Shivamogga and Bangalore rural of Karnataka state during May 2018. Within a short period, from May 2018 to August 2019, fall armyworm spread to almost all states of India (Fig. 1) except Himachal Pradesh and Jammu-Kashmir (Suby *et al.*, 2020). Later, it was recorded in Himachal Pradesh in July 2020 (Sharma *et al.*, 2020).

FAW is a pest which can destruct complete maize plant as it feeds on all stages of plant and by defoliation can destroy whole plant. In India, several studies recently reported crop loss in maize and other crop fields due to FAW in the states of Maharashtra, Rajasthan, Chhattisgarh, West Bengal and Karnataka.

Management Practices Against Spodoptera frugiperda:

For fall armyworm infestation, a single management practice is not working, thus

integrated pest management methods become important to control this pest (Bista *et al.*, 2020). These methods are sustainable and cost-effective, with the least amount of harm to the environment, non-target organisms as well as human beings. For the management of FAW, different practices are in use which includes physical, mechanical, biological control methods, including control using natural enemies or botanicals and lastly chemical control which depends on availability of resource and pest population status in the field.

1. *Physical Control:*

Monitoring is a type of physical management that involves actively tracking a pest's presence, population, and movement within a defined area. Early detection of FAW can be efficiently done using Scouting, pheromones traps, light traps etc. Scouting entails determining overall crop health and estimating pest infestation in a rapid and systematic manner. Pheromone traps are insect traps that use pheromone to attract males and have been found to be an effective method for controlling male population. The most often used pheromones are sex pheromones and aggregation pheromones. Adult moths can also be caught using black light traps due to their nocturnal habits (Prasanna *et al.*, 2018).

Monitoring and scouting provides infestation amount in field, which serve to decide spraying and other control strategies to developed health plants. Such scouting studies were conducted in the parts of India, which estimates upto 66.50% crop loss in maize (Mallapur *et al.*, 2018) Such data help to built up control strategies but not helpful for the actual field control of the pests.

2. *Cultural Control:*

As healthy plants are less susceptible to pest and pathogen assault, cultural control is optimum agronomic technique that encourages the establishment of healthy plants. It enables to reduced FAW infestation by different practices like use of high-quality seeds, timely sowing, deep ploughing prior to sowing, and balanced

fertilizers, which ensures healthy plants. Protection of predators like ant and social wasp nests in and around crop fields is a simple and effective strategy for FAW control. Intercropping of maize with suitable pulse crops has been suggested instead of single crop and applying push-pull strategies by sowing of 3-4 rows of trap crops like Napier around maize field (Prasanna *et al.*, 2018).

Several Kenyan farmers reported considerable production loss due to FAW on late planted maize plots compared to adjacent plots that were planted earlier (FAO, 2018). In Nicaragua, a maize-bean intercrop reduced FAW infestation on maize by 20-30% (Abrahams *et al.*, 2017).

Intercropping of pest repellent species with main crop maize and surrounded by pest attractive species is beneficial to control FAW population in some extends.

3. *Mechanical Control:*

The reduction or suppression of insect populations by affecting them physically or alter their physical environment is referred to as mechanical control. It involves hand-picking egg masses during routine field monitoring to check pest population on a modest scale and has proven to be partially beneficial (Rwomushana *et al.*, 2018). Use of entomopathogenic nematodes, nucleo-polyhedrosis virus, or bacteria can kill FAW larvae. Applying dry sand, sawdust, and wood ashes into the whorl of infested plants soon after observation of FAW incidence is also an effective mechanical control method for fall armyworm infestation (Abate *et al.*, 2000).

Mechanical control by squashing egg masses and handpicking small larvae is feasible only in small area of maize field but its difficult to apply on large maize plot. Mechanical control is an initial stage of crop protection.

4. *Biological Method:*

Biological control, often known as biocontrol, is a kind of pest control that necessitates the use of

other species to control pests; it relies on predation, parasitism, herbivory, and other natural mechanisms. Biological control is an important feature of IPM and mutually compatible pest-suppression approaches that aim to increase revenues by lowering pest infestation and protects the environment as well as human health. It was reported that, *Spodoptera frugiperda* is the first host for *Glyptapanteles creatonoti* across the globe (Table 1). *Glyptapanteles creatonoti* was found to be an effective parasitoid to control *Spodoptera frugiperda* and other noctuid pests in India and Malaysia (Shylesha *et al.*, 2018). *Telenomus remus* Nixon (Hymenoptera: Platygasteridae) is a potent natural enemy for *Spodoptera* species as an egg parasitoid (Molina-Ochoa, 2003). It was reported that, earwings (*Forficula* sp.) (Dermaptera: Forficulidae), is also one of the potent predators (Table 1) against *Spodoptera frugiperda* on maize in India (Shylesha *et al.*, 2018). Parasitoids lay their eggs on egg masses, larvae or adult of fall armyworm. Most of parasitic Hymenoptera, act as larval parasitoids against fall armyworm. All these naturally existing enemies act as bio-control agent for FAW. As a smaller number of bio-control agents present to reduce FAW infestation, diversity conservation of such natural enemies by planting non-host plants around maize field provides shelter, alternative food sources and condition for multiplication of beneficial species.

5. Botanicals:

Botanical pesticide is a plant-based pesticide prepared from different parts of plant or plants. Pesticides derived from plants sources are naturally occurring secondary metabolites (phytochemicals) which serve for controlling and killing the pest in crop field. Plant derived biopesticides or botanicals are most important alternatives to chemical pesticides (Chengala and Singh, 2017). Botanicals can control the pests by non-toxic mechanisms and reduces agricultural toxicity (Dutta, 2015).

Azadirachta indica (Neem) is a most effective

and potent plant to control fall armyworm (Table 2). It causes more than 70% mortality in fall armyworm in laboratory conditions (Maredia *et al.*, 1992). Neem also affects insect growth, development, egg laying and shown antifeedant and larvicidal activity in fall armyworm (*et al.*, 2019b). Salinas- Sanchez *et al.* (2012) reported that *Tagetes erecta* plant showed 48–72% larval mortality, antifeedant effect causing 50% reduction of larval weight, 40–80% pupal mortality while *Myrtillocactus geometrizans* showed growth inhibition and larvicidal activity. Santos (2012) reported that extracts of *Zizyphus joazeiro*, *Morinda citrifolia*, *Nicotiana tabacum*, *Zingiber officinale*, *Annona squamosa* and *Calotropis procera* showed increased larval mortality and decreasing pupal weight in fall armyworm. As botanicals showed promising results for many insect pests and are easily available in the localities and are eco-friendly hence, these methods could be explored to develop newer strategies to control FAW (Table 2).

6. Chemical Control:

Chemical control methods include use of synthetic chemical compounds. Chemical pesticides affect the pest by altering life stages which leads to killing of the pest and quick reduction in damage of agricultural crop. Generally, farmers apply large amount of chemical pesticides on crop to minimize the damage caused by pest. It results in accumulation of pesticidal chemical residue in environment and causes adverse effect on non-target organisms including humans and on biodiversity (Kaur *et al.*, 2019). *Spodoptera frugiperda* can be controlled by many synthetic pesticides (Viteri *et al.*, 2018) causing environmental contamination and negative effect on ecosystem, as well as these are of high cost. Common Synthetic pesticides for FAW control are - Esfenvalerate, Carbaryl, Chlorpyrifos, Malathion, Permethrin and Lambda-cyhalothrin (Table 3). FAW is also controlled by applying spray of chemical like Methomyl, Cyfluthrin,

Table1: Some biological control agents used against fall armyworm

Type	Biological agent	Host stage	Place	Cited by
Parasite	<i>Glyptapanteles creatonoti</i>	Larvae	India	Shylesha <i>et al.</i> , 2018
Parasite	<i>Coccygidium melleum</i>	Larvae	India	Kalleshwaraswamy <i>et al.</i> , 2019
Parasite	<i>Chelonus</i> sp.	Eggs/ Larvae	Kenya, Barbados, India, Trinidad &Tobago	Suby <i>et al.</i> ,2020
Predator	<i>Harmonia octomaculata</i>	Larvae	India	Suby <i>et al.</i> ,2020
Predator	<i>Forficula</i> sp.	Larvae	India	Shylesha <i>et al.</i> , 2018
Pathogen	<i>Nomuraea rileyi</i>	Larvae	India, Nicaragua;Venezuela	Mallapur <i>et al.</i> , 2018
Pathogen	<i>Spodoptera frugiperda</i> multiple nucleopolyhedrovirus (<i>SfMNPV</i>)	Larvae	North and South America, India	Sivakumar <i>et al.</i> , 2020; Popham <i>et al.</i> , 2021
Pathogen	<i>Metarhizium anisopliae</i>	Eggs/ Larvae	India	Ramanujam <i>et al.</i> , 2020

Table 2: Botanicals with their mode of action for control of *Spodoptera frugiperda*

PLANT	FAMILY	ACTION	CITED BY
<i>Dysphania ambrosioides</i>	Amaranthaceae	Mortality, decreased pupal weight	Sisay <i>et al.</i> , 2019
<i>Yucca periculosa</i>	Asparagaceae	Reduced pupation survival, reduced insect growth	Torres <i>et al.</i> , 2003
<i>Senecio salignus</i>	Asteraceae	Juvenomimetric activity, antifeedant, insecticidal,	Romo Asncion <i>et al.</i> , 2016
<i>Cymbopogon winterianus</i>	Cardiopteridaceae	Biochemical profile of larvae is altered, decline reproduction, failure to reproduce	Silva <i>et al.</i> , 2017
<i>Carica papaya</i>	Caricaceae	90% mortality	Perez-Gutierrez, 2011
<i>Ricinus communis</i>	Euphorbiaceae	Insectistatic, larvicidal, growth inhibition	Ramos-Lopez., 2012
<i>Jatropha gossypifolia</i>	Euphorbiaceae	Larval antifeedant, synergistic effect	Bullangpoti, 2012
<i>Copaifera langsdorffii</i>	Leguminosae	Eggs with a low viability rate, Low fertilityand fecundity, decrease in larval growth, egg abnormalities, suppressed trypsin activity	Soares <i>et al.</i> , 2011
<i>Salvia ballotiflora</i>	Lamiaceae	Increased duration of larval and pupal stages,pupa weight was lowered, insectistatic, insecticidal	Cardenas-Ortega <i>et al.</i> , 2015
<i>Salvia microphylla</i>	Lamiaceae	Juvenomimetric activity, insecticidal, antifeedant	Romo-Asncion <i>et al.</i> , 2016
<i>Melia azedarach</i>	Meliaceae	Reduced larvalfeeding and growth,synergistic with pesticide	Bullangpoti <i>et al.</i> , 2012
<i>Melia abyssinica</i>	Meliaceae	High mortality	Sisay <i>et al.</i> , 2019

<i>Azadirachta indica</i>	Meliaceae	Antifeedant activity, larvicidal, increased development period, reduced insect growth, mortality, low egg laying	Sisay <i>et al.</i> , 2019; Campos, 2012
<i>Phytolacca dodecandra</i>	Phytolaccaceae	High mortality	Sisay <i>et al.</i> , 2019
<i>Piper hispidinervum</i>	Piperaceae	Affects spermatogenesis and egg laying	Alves <i>et al.</i> , 2012
<i>Psychotria goyazensis</i>	Rubiaceae	Reduced hatching rate, egg mortality	Tavares <i>et al.</i> , 2013
<i>Nicotiana tabacum</i>	Solanaceae	High mortality	Phambala <i>et al.</i> , 2020

Table 3: Some registered insecticides/chemical compound and their mode of action for Fall armyworm control on maize (Bezuidenhout and Nunkumar, 2017)

Active Component	Chemical Classification/ Nature	IRAC Classification		
		Group	Mode of Action	Target site
Carbosulfan	Carbamate	1-A	Inhibitors of acetylcholinesterase (AChE)	Nerve action
Chlorantriliprole	Diamides	28	Ryanodine receptor modulatr	Nerve action
Chlorpyrifos	Organophosphate	1-B	Inhibitors of acetylcholinesterase (AChE)	Nerve action
Emamectin benzoate	Avermectin	6	Allosteric modulators of glutamate gated chloride channels (GluCl)	Muscle and Nerve action
Indoxacarb	Oxadiazine	22-A	Block to voltagedependent sodium channel	Nerve action
Lufenuron	Benzoylureas	15	Chitin biosynthesis inhibitors	Growth regulation
Mercaptothion	Organophosphates	1-B	Inhibitors of acetylcholinesterase (AChE)	Nerve action
Methomyl	Carbamate	1-A	Inhibitors of acetylcholinesterase (AChE)	Nerve action
Novaluron/ Indoxacarb	Benzoylureas/ Oxadiazine	15/22-A	Inhibitors of chitin biosynthesis, type 0/ Voltagedependent sodium channel blockers	Growth regulation /Nerve action

Spinetoram/ Methoxyfenozide	Spinosyns/ Diacylhydrazines	5/18	allosteric modulators of nicotinic acetylcholine receptor (nAChR)/Ecdysone receptor agonists	Nerve action/ Growth regulation
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Methyl parathion. Most of these synthetic chemical pesticides are carcinogenic in nature which can cause cancer of thyroid, brain and leukaemia also (Asghar *et al.*, 2016).

Chemical pesticides are easy way of crop protection against many insect pests, but its indiscriminate use results in accumulation of pesticidal residue in environment and causes adverse effect on non-target organism including humans and biodiversity. Due to risk associated with hazardous chemical pesticide, minimize the use of chemical pesticides and use IPM methods against fall armyworm for eco-friendly and safe crop protection.

Conclusion

Fall armyworm as a most destructive invasive insect pest which causes huge damage to agricultural crops due to high dispersal capability leading to rapid global expansion including India. Its high fecundity, migratory potential and broad host ranges makes it very difficult to control. Physical, cultural, mechanical, biological and chemical pesticides are all available options for managing FAW. All these control strategies have some limitations or else cause adverse effects on non-target animals and also harm ecosystem. Management of FAW using bio-control agents and bio-pesticides would be a better option to reduce crops losses and helpful to maintain eco-friendly environment.

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