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Fall armyworm (*Spodoptera frugiperda*): A threat in crop production in Africa and Asia

El cogollero del maíz (*Spodoptera frugiperda*): Una amenaza en producción de cultivos en Africa y Asia

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Abstract

Spodoptera frugiperda (J.E. Smith) (Lepidoptera: Noctuidae), Fall Armyworm (FAW) is a crop pest with more than 80 host species causing severe damage to maize cereals. FAW, native to the tropical and subtropical region of America, 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. However, there are several control measures reported in various countries. Integrated pest management (cultural, chemical, and biological) is widely used to control this pest. Because the pest has become resistant to many insecticides, its use is not recommended at the initial stages of infestation. But, the last choice for this seriously infested pest management is the use of pesticides below the economic threshold level. This review focuses on insect distribution, biology, maize damage, and possible strategies for its management.

Keywords: *Fall armyworm, maize, Integrated Pest Management.*

Resumen

El cogollero del maíz (FAW, por sus siglas en inglés), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) es la plaga esporádica que tiene más de 80 especies huéspedes y que causa graves daños al cultivo de maíz. La FAW, originaria de la región tropical y subtropical de América, se está extendiendo rápidamente en todo el mundo. Las larvas y los adultos de FAW dañan las hojas jóvenes, los verticilos de las hojas, las borlas o las mazorcas del maíz. Bajo una fuerte infestación de FAW causan 50-80% de pérdida de rendimiento en los cultivos. Esta plaga tiene la capacidad de reproducirse rápidamente, migrar y alimentarse de una amplia gama de plantas hospederas, lo que la hace muy difícil de controlar. Sin embargo, se han notificado varias medidas de control en varios países. El manejo integrado de plagas (cultural, químico y biológico) se utiliza comúnmente para controlar esta plaga. Dado que la plaga se ha hecho resistente a muchos insecticidas, no se recomienda su uso en las etapas iniciales de la infestación. Sin embargo, la última opción para su manejo en caso de infestación grave es el uso de plaguicidas por debajo del nivel de umbral económico. Esta evaluación se centra en la distribución de los insectos, la biología, los daños al maíz y las posibles estrategias de gestión.

Palabras clave: *Gusano cogollero del maíz, maíz, Manejo Integrado de Plagas.*

Introduction

Maize (*Zea mays*) is one of the world's major cereal crops because of its high importance as a staple food and its stover need for animal feed and fuel (Abebe et al., 2017). Maize is also called as a queen of cereals and miracle crops because of its immense potential (Jeyaraman, 2017). The crop is rich in nutrients containing approximately 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g (Ranum et al., 2014). In recent years, the productivity of maize is getting lower than its potential due to many biotic and environmental constraints. Prominent among such constraints are pests and disease which reduces the production and yield of the crop. Many insects

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are directly responsible for the damage and reduction in yield of maize.

Fall armyworm (FAW) is considered as the most important and devastating insect pest causing severe damage to maize crops (Ayala et al., 2013). It is a noctuid moth pest native to America's tropical and subtropical areas (Luginbill, 1928; Pogue, 2002; Early et al., 2018). The spread of the pest then began rapidly and almost all Sub Saharan African countries were invaded by 2017 (Day et al., 2017). FAW moth performs migratory habit as well as localized dispersal habit. Until oviposition, the moth will migrate over 500 km (300 miles) (Prasanna et al., 2018). The strong-flying ability of adults (100 km per night) and high reproduction rate has spread its population rapidly, hence causes serious consequences (Food and Agriculture Organization [FAO], 2019). FAW is a polyphagous insect with several hosts species (Roger et al., 2017) and has the ability to cause severe famine since its hosts are the main staple food crops (Daily Nation, 2018). It results in loss of photosynthetic area, slower or impaired reproduction, grain damage, structural damages, and lodging of the maize plant (Chimweta et al., 2019). Two strains of FAW are mostly prevalent namely the rice and the maize strains (Adamczyk et al., 1997). Among these, the maize strain is most prevalent and causes serious damage to maize. Since maize is the staple food for many people across the world, proper control and management of FAW are required before it does great damage to the crop fields. Despite heavy concerns of scientists, fall armyworm is spreading rapidly in many countries all over the world for the last two years (FAO, 2018). Thus, proper knowledge of insect biology, host range and management practices are needed to control the insect (Rwomushana et al., 2018). Therefore, the main aim of this review is to highlight the status and control measures in maize field of this devastating and challenging pest.

Distribution of FAW

Fall Armyworm is a threatening pest and a major concern for the researchers worldwide. The global distribution of fall armyworm in different continents is given is Table 1. Being native to America, FAW was first recorded in early 2016 in Central and Western Africa (Goergen et al., 2016). In Asia, Indian state of Karnataka at College of Agriculture, recorded the new invasive pest FAW in May, 2018 (Kalleshwaraswamy et al., 2018). In July 2018, 70% of maize fields in Chikkabalpura district of Karnataka were affected with FAW as reported by the Indian Council of Agricultural Research (ICAR). The infestation was seen in maize and sugarcane in other five states namely: Tamil Nadu, Telangana, Andra Pradesh, Maharashtra and West Bengal within less than five months of infestation in Karnataka (Bhosale, 2018). In June, 2018 FAW larvae were first identified in Srilanka in Damana area of Ampara district of Eastern Province. In Bangladesh the FAW larvae were firstly recorded for in different districts in two different crops cabbage and maize by the Bangladesh Agriculture Research Institute. In Nepal, the first case of Fall Armyworm was documented from Nawalparasi district on 9 May, 2019 and then it was seen in the neighboring district Chitwan (Bajracharya & Bhat, 2019). After a few months the infestation was also seen in the districts like Kavre, Sarlahi, Sindupalchowk, and Bhojpur. By early 2019, it subsequently appeared in additional Asian countries: Myanmar, Thailand, China, Vietnam, Malaysia, Japan and Indonesia. Japan reported the presence of FAW in July 2019 (FAO, 2019).

Table 1. Global distribution of FAW.

Continent	Total Number of Countries per Continent	Nº of Countries (Incidence of FAW)
Africa	54	47
Asia	48	17
Europe	44	4
North America	23	23
Oceania	14	1
South America	13	13

Source: CABI, 2020

FAW Hosts

A huge number of cultivated plant species are threatened by *Spodoptera frugiperda* (Casmuz et al., 2010). Severe infestation is caused on its primary hosts, maize and sorghum and other monoculture crops like soybean and cotton (Pitre & Hogg, 1983; Bueno et al., 2011). Serious invasion is caused on the cereals and forages and FAW caterpillars feed on about 186 plant species from 42 diverse families (Casmuz et al., 2010). It causes severe damage to maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L., Moench), rice (*Oryza sativa*), cotton (*Gossypium hirsutum* L.), potato (*Solanum tuberosum* L.), vegetables, as well as other cultivated and wild plant species (Goergen et al., 2016). The favourite hosts of FAW are bermuda grass (*Cynodon dactylon* L., Pers.) and Peanut (*Arachis hypogea* L.) (Sparks, 1979) (Table 2).

Biology of FAW

Spodoptera frugiperda is a holometabolous insect with a high rate of reproduction. Warm, humid temperature with heavy rainfall is suitable for survival and multiplication as the insect cannot develop below 10°C. Its life-cycle composes four advancement stages viz. egg, six larval instars, pupae and adult, and is completed within about a month in summer, but 2 months in the spring and autumn, and about 3 months in the winter (Reinert & Engelke, 2010). FAW is reproductively active in tropical, where the insect can produce 10 generations per year than temperate where the generation per year is two or fewer (Chhetri & Acharya, 2019; Metcalf et al., 1965).

The life cycle of FAW begins when the adult female lays eggs on the upper or underside of leaves, more commonly

Table 2: Common feeding host of *Spodoptera frugiperda*.

Common name	Scientific name	Family	References
Peanut	*Arachis hypogea* L.	Fabaceae	Sparks (1979); Yu (1982)
Bermuda grass	*Cynodon dactylon* (L.) Pers.	Poaceae	Sparks (1979)
Maize	*Zea mays* L.	Poaceae	Paulillo et al. (2000); FAO (2018)
Sweet corn	*Zea mays saccharata* (L.) Sturt	Poaceae	Meagher et al. (2016); Seal (2018); Jeger et al. (2018); Chormule et al. (2019)
Sugarcane	*Saccharaum officinarum* L.	Poaceae	Chormule et al. (2019)
Sorghum	*Sorghum bicolor* (L.) Moench	Poaceae	Fuller et al. (1997); Chormule et al. (2019)
Rice	*Oryza sativa* L.	Poaceae	Stout et al. (2009); Whitford et al. (2015), FAO (2017)
Wheat	*Triticum aestivum* L.	Poaceae	Murúa et al. (2008); Pitre et al. (1983)
Millet	*Pennisatum americanum* L.	Poaceae	Ríos-Díez and Saldamando-Benjumea (2011), FAO (2017)
Oat	*Avena sativa* L.	Poaceae	Silva et al. (2017)
Barley	*Hordeum vulgare* L.	Poaceae	Alfonso et al. (1997)
Rye grass	*Lolium perenne* L.	Poaceae	Pitre and Hogg (1983)
Para grass	*Brachiaria mutica* L.	Poaceae	Ashley et al. (2006); de Sa et al. (2009)
Cotton	*Gossypium hirsutum* L.	Malvaceae	Hardke et al. (2015)
Cowpea	*Vigna unguiculata* (L.)Walp	Fabaceae	Yu (1982)
Soybean	*Glycine max* (L.) Merril	Fabaceae	Yu (1982)
Chickpea	*Cicer arietinum* L.	Fabaceae	Montezano et al. (2018)
Potato	*Solanum tuberosum* L.	Solanaceae	Yu (1982)
Cucumber	*Cucumis sativus* L.	Cucurbitaceae	Yu (1982); Montezano et al. (2018)
Cabbage	*Brassica oleracea var. capitata* L.	Brassicaceae	Montezano et al. (2018)
Mustard	*Brassica juncea* L.	Brassicaceae	Yu (1982)
Turnip	*Brassica rapa* L.	Brassicaceae	Yu (1982)
Onion	*Allium cepa* L.	Amaryllidaceae	Fernandes et al. (2012)
Beet	*Beta vulagris* var. *vulagaris* L.	Amaranthaceae	Montezano et al. (2018)
Sweet Potato	*Ipomoea batatas* (L.) Lam.	Convolvulaceae	Montezano et al. (2018)
Alfalfa	*Medicago sativa* L.	Fabaceae	Murúa et al. (2008)
Tobacco	*Nicotiana tabacum*	Solanaceae	Leal-Bertioli et al. (2003); Martinelli et al. (2007)
Tomato	*Solanum lycopersicum* (L.) Mill.	Solanaceae	Rojas et al. (2003)

near the base junction of leaf and stem on the underside of leaves (Jarrod et al., 2015). The number of laid eggs per mass can vary between 150 to 200 (Prasanna et al., 2018). A single female can lay from 1500 to over 2000 (maximum) eggs (Igyuve et al., 2018). The newly deposited eggs are dome shaped with flattened base measuring 0.4mm in diameter and 0.3 mm in height (Jarrod et al., 2015). Eggs are pale yellow or creamy white in color then turn to light brown before hatching where female covers the egg mass with downy materials (a layer of scales) that gives moldy appearance (Kalleshwaraswamy et al., 2018) The pre-oviposition period of this insect ranges from 3-4 days depending on temperature. The incubation period of the egg was found to be only 2 days at 30°C (Garcia et al., 2017).

Depending upon temperature and climatic conditions, during the summer, larva completes its stage in about 14 days and 30 days during winter (Capinera, 2002). Young larvae are generally greenish with black head turning to brownish body with reddish brown head of the sixth instars. The mature larvae also contain a white inverted 'Y'shaped mark in the face (Oliver & Chapin,1981). Rearing the larvae at 25°C, mean development of instar from first to sixth stage takes 3.3, 1.7, 1.5, 2.0 and 3.7 days respectively (Pitre & Hogg, 1983). Pupation typically occurs at a depth 2 to 8 cm below the soil (Capinera, 2002) but also can take place in the reproductive part of maize such as mature maize ears. The larvae create a cocoon, oval in form and length of 20-30mm, by adding silk to soil particles after eating voraciously for 2-3 weeks. A reddish brown pupae of 14 to 18 mm length and 4.5 mm width dwells inside the cocoon (Igyuve et al., 2018). The pupal stage is completed in 9-12 days (Rwomushana et al., 2018). Debora et al. (2017) reported the pupal period of *S. frugiperda* on maize was found to be 8.54 days.

Adult female is larger than male with a body length of 1.7 cm a wingspan of 3.8 cm. The males have the body length of 1.6 cm and 3.7 cm wingspan. The male forewing is mottled with a discal cell having straw color on three quarters and dark brown on one quarter of the area having triangular white spots at the tip and near the middle of the wing (Bhushal & Chapagain, 2020). The females forewing are less distinctly marked, ranging from a uniform greyish brown to a little grey brown mottling. Both male and female contain hindwing with straw colour having dark brown margin (Igyuve et al., 2018).

Economic importance and damage of FAW

Spodoptera frugiperda, being a major pest of the maize field, have been responsible for 40-70% of overall maize yield loss in Africa (Day et al., 2017). Late planted fields and later maturing hybrids are more likely to become infested. The favorable environment condition with the constant fecundity of the pest leads to the severe damage of the crop (Goergen et al., 2016). Larvae are voracious feeders and feed whorls of young leaves, ears and tassels, depending on the growth stages, causing a huge damage to the host (Sarmento et al., 2002). When the larval population rises; they defoliate every plant that comes on their way (Bhushal & Chapagain, 2020). Typical damage signs of FAW larvae are the presence of holes in the maize leaves due to the feeding of epidermal tissues (Sisay et al., 2019). Larger larvae entirely section the stem seedlings (Goergen et al., 2016) and feed on the kernels and cob decreasing the yield and quality of the maize grains (Capinera, 2017).

The outcome recorded by Hruska and Gould (1997) revealed that 55-100% *S. frugiperda* infestation during the mid-to-late corn stage resulted in 15-73 percent yield losses Nicaragua. Over 12 African countries reported the loss of 8.3-20.6 million tons of maize annually due to FAW infestation (Day et al., 2017). Similarly, America revealed about 39% yield loss in maize due to FAW damage (Cruz et al., 2012**)**. Studies have shown that less than 1% of the total area planted with maize had been affected in China but there is an increasing risk that FAW could spread to various parts of China (FAO, 2019). In India, infestation level has been documented upto 49.2% on maize (Chormule et al., 2019; Deole & Paul, 2018; Dhar et al., 2019) except 100% infestation has been reported from Karnataka (Mallapur et al., 2018). In Srilanka, 50% of the maize-grown area was affected and 10% of originally anticipated production was lost due to FAW infestation (FAO, 2019). In Nepal, loss by fall armyworm had reached up to 70% without control measures and 20-30% with control measures (National Plant Protection Organization [NPPO], 2019). Any official estimation of losses due to FAW in many South Asian countries are not currently available.

Integrated pest management of FAW

IPM (Integrated Pest Management) is an integrated pest control strategy for preventing insect pests and their damage. Practice of IPM mainly incorporate the use of biological, cultural physical methods of pest control (Prasanna et al., 2018). IPM highlights the growth of healthy crop with the minimum damage to agro-ecosystems and encourages various mechanisms for natural pest control. IPM is the best option for FAW management (Day et al., 2017). The devastating loss caused by FAW forced farmers to use chemicals directly rather than the IPM methods in Nepal (Bhushal & Chapagain, 2020). However, this pest can be managed in the incidence phase by the use of IPM practices. A technical guide for IPM was published in Africa by International Maize and Wheat Improvement Center (CIMMYT, 2018).

Cultural practices for managing FAW

Cultural practices are most efficient for controlling FAW infestation. Avoiding late season planting, avoiding staggered planting, planting early maturing variety reduces the infestation as the maize are severely affected by FAW during late season. FFS (Farmer Field Study) in Kenya revealed high infestation of FAW during late planting maize compared to earlier planted crops, in January 2018 (Pechan et al., 2000). Invasion of FAW can also be minimized by maize intercropping and crop rotation with non-host crops like bean and sunflower (FAO, 2018). 10 days ahead of the maize plantation, the planting of the trap crops such as beans at the boundary of maize can attract FAW towards the bean and thus the main crop will be protected. The main cultural practices include: ploughing properly, maintenance of good soil health and adequate moisture, clean cultivation, proper weeding. Use of Push-pull strategy has been proven best that controls the pest population. Intercropping of maize with pest-repellent "Push crop *(Desmodium uncinatum* and *Desmodium intortum)* and planting pest-attractive "pull crop" (*Pennisetum purpureum* or *Brachiaria spp*) around it comes under this strategy (Dively, 2018). Some of the farmers in Kenya, Tanzania, Uganda, adopted climate-smart-push-pull technique which showed the depletion of FAW larvae by 82.7% per plant and subsequently plant damage reduced by 86.7% per plot (Khan et al., 2018).

Pest monitoring for managing FAW

The effective implementation of IPM also depends upon the pest monitoring. Most effective monitoring tools of FAW management are Pheromones and Light traps. Mating disruption is possible (Shorey et al., 1994) by using sex pheromone for *S. frugiperda* which includes (Z)-9-Tetradecenyl acetate (Z-9-14: OAca) that is similar to *Trichoplusia ni, S. exigua* and *Agrotis ipsilon exigua* (Klun et al., 1996). Sex pheromones attract the males as the pheromones are similar to the chemicals produced by females and aggregation pheromones are also used in monitoring of *S. frugiperda* (Prasanna et al., 2018). Since adult FAW show nocturnal behaviour, it is easier to control them through black light traps (Hunt et al., 2001; Qureshi et al., 2006). However, for detecting and monitoring adult FAW, pheromone traps were found more effective than black light traps (Starratt & McLeod, 1982). During regular monitoring, hand collection of the egg masses and destroying under small scale can be effective. This method was found to be 'somewhat successful' by the majority of farmers (Rwomushana et al., 2018). For the management of *S. frugiperda* in Ethiopia, 15 percent farmers practice handpicking (Kumela et al., 2019). In addition to handpicking, destruction of eggs and larvae, and keeping the mixture of sand with lime or ash in the whorl of the attacked maize can kill the larvae in Ethiopia (Gebreziher, 2020).

Biological measures for managing FAW

Biological control method is the alternative pest control measures providing environmentally safe and sustainable plant protection by the use of natural enemies of the pest (Bhushal & Chapagain, 2020) . In this method of pest management, the population of FAW is decreased by the use of antagonist natural enemies [parasitoids (Table 3), predators (Table 4) and pathogens (Table 5)]. The most important biological control agent for to control FAW in maize and vegetables is *Telenomus remus* (Pomari et al., 2012). As a part of IPM programme, *T. remus* had been released to the maize field in Venezuela that has caused the FAW parasitism up to 90% showing the high biocontrol capability for *S. frudiperda* (Ferrer, 2001).

Various predators like *Calosoma granalatum* (Prasanna et al., 2018), assasin and flower bug (Van Waddill & Whitcomb, 1982), earwigs (Romero-Sueldo et al., 2014; Silva et al., 2018), ladybird beetle, ant etc. attack the FAW at various stages. The enthomopathogen like *Spodoptera frugiperda, Nucleo polyhidroxy virus*

Table 4: Predators of FAW larva and pupa in maize

Natural Enemy	Life Stage
Calleida decora	Larva
Calosoma alternans	Larva
Calosoma sayi	Larva
Carabidae	Larva/pupa

Source: CABI, 2020

Table 3: Parasitoid Natural Enemies of Fall Armyworm

Parasitic Natural Enemy	Host Stage Attacked	Crop	References
Archytas incertus	Larva	Maize	Virla et al. (1999)
Archytas marmoratus	Larva/Pupae	Maize/Sorghum	Van Waddill and Whitcomb (1982)
Charops ater	Larvae	Maize	Sisay et al. (2018)
Chelonus curvimaculatus	Eggs/Larva	Maize	Valicente and Barreto (1999)
Chelonus insularis	Eggs/Larva	Maize/Sorghum	Virla et al. (1999); Bahena and García (1991)
Coccygidium luteum	Larvae	Maize	Sisay et al. (2018)
Cotesia icipe	Larva	Maize	Sisay et al. (2018)
Cotesia marginiventris	Larva	Maize	Alam (1978)
Cotesia ruficrus	Larva	Maize	Yaseen (1979)
Euplectrus platyhypenae	Larva	Maize	Alam (1978)
Palexorista zonata	Larvae	Maize	Sisay et al. (2018)
Telenomus remus Nixon	Egg	Maize/Vegetables	Kenis et al. (2019)
Trichogramma rojasi	Egg	Maize	Behle & Popham (2012)
Trichogramma spp	Egg	Maize	Luginbill (1928)

Table 5: Pathogenic Natural Enemy of Fall Armyworm

Natural Enemy	Host Stage Attacked
Bacillus cereus	Larvae
Bacillus thuringiensis	Larvae
Bacillus thuringiensis alesti	Larvae
Bacillus thuringiensis darmstadiensis	Larvae
Bacillus thuringiensis thuringiensis	Larvae
Bacillus thuringiensis kurstaki	Larvae
Beauveria bassiana	Eggs/Larvae
Granulosis virus	Larvae
Metarhizium anisopliae	Eggs/Larvae
Nucleopolyhedrosis virus	Larvae
Spodoptera frugiperda multiple nucleopolyhedrovirus	Larvae

Source: CABI, 2020

Table 6. Biopesticides registered to control *Spodoptera frugiperda.*

Active substance	Target	Crops	Countries registered
Beauveria bassiana strain R444	Lepidoptera, including *Spodoptera frugiperda*	Barley, brassica, maize, sweetcorn, sorghum, tomato, wheat	South Africa (emergency approval in 2017).
Bacillus thuringiensis subspecies kurstaki strain SA-11	Lepidoptera, including *Spodoptera frugiperda*	Maize, sweetcorn, sorghum, wheat	South Africa (emergency approval in 2017)
Baculovirus	*Spodoptera frugiperda*	Unspecified	Pending, Brazil
SFMNPV-*Baculovírus Spodoptera frugiperda*	*Spodoptera frugiperda*	Cereals, Cotton, Sweetcorn, sorghum, Turf Brazil (monograph B51),	USA

Source: FAO, 2018

(Sf NPV), *Metarhizium anisopilae*, *Beauveria bassiana*, and *Bacillus thuringiensis* are useful to decrease FAW population (Molina-Ochoa et al., 2003). FAO (2018) suggests options such as spraying sugar water to attract and maintain populations of ants and other natural enemies. It also recommends "recycling pathogens" by collecting caterpillars killed by disease, and using them to prepare a solution for spraying on plants. Technique of biological control not only controls the pest population but also benefits the environment and human health (Parra, 2010).

Botanicals for managing FAW

The plant extracts of *Azadirachta indica*, *Nicotina tabacum*, *Chrysanthemum cinerariifollium*, *Tephrosia vogeli are* used for controlling FAW population. Botanicals like *Azadirachta indica*, *Phytolacca dodecandra*, and *Schinnus molle* were found most effective against FAW larvae causing the highest mortality (96%) (Sisay et al., 2019). 5% Neem Seed Kernel emulsion was found to have repelling property against FAW (Lamsal et al., 2020). Research in feeding bioassay revealed the highest FAW larval mortality by the use of *L. javanica* (62%) and *N. tabacum* (60%) with highest concentration evaluated at 10% *w*/v (Phambala et al., 2020). Similarly, tobacco leaf extracts at 50% concentration are found effective against FAW (Sakadzo et al., 2020). Methanolic extracts of *Melia azedarach* seed (1% and 10%) caused FAW larval mortality because of decline in feeding (Bullangpoti et al., 2012). The use of ethanolic extracts of *Argemone ochroleuca* also reduced larval feeding activity (Martínez et al., 2017). Also, biopesticides from the extracts of weed like Water lettuce reduced the survival rate of FAW by 14% while hydrilla and duckweed caused 11% and 9% reduction of FAW growth, respectively (Fu et al., 2020). *Zingiber officinale* and *Malva sylvestris* were effective causing mortality for caterpillars of FAW (Rioba & Stevenson, 2020).

Biopesticides for managing FAW

Biopesticides are based on naturally occurring substances or organisms that kill pests. They are the formulations obtained from particular bacteria, fungal or viral strains (Prasanna et al., 2018) Various biopesticides like *Beauveria bassiana* strain R444, Baculo virus, *Bacillus thuringiensis* sub-species *kurstaki* strain SA-11 (Table 6), Cowurine, bacterial fermentation products like Spinetoram and Spinosad are helpful to control FAW (Prasanna et al., 2018). Baculovirus is extremely host-specific, non-pathogenic for beneficial insects and other non-target organisms, and best suited for integrated pest management. Neem-based biopesticides are similarly effective as insecticides to fight against fall armyworm (CABI, 2020).

Chemical control for managing FAW

Synthetic pesticides are hazardous in sustainable agriculture and use of the pesticides are not considered good in IPM technology. However, chemicals are used under the economic threshold level in severe condition (Khan et al., 2018). Chemicals like cypermethrin, Lamda, Cyhalothrin, Bifenthrin, Beta Cyfluthrin, Deltamethrin were effective in reducing the populations of FAW worldwide (FAO, 2018). ICAR-Indian Institute of Maize Research has recommended some pesticides like emamectin benzoate, spinosad and chlorantraniliprole having reducing property against FAW (Lamsal et al., 2020). Furthermore,chemicals like Radient, Tracer, Karate, Ampligoposses were found to have efficacy causing 90% mortality of FAW larvae at 72 h of application (Sisay et al., 2019).

The different insecticides used for control of fall armyworm is given in Table 7.

Conclusion

FAW (*Spodoptera frugiperda)* infestation causes the greatest economic loss to a top rank cereal, maize and affects millions of people worldwide. It has the ability to breed rapidly and migrate to new territory due to its strong-flying nature. It possesses the potential of causing approximately 100% crop loss in maize if not managed in time. FAW was reported firstly in central and western Africa in 2016 followed by five Asian countries possessing threat to south America in the last 3-4 years. If the necessary precautions are not taken with the ongoing pest distribution, it can

Table. 7. Different modes of action on the insecticides registered for the control of Fall armyworm on maize.

Active ingredient	Chemical class	IRAC classification (Mode of Action)
Benfuracarb/Fenvalerate	Carbamate/Pyrethroid	1A/3A Acetylcholinesterase (AChE) inhibitors/ Sodium channel modulators
Carbosulfan	Carbamate	1A Acetylcholinesterase (AChE) inhibitors
Chlorantraniliprole	Diamides	28 Ryanodine receptor modulators
Chlorpyrifos	Organophosphate	1B Acetylcholinesterase (AChE) inhibitors
Chloropyrifos/ Cypermethrin	Organophosphate/ Pyrethroid	1B/3A Acetylcholinesterase (AChE) inhibitors/Sodium channel modulators
Chlorantraniliprole/ Lamda-cyhalothrin	Diamides/Pyrethroid	28/3A Ryanodine receptor modulators/Sodium channel modulators
Emamectin benzoate	Avermectin	6 Glutamate-gated chloride channel (GluCl) allosteric modulators
Flubendiamide	Diamides	28 Ryanodine receptor modulators
Indoxacarb	Oxadiazine	22A Voltage-dependent sodium channel blockers
Lufenuron	Benzoylureas	15 Inhibitors of chitin biosynthesis, type 0
Mercaptothion	Organophosphates	1B Acetylcholinesterase (AChE) inhibitors
Methomy	Carbamate	1A Acetylcholinesterase (AChE) inhibitors
Novaluron/Indoxacarb	Benzoylureas/ Oxadiazine	15/22A Inhibitors of chitin biosynthesis, type 0/ Voltagedependent sodium channel blockers
Profenofos	Organophosphates	1B Acetylcholinesterase (AChE) inhibitors
Pyridalyl dichloropropene derivative	Pyridalyl	UN Compounds of unknown or uncertain MoA
Spinetoram/ Methoxyfenozide	Spinosyns / Diacylhydrazines	5/18 Nicotinic acetylcholine receptor (nAChR) allosteric modulators/ Ecdysone receptor agonists
Spinetoram	Spinosyns	5 Nicotinic acetylcholine receptor (nAChR) allosteric modulators

Source: Bezuidenhout and Nunkumar, 2017

cause major threats to agricultural crops worldwide challenging food security. Starting from the larval stage it voraciously feeds on maize cob and whorls, continuing towards stem destruction on its adult stage causing tons of damage to the crop. So necessary control strategies should be implemented to avoid the huge amount of loss. The use of pheromone traps, light traps as mechanical control, biological control and botanical control reduces the outbreak of FAW populations. Being eco friendly, these measures preserve the soil as well as environmental health protecting the crop. Chemical measures should be avoided as much as possible until and unless the infestation exceeds 50%. With the best possible strategies and measures, FAW infestation can be reduced to an extreme limit encouraging the better production of crops.

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