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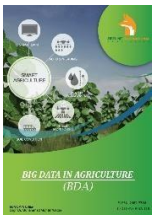

RESEARCH ARTICLE

EMERGING IMPACT OF *Spodoptera frugiperda* (FALL ARMYWORM) ON MAIZE IN NEPAL AND ITS CONTROL MEASURES

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ABSTRACT

Spodoptera frugiperda is a migratory pest that infects maize and is noted for its high likelihood of dispersing quickly. It was originally discovered in central and western Africa in 2016, and Nepal's first incidence of FAW was discovered in a maize crop on May 9th, 2019. S. frugiperda severely harmed maize harvests across the country in 2020, at a greater rate than the previous year. The cause and impact of FAW in Nepal have been identified as Nepal's open border and a lack of seed quarantine control for late-maturing hybrids and late planting maize types. By heavily feeding on leaves, younger larvae inflict significant crop damage. Integrated pest management (IPM) techniques, which combine physical and mechanical, cultural, botanical, biological, and chemical methods, have been found to be effective in controlling and monitoring FAW in Nepal. As a result, the focus of this research is on the developing implications of FAW in Nepal, as well as control and prevention approaches to reduce the loss caused by FAW through appropriate management alternatives.

KEYWORDS

Control, Damage, IPM, Maize, Spodoptera frugiperda

1. INTRODUCTION

The Fall Armyworm (FAW) is a significant polyphagous insect that wreaks havoc on maize harvests. It targets 42 plant families, totaling 186 species (Early et al., 2018). FAW is a member of the Insecta class, Lepidoptera order, and Noctuidae family, and it is native to the tropical and subtropical regions of the United States (CABI, 2017; FAO, 2017). S. frugiperda behaves like an army, marching across crops and causing devastation and crop loss (FAO, 2018; Hruska, 2019). The larval stage of the fall armyworm causes severe damage to maize, rice, and sorghum (GC et al., 2019). It was first discovered in central and western Africa in 2016, but Nepal documented its first instance of FAW on May 9th, 2019 in the Nawalparasi district of the Maize crop, and it is now found in hundreds of nations around the world (Du Plessis et al., 2018; Goergen et al., 2016; Kandel and Poudel, 2020).

The cause and impact of FAW in Nepal have been identified as Nepal's open border and a lack of quarantine seed management of delay maturing hybrids and late planting maize kinds (Kandel and Poudel, 2020). The earliest signs of this FAW include different widths of papery windows, appearance in leaf by larva with significant defoliation, presence of fecal matter, and poor growth and development in later growth stages (Reddy, 2019). Maize is known as the "Queen of Cereals" and "oldest & powerful crop" because of its high yield and nutritional composition. It is also known as the "Queen of Cereals" and "oldest & powerful crop" because of its wide range of uses from animal feed in seed or fodder forms to industrial raw materials. Even a minor impact of FAW on maize would result in a significant economic loss (Bariw et al., 2020; Rouf Shah et al., 2016).

Due to a lack of market access and chemical availability, producers are able to adopt a push-pull strategy, which can be used to effectively control FAW. Small growers can reduce insect losses by picking by hand and using mechanical traps such as light and pheromones. In terms of the last option, chemicals such as spinosad, chlorantraniliprole, and others can be used in the crop field to suppress FAW (Sagar et al., 2020). Prevention programs focusing on the signs and symptoms of economic losses, early inspection, FAW mitigation measures, and the proper application of biopesticides and insecticides could all help to reduce losses. Planting FAW-tolerant crop varieties, national policies, and actions promoting lowest risk mitigation choices by giving terminal subsidies, and rapid evaluation and deployment of biopesticides and biocontrol techniques should all be implemented (Day et al., 2017). This study was conducted to better understand the developing effects of FAW in Nepal. It emphasizes the introduction method, present status, biology, lifetime, threat and harm of FAW, control and prevention ways to limit FAW loss, as well as appropriate management alternatives.

1.1 Classification

Domain: Eukaryota

Kingdom: Metazoa

Phylum: Arthropoda

Subphylum: Uniramia

Class: Insecta

Order: Lepidoptera

Family: Noctuidae

Genus: *Spodoptera*

Species: *Spodoptera frugiperda*

Source: (CABI 2017)

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1.2 Biology of FAW

FAW is a noctuid family pest, hence called moth native to the western Hemisphere mostly in South and North America (Nagoshi et al., 2012). FAW goes through many transformations (metamorphosis) in a year with the life process including eggs, 6 caterpillar growth stages (Instars), Pupa and adult (moth) which is generally completed in a month during summer and 60 days during winter and it might also take about 28 days in the southern part and up to 12 weeks during the low temperature of spring and autumn (Hardke et al., 2015; Hruska, 2019). The lifecycle starts with an adult female moth laying eggs under the lower surface of leaves, generally at the bottom of the crop, near the joint of stem and leaves, however during high oviposition, the female moth oviposits the eggs all over the plant structures (Hardke et al., 2015). The mother protects egg masses by covering them with protective scales that are rubbed off from the moth's abdomen after laying.

After 3-6 days, eggs start to hatch out and young caterpillars start feeding on the surface, beginning on the undersides of leaves (De Groote et al., 2020). The surface feeding makes semi-transparent patches on the leaves which is also called "papery Window". In between 6-14 days, the larva reaches leaf whorl, causing major havoc, making ragged holes in the leaves, which might lead to the killing of the growing point of young plants, as a result, no new leaves or cob development occurs. The larvae favor leaf whorls in young maize plants and leaves around cob silks and young kernels in older plants. If the maize plant has already begun producing cobs, the FAW will voraciously eat the side of the cob from the protective leaf bracts and starts feeding on young seeds (maize kernels). Most of the time there are only about 1 or 2 armyworm larvae in each whorl as they develop cannibalism nature where larger larva will eat another to decrease the competition for food. The feeding of caterpillars is more prominent during the night.

The premature instars prefer vegetative tissue while the mature ones prefer reproductive structures like silk and cob of maize (Hardke et al., 2015). There might be 6-7 instars relying on food availability and the environment. Later instars increase feeding rate and the mature instars consume food in huge quantity than all other pre-instars combined. The larval development duration also varies accordingly, at 25 C larval development takes about 22 days.

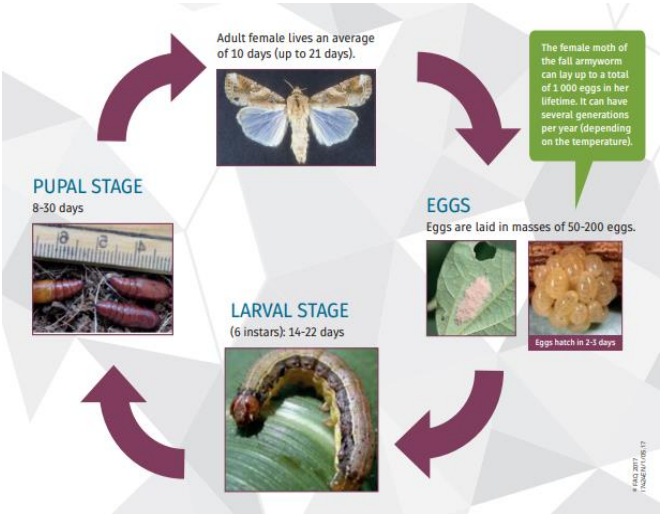

Figure 1: Life Cycle of Fall Armyworm, *Spodoptera frugiperda (FAO* (Food and Agriculture Organization of the United Nations, 2018)

After approximately feeding for 2 weeks the mature caterpillars will fall on the ground. The caterpillar then bore 2-8 cm deep into the soil for pupation, if the soil is too dry & hard for the caterpillar to bore then, the caterpillar will wrap itself with leaf debris before pupation (Prasanna et al., 2018). The depth of pupation of larva depends upon several edaphic factors like soil texture, soil moisture & soil temperature (Baudron et al., 2019). The pupa is a loose, silk, oval-shaped cocoon of 20-30mm in length inside which an adult moth develops within 8-9 days, emerges from the soil. The adult moth then again re-initiate the lifecycle by mating which might take place nearby or may migrate up to 300 miles before mating and, then lays eggs (Overton et al., 2021).

1.3 Identification of FAW

FAW is a very destructive pest so, we have to identify its every life stage to effectively scout & prevent yield loss.

1.3.1 Eggs

The freshly laid eggs are greenish gray in color at first. They have an "Oblate-Spheroidal" shape with a length of 0.39mm and a diameter of 0.47 mm. 12 hours later the eggs turn brown & become black at the time just before larval enclosing (Harrison et al., 2019).

Figure 2: Egg of the FAW, *S. frugiperda*

1.3.2 Larva

Figure 3: Hatching of eggs of the FAW, *S. frugiperda.*

Figure 4: Newly hatched larva of the FAW, *S. frugiperda*

Figure 5: Mature larva of the FAW, *S. frugiperda*

Figure 6: Head capsule of the FAW, *S. frugiperda* showing light-colored inverted "Y" in front of the head.

Figure 7: Mature instar showing four black dots in a squared pattern on an eighth abdominal segment of the FAW, *S. frugiperda*

The early larval instars especially the first(L1) have greenish color which then changes to orange in color. Caterpillars are of 1mm in 1st larval (instar) period and the length increases up to 4.5cm in 6 instars whereas, head capsule width ranges from 0.314mm to 2.78mm from first to sixth instars respectively (Luginbill et al., 2018). The 4th and the 6th instar larva have a reddish-brown mottled head and white lateral lines (Bhandari, 2021). The last three stages (L3-L6) of larval instars have a characteristic inverted "Y" shape on the capsule of the head. Overall, the capsule of the head is dark in color, fourth & fifth instars are generally smooth in texture and lack primary setae (Hardke et al., 2015). Larvae also possess distinct 4 "dots" on the 8th stomach region. The FAW larva possesses a sharp tooth-like projection on their mouth.

1.3.3 Pupa

Orange-Brown pupa covering is typical to Noctuids and it is the same for FAW pupa which turns darker with age (Hardke et al., 2015). Loose oval silky cocoon of 2-3 cm length is secreted during the pupa formation inside which a reddish-brown colored pupa of about 4.5 mm width and 14-18 mm length differentiates to adult (Kandel and Poudel, 2020).

Figure 8: The pupa of FAW, *S. frugiperda*

1.3.4 Adult

The wingspan of adult FAW (Moth) is about 1.5 inches (3.81cm) with the upper part of forewing with dark grey mottled in color and a distinguishing triangular whitish spot close to the hind tip or wingtips, but the lower part of the forewing has a light greyish to brownish color whereas, the hind wing appears white to light grey (Bhandari, 2021). The adult phase of Fall Armyworm lasts for about 1-3 weeks.

Figure 8: Typical adult male FAW, *S. frugiperda*

Figure 9: Typical adult female FAW, *S. frugiperda* (University of Florida, 2018)

2. METHODOLOGY

Various secondary sources of data were accessed for this research. Journals from Elsevier and springers were also reviewed. Different

articles, books and review papers were accessed, and secondary source of information were taken and their proper referencing was done in this study.

3. Results and Discussions

The results are described here under different sub-headings:

3.1 Impacts

In 2018, the Democratic Republic of Congo reported that FAW attacks resulted in the loss of around 45 percent of maize crop, with 0.89 million tons of corn lost during the maize harvesting season (FAO, 2018). Similarly, Nicaragua reported a yield loss of more than 70%, America reported a yield loss of 39%, and Argentina reported a yield loss of 72 percent (Chamberlain et al. 2006; Hruska and Gould 1997; Cruz et al., 2012). In compared to the year 2019, S. frugiperda has had a significant impact on maize production across the country in 2020, affecting farmers who were already dealing with the Covid-19 pandemic (Sen, 2020). The pest's devastating spread has concerned many small to large maize growers across the country. Thousands of hectares of maize crop farms have been damaged across Nepal, in different districts.

The fall armyworm (S. frugiperda) was originally discovered in Nepal's Nawalpur area, where it is thought to have arrived via India's open border (Bajracharya et al., 2019). The chaos of harmful insects, fall armyworms, has intensified difficulties in crop development and production as nations face the perils of global warming and climate change in agricultural output. FAW is a migratory pest that has a higher chance of dispersing quickly due to its natural distribution range. It poses a threat to food and nutrition security, as well as the lives of millions of small-scale farmers in rural areas (Bista et al., 2020). Various studies on the harmful degree of FAW on various crops have been conducted in Nepal, Kenya and several other nations (Bhusal and Bhattarai, 2019; De Groote et al., 2020). The pest's high fertility under ideal climatic circumstances is expected to result in severe crop damage (Goergen et al., 2016).

Both the vegetative and reproductive structures of the crops are devoured by the larvae. Young larvae devour a lot of leaf epidermal tissue and puncture the leaves; FAW damage signs are specific (Bhusal and Bhattarai, 2019). Different investigations by different researchers have indicated loss of photosynthetic areas, limited reproduction, crop damage, lodging, and structural damage in the whorl (Chimweta et al., 2019). FAW devastates maize crops by consuming the tassels, ears, and leaf whorls, resulting in complete crop collapse. Many farmers are threatened by FAW attacks and direct foliar damage; nevertheless, in many situations, the injury does not result in significant output loss (Hruska, 2019). Late-sown and late-maturing hybrid maize cultivars are particularly vulnerable to the insect.

The FAW produces severe leaf foliar damage as well as direct ear irritation younger larvae feed heavily on foliage and leaves, causing significant crop damage (Bessin and Entomologist, 2004). Early instars feed on the leaf tissue, which causes holes in the tissue, which is a common indication of the pest (Sisay et al., 2019). FAW feeding on the young plant through the whorl usually results in a dead heart. Mature instars can defoliate entire plants, leaving just the ribs and stalks, resulting in a ragged or shredded appearance that can cause significant harm (Midega et al., 2018). In comparison to the early whorl leaf stage, the late whorl stage was the most vulnerable to harm, Caterpillars crawl into the growing parts of the plant, such as the whorl, buds, and so on, obstructing maize growth and development (Wan et al., 2021). FAW frequently infects ears that are not eaten by humans. As a result, the FAW has no direct impact on maize food safety; instead, maize may become more susceptible to aflatoxin contamination (FAO, 2018).

FAW has an influence on natural capital due to economic breakdown and the capacity of farmlands to respond slowly to shocks, raising the cost of production and potentially affecting the household's physical and social assets (the capitals for households). The FAW has an influence on maize imports and exports both within and outside the country since it poses a risk of introducing pests to new locations. Maize crop farmers are particularly vulnerable due to these many factors. FAW is a dangerous insect that has a ravenous appetite for maize and other cereal crops, therefore its impact on Nepalese pheasants and the country's economy would be significant (Singhadurbar, 2018). Pests eat maize, paddy, potato, millet, sorghum, sugarcane, vegetables, and cotton, which are all important food crops in Nepal.

Figure 10: Maize leaf damage caused by the FAW, *S. frugiperda*

3.2 Mitigations

3.2.1 Integrated mitigating measures of FAW

The most important thing to do for fall armyworm control and management is to inspect them before they infest and cause severe damage. Its control should be done with caution because it is one of the most dangerous pests known. Though total eradication of FAW is challenging, many control strategies should be combined for effective control and management to maintain them below the threshold level. The following headings describe some of the management practices.

3.2.2 Physical and Mechanical Method

Hand-picking egg masses during routine field monitoring aids in local pest control. The majority of farmers who employed these tactics described them as "fairly successful" In Ethiopia, 15% of locals utilized exclusively handpicking to control fall armyworms (Kumela et al., 2018; Day et al., 2017). Using pheromone traps at a rate of 5 per acre at the likely location of pest dispersion during the crop season and off-season helps to lower the prevalence of FAW (Huma et al., 2019). Light traps can be used to catch and control adult male and female FAWs because they are nocturnal. Adult FAW moths were caught using Blacklight (BLB Sylvania®) traps (Herlinda et al., 2021; Tambo et al., 2020).

3.2.3 Cultural method

Deep plowing before planting crops is a common cultural technique that aids in the eradication of larvae and pupae (Kandel and Poudel, 2020). Fall armyworm treatment has been observed to be successful when corns are intercropped with pest-repellent push-plants (desmodium spp.) surrounded by pest-attractive pull-plants like Napier (Pennisetum purpureum) (Midega et al., 2018; Pradhan et al., 2019). Napier attracts FAW and stem borers to lay eggs on it, but the larvae cannot grow properly due to a lack of nutrition, and only a few larvae survive. Desmodium releases a volatile chemical compound that repels the stem borer or fall armyworm.

When maize is grown alongside edible leguminous crops, the number of fall armyworms is reduced. Intercropped leguminous crops such as groundnut, French bean, and soybean, in contrast to mono-cropped corn fields, provide significant protection to the maize crop (Hailu et al., 2018). FAW eggs, larvae, pupa, and adults can all be killed by good soil tilth, crop rotation and varietal selection, regular field inspections, and burning of crop stubble and residues (Assefa, 2018). Planting should not be postponed: take advantage of the first good rains to sow the crop, since the number of fall armyworms grows as the crop season progresses (Day et al., 2017).

3.2.4 Biological method

Several entomo-pathogenic pathogens, such as Beauveria bassiana, Metarhizium anisopliae, and Bacillus thuringiensis (B.t), have been discovered to be particularly effective against fall armyworms Bacillus thuringiensis var kurstaki formulations at 2g/liter can effectively control S. frugiperda (Clark et al., 2007). After 15-25 days of sowing, apply Metarhizium anisopliae powder formulation at 5g/liter whorl application. Similarly, depending on the severity of the FAW infestation, 1-2 sprays every 10 days have been found to be effective in preventing the pest injury from spreading. Because it parasitizes the eggs of fall armyworms, the braconid wasp Chelonus insularis Cresson is an essential natural biological control agent (Meagher et al. 2019). The Spodoptera frugiperda Multiple Nucleo Polyhedron Virus (SfMNPV), predatory insects and

parasitic wasps (parasitoids), genetically modified crops containing Bt genes that produce proteins that are toxic to FAW larvae, and mass trapping of male moths using pheromones to prevent them from mating are all important biological controls (Day et al., 2017). Among the most important predatory insects are earwigs, ladybird beetles, flower bugs, and ants (FAO, 2018).

3.2.5 Botanical Control

Because they have a lesser effect on non-target creatures and the ability to provide growth stimulation to some pesticide's plants, botanical pesticides are claimed to be effective at decreasing the use of synthetic insecticides (Mkindi et al., 2020; Rioba and Stevenson, 2020). *Milletia ferruginea, Azadirachta indica, Jatropha curcas, Nicotiana tabacum, Chrysanthemum cinerariifollium,* and *Croton macrostachyus*, among others, have been demonstrated to be beneficial in reducing insect pests (Addisu et al., 2014). Fall armyworms are controlled utilizing a range of locally available materials and botanical treatments around the world, including local plant extracts, soil, sand, wood ash, lime, oils, and soaps, among others (Hruska, 2019). Neem seed powder was proven to be effective in killing more than 70% of FAW larvae in the lab (Maredia et al., 2008). Turmeric, clove, palmarosa, and neem plant oils are effective in reducing FAW larvae in the first and second instars (Barbosa et al., 2018).

3.2.6 Chemical control

In the fight against the autumn armyworm, the timing of pesticide applications is crucial. Farmers should be aware of the FAW life cycle and when to apply the pesticide; for example, spraying during the day when the larvae are deeply embedded inside the whorls and ears of corn is useless. Because the larvae only emerge to feed on plants at night, dawn, or dusk, spraying at night or early in the morning is effective (Day et al., 2017). Insecticides like spinosad and chlorantraniliprole can help reduce pest populations as a last resort. The insecticide spinosad produced the best results, killing almost 90% of the larvae (Cruz et al., 2012). Emamectin benzoate 0.4gm/L, chorantraniprol 0.4ml/L, and spinosad 0.3ml/L have all been shown to be effective against FAW in Nepal (Acharya et al., 2020).

4. Conclusion

Fall armyworm (S. frugiperda) is a destructive agricultural pest that can wipe out a wide region of agricultural crop output in a short period of time. Fall armyworm control is more difficult than it is for other crops. The best control and preventative techniques for FAW are reported to be the use of botanical extracts, effective crop husbandry, cultural control, regular monitoring and scouting for pests as well as natural enemies, and employing an integrated pest management approach. Heavy use of chemical pesticides as a management approach, even for a short time, may result in the establishment of insecticide resistant strains of fall armyworm in the future. Farmers, researchers, and extension workers should all be adequately trained and educated on FAW, and the potential for future disaster should also be recognized now.

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