



Integrated Strategies for Managing Fall Armyworm in Maize Cultivation

*Narne Kavya and Ritu Mishra

Department of Entomology, College of Agriculture, GBPUA&T, Pantnagar, Uttarakhand, India

*Corresponding Author's email: kavyanarne22@gmail.com

The fall armyworm (*Spodoptera frugiperda*) is a highly destructive pest of maize, causing significant yield losses and threatening food security globally. Effective and sustainable management of this invasive pest requires an integrated approach combining multiple strategies. This study explores integrated management practices for controlling fall armyworm in maize, emphasizing cultural, biological, chemical, and mechanical methods. Key strategies include timely monitoring, the use of resistant maize varieties, application of bio-pesticides such as *Bacillus thuringiensis*, deployment of natural predators and parasitoids, and judicious use of chemical insecticides. By adopting these integrated measures, farmers can effectively reduce pest populations, minimize environmental impacts, and ensure sustainable maize production. The findings of this study provide practical insights for policymakers, researchers, and farmers to collaboratively address the challenges posed by fall armyworm infestations.

Introduction

Maize (*Zea mays* L.) is a vital cereal crop grown globally due to its adaptability and high productivity. Its popularity among farmers continues to rise. Maize is cultivated on approximately 193.7 million hectares worldwide, with an average yield of 5.75 tonnes per hectare, producing around 1147.7 million tonnes of maize annually [FAOSTAT]. It is commercially grown in more than 100 countries, with major contributions from the United States, Brazil, China, and India.

Despite being relatively new in some regions, maize has gained prominence due to its exceptional performance in both rainfed and irrigated ecosystems, coupled with its ease of cultivation. Currently, maize ranks as the third most important food crop after rice and wheat, thanks to its widespread use in various industrial applications (Andorf et al., 2019). It serves as a crucial raw material for producing corn oil, margarine, corn syrup, sweeteners, marmalade, and non-dairy coffee creamers, in addition to its primary role as animal and bird feed.

Furthermore, maize is utilized in the production of beverages, industrial chemicals, ethanol, fuel, plastics, and high-quality paper, among other products. To meet this increasing demand, advancements in biotechnology have led to the development of superior maize cultivars with traits such as herbicide resistance, drought tolerance, and enhanced protein content (Malenica et al., 2021).

Unique characteristics

The fall armyworm (FAW), an invasive insect pest, inflicts significant damage to maize at all stages of its growth. First reported in India in May 2018, this pest has become a major concern for maize cultivation. Female moths lay their eggs in clusters on the upper or lower surfaces of leaves, covering them with tan scales. Each egg mass contains 50–150 eggs, with

an incubation period of 4–5 days. The larvae have smooth skin with three creamy yellow dorsal and lateral lines along their bodies, which vary in color from light tan or green to dull grey. The larva's reddish-brown head is characterized by a distinctive white, inverted Y-shaped marking between the eyes. There are six larval instars, each lasting between 15 to 18 days. On the eighth abdominal segment, four large spots form a square pattern, while a trapezoid pattern is visible on the ninth segment. The pupae are reddish-brown, and adult moths emerge within 7–9 days. Adult male moths feature a fawn-colored spot and a white patch on the apical margin of their wings, while female moths are less distinctly marked, appearing uniform greyish-brown or faintly mottled. The pest's lifecycle spans 30–35 days, depending on climatic conditions, with adults living for 4–7 days. Remarkably, before laying eggs, the adult moth is capable of flying up to 500 miles (Houngbo *et al.*, 2020).

Classification

Kingdom	:	Animalia
Phylum	:	Arthropoda
Class	:	Insecta
Order	:	Lepidoptera
Superfamily	:	Noctuoidea
Family	:	Noctuidae
Genus	:	<i>Spodoptera</i>
Species	:	<i>S. frugiperda</i>

Biology

The fall armyworm (*Spodoptera frugiperda*), a highly invasive pest in Africa. It can consume over 80 plant species, including maize, rice, sorghum, and sugarcane. Its rapid reproduction and dispersal capabilities further enhance its success as an invasive species. The life cycle of this pest consists of four stages: the egg, six caterpillar instars, the pupa, and the adult moth. Warm and humid growing seasons with substantial rainfall are ideal for its survival and population growth, as temperatures below 10°C inhibit its development (Stokstad, 2017). The adults are nocturnal, and females typically begin laying eggs after a pre-oviposition period of three to four days. Most eggs are deposited within the first four to five days of adulthood, although oviposition can continue for up to three weeks. Adult lifespans average 10 days but can range from 7 to 21 days (Capinera, 2000). Depending on the climate, the lifecycle of the fall armyworm allows for 2 to 10 generations per cropping season. In tropical regions, the warmer temperatures enable up to 10 generations annually, whereas temperate regions may see only two or fewer. The number of eggs laid by a single female varies, ranging from 1,342 to 1,844 depending on the host plant, such as millet, corn, soybean leaves, or cotton.

Like all holometabolous insects, the fall armyworm undergoes four developmental stages: egg, larva, pupa, and adult. Eggs are usually laid on the upper leaf surface but may occasionally appear on other parts of host plants. Each egg mass contains between 100 and 200 eggs, which hatch within two to four days at temperatures between 21–27°C. The larvae progress through six developmental instars, with the final instar responsible for over 70% of the total damage. A single larva can consume approximately 140 cm² of maize leaf area during its development. The larval stage lasts around 14 days in summer and up to 30 days in cooler weather.

Pupation typically occurs in the soil at depths of 2 to 8 cm (Capinera, 2000). The larva constructs a loose, oval-shaped cocoon, 20–30 mm long, by binding soil particles together with silk. In cases where the soil is too hard, larvae use leaf debris and other materials to create a cocoon on the soil surface. Unlike some other pests, the fall armyworm's pupal stage cannot enter diapause to survive extended periods of cold or dry conditions without host plants. The pupal stage lasts about 8 to 9 days during summer but can extend to 20–30 days in colder conditions, such as in Florida (Silva *et al.*, 2017).

Nature and Symptoms of Damage

The larval stage is the primary pest phase of the fall armyworm. Immature larvae begin feeding on the upper surface of the leaf blade, leaving the lower epidermal layer intact. As they progress to the second or third instar, the larvae start boring holes into young leaves. As they mature, they feed inward from the edges of the leaves. During the early larval stage, damage is limited to the leaf whorl, but as the leaves fully expand, the affected plants display characteristic "shot hole" symptoms (Du Plessis *et al.*, 2020).

Although the density of young larvae tends to be higher initially, it decreases in the later instars, with only one or two larvae typically found per plant due to their cannibalistic behavior. In their later stages, larvae cause severe defoliation. Without proper management, the larvae can consume all the green foliage in a short time, leaving behind only leaf ribs and stalks, giving the plant a tattered appearance. The crop's sensitivity to damage varies with growth stages. The early whorl stage is the least sensitive, the mid-whorl stage is moderately sensitive, and the late whorl stage is the most vulnerable. Larval densities ranging from 0.2 to 0.8 per plant during the late whorl stage can result in yield reductions of 5% to 20%. In severe infestations, the larvae may migrate to the ear and feed on the kernels, potentially leading to total yield loss.

Currently, the crop is affected by over 25 insect pests at different stages of its growth. Among them is the fall armyworm (*Spodoptera frugiperda*), a highly invasive pest with a broad host range. This pest is capable of causing substantial yield losses across vast areas of infestation.

Management Approaches

Cultural control

Winter kill, which exposes larvae and pupae near the soil surface, is a crucial part of the FAW pest management strategy as it reduces the likelihood of pest infestations. Cultural practices, such as avoiding late planting, are important because maize planted late tends to have higher FAW infestations compared to early-planted maize. Additionally, intercropping and rotating maize with non-host crops like sunflower and beans can help reduce FAW outbreaks.

Physical control

Effective monitoring is essential for the successful implementation of integrated pest management. Pheromones and light traps have proven to be effective tools for monitoring fall armyworm. The most commonly used pheromones are sex pheromones and aggregation pheromones (Prasanna *et al.*, 2018). Additionally, black light traps are useful for capturing adult moths.

Mechanical control

Monitoring for damage is crucial for managing this pest, as it feeds quickly and causes significant destruction. Regular field inspections to manually remove egg masses can help control the pest on a small scale and has shown some success.

Biological control

Metarhizium anisopliae and *Beauveria bassiana* have been shown to effectively target the eggs and second-instar larvae of fall armyworm. *B. bassiana* resulted in a moderate mortality rate of 30% in second-instar larvae, while *M. anisopliae* caused 79.5–87.0% egg mortality under laboratory conditions. Other important biological control methods include the use of *Spodoptera frugiperda* Multiple Nucleopolyhedrovirus (SfMNPV), predatory insects, parasitic wasps (parasitoids), genetically modified Bt crops that produce proteins toxic to FAW larvae, and mass trapping of male moths with pheromones to prevent mating. Key predatory insects include earwigs, ladybird beetles, flower bugs, and ants.

Chemical control

Fall armyworm can be controlled using synthetic insecticides. In Ethiopia and Kenya, smallholder farmers commonly use dry sand mixtures with trichlorfon (granules or powder), applied to whorls using a plastic bottle, which is considered effective. However, chemical

control is not always economical for managing fall armyworm, as the insect's frass can accumulate, forming a "plug" that reduces the insecticide's effectiveness and prevents it from reaching the whorl where the larvae feed. In cases of severe infestation or plant stress, chemical control may be necessary. If 75% of the plant's whorl shows feeding damage, larvae are less than 31 mm long, and the plants are stressed, insecticides might be recommended. Insecticides should not be applied during the day, as the pest is nocturnal (Day et al., 2017). Emamectin benzoate (0.4 gm/L), chlorantraniliprole (0.4 ml/L), and spinosad (0.3 ml/L) have been found effective against FAW in Nepal. However, the lack of clear threshold levels before resorting to chemical control may lead to plant damage, resistance development, and risks to human health and the environment.

Conclusion

Integrated pest management (IPM) offers a sustainable and effective solution to mitigate the impact of fall armyworm in maize cultivation. The adoption of a multi-pronged strategy—combining early detection, biological controls, cultural practices, and selective chemical interventions—can significantly reduce pest damage while safeguarding environmental and human health. Promoting awareness, capacity building among farmers, and the development of pest-resistant maize varieties are critical to the successful implementation of IPM strategies. Collaborative efforts involving farmers, extension workers, researchers, and policymakers are essential to ensuring the long-term control of fall armyworm and enhancing the resilience of maize production systems.

References

1. Andorf, C.; Beavis, W.D.; Hufford, M.; Smith, S.; Suza, W.P.; Wang, K.; Woodhouse, M.; Yu, J.; Lübberstedt, T. Technological advances in maize breeding: Past, present and future. *Theor. Appl. Genet.* 2019, 132, 817–849
2. Capinera, J. L. (2000). Fall armyworm, *Spodoptera frugiperda* (JE Smith)(Insecta: Lepidoptera: Noctuidae). University of Florida IFAS Extension.
3. Du Plessis, H.; Schlemmer, M.-L.; van den Berg, J. The effect of temperature on the development of *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *Insects* 2020, 11, 228
4. FAOSTAT. Statistics; Food and Agriculture Organization of the United Nations: Rome, Italy, 2020.
5. Hounbo, S., Zannou, A., Aoudji, A., Sossou, H. C., Sinzogan, A., Sikirou, R., . . . Ahanchédé, A. J. A. (2020). Farmers' knowledge and management practices of fall armyworm, *Spodoptera frugiperda* (JE Smith) in Benin, West Africa. *10*(10), 430.
6. Jirnmci, E., 2013. Efficacy of botanical extracts against termites, *macrotermes* spp., (IsopteraTermitidae) under laboratory conditions.
7. Malenica, N.; Dunić, J.A.; Vukadinović, L.; Cesar, V.; Šimić, D. Genetic approaches to enhance multiple stress tolerance in maize. *Genes* 2021, 12, 1760.
8. Moovenhan, P.; Baskaran, R.; Kaushal, J.; Kumar, J. Integrated Management of Fall Armyworm in Maize; ICAR-National Institute of Biotic Stress Management: Raipur, India, 2019; p. 225.
9. Prasanna, B.M., Huesing, J.E., Eddy, R., Peschke, V.M., 2018. Fall armyworm in Africa: a guide for integrated pest management.
10. Silva, D. M. D., Bueno, A. D. F., Andrade, K., Stecca, C. D. S., Neves, P. M. O. J., & Oliveira, M. C. N. D. (2017). Biology and nutrition of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) fed on different food sources. *Scientia Agricola*, 74(1), 18–31.
11. Stokstad, E. (2017). New crop pest takes Africa at lightning speed. American Association for the Advancement of Science. Retrived from <https://science.sciencemag.org/content/356/6337/473.summary>