

## Worldwide Distribution and Management of Fall Armyworm: A Review

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### ABSTRACT

The fall armyworm (*Spodoptera frugiperda*), a significant global agricultural pest, poses a substantial threat to maize and other crops, leading to drastic yield losses. Initially identified in Africa, it has since invaded several regions, including sub-Saharan Africa and Asia, impacting many plant species. This research outlines the pest's biology, including its two strains with distinct host preferences, and mechanisms of damage to maize, which can result in yield reduction of up to 73%. Effective management strategies are critical to mitigate its impact. Cultural practices, biological controls, and targeted chemical interventions are evaluated for their efficacy in managing FAW populations. The integration of these strategies, particularly the use of environmentally friendly biological control agents and cultural practices, is

emphasized as a sustainable approach. This review paper also highlights the importance of early detection and intervention, as well as the significant role of local and botanical remedies in pest management. The findings underscore the urgent need for adaptive management practices to protect global food security from the threats posed by the fall armyworm.

**Keywords** Distribution, Fall armyworm, Maize, Management, *Spodoptera frugiperda*.

### INTRODUCTION

*Spodoptera frugiperda* belonging to family Noctuidae, order Lepidoptera is the most significant pest of maize causing major losses to global agriculture. It is reported to cause a yield reduction of 15–73% (Hruska and Gould 1997). It was initially discovered in the African continent (Goergen *et al.* 2016). Fall armyworms do not feed similarly on all crops, despite their broad host range (Barros *et al.* 2010). Corn is the most favored host of FAW (Murúa *et al.* 2008). FAW consumes and assaults nearly every portion and stage of the corn crop. In maize, it causes a yield reduction of roughly 58% (Kumar *et al.* 2022). Strong flight of FAW help it to spread swiftly to other countries. It has a night time flying range of 100 km. Additionally, fall armyworms don't hibernate in the winter; they are active year-round (Garcia *et al.* 2018 and Harrison *et al.* 2019). Even below 18°C FAW can finish the developing process. Fall armyworm is now more damaging because to these unique characteristics

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(Barfield *et al.* 1978). However, following an initial feeding phase, young larvae primarily disseminate by ballooning onto other surrounding plants because of the large number of eggs in the FAW egg masses (Sokame *et al.* 2020).

There are two strains of FAW. These strains of FAW have similar morphologies but different host plant preferences. Despite changes in the entire genome, transcriptome, these two strains lack any distinct biological characteristics (Gouin *et al.* 2017, Silva-Brandao *et al.* 2017). According to the study, fall armyworms from Asia and Africa share genetic similarities, suggesting that a small number of populations from the Western Hemisphere invaded. Inter-strain mating may be the cause of the confusion between R-strain and C-strain (Nagoshi *et al.* 2020). It has long been believed that the rice strain primarily targets rice and other grasses, whereas the maize strain favors maize, sorghum, and cotton (Sparks 1979). Nonetheless, maize has recently been shown to be the preferred oviposition host for both strains in a lab setting (Ingber *et al.* 2021).

The fall army worm damages both vegetative and reproductive sections, but feeding harm causes ragged and elongated holes and white patches. The development of the tassel may even be impacted by increased feeding farther in the whorl. Stunted plants and a decrease in grain yield could arise from severe induced leaf damage that drastically reduces the photosynthetic area. The quality of the grain and yield may be impacted during the reproductive stage if the larvae bore through the top or side of the ear head and begin feeding on kernels at the milky stage. Fall armyworm moths are nocturnal in nature that hide in maize plant whorls during the day and are more active during the evening. Female moths lay eggs above or below the leaf surface, and after hatching, they spread through wind. Early instars feed on leaves, causing whitish patches. Grown-up caterpillars feed on leaf tissues, causing ragged holes and sickly appearance. Larvae start feeding on leaves and kernels after 10-20 days of sowing. Faecal contents, extensive plant defoliation, and subsequent stages that affect plant growth and development are among the symptoms, which start with the larval stage, which creates different sizes of papery windows in leaves

(Reddy *et al.* 2020).

### **Invasion of fall armyworm in different countries**

Fall armyworms are the most destructive pests in the world. Since initial discovery of FAW in Africa in 2016 (Goergen *et al.* 2016), the pest has expanded throughout sub-Saharan Africa (SSA) and Asia, seriously harming crops and inflicting financial losses (Day *et al.* 2017). Subsequently, it expanded throughout the remainder of SSA, 17 Asian nations, and Australia (CABI 2020), with a high risk of near-global invasion (Early *et al.* 2018). After being discovered on a few hectares of irrigated maize fields in southern Ethiopia in February 2017, the FAW is currently dispersed over 640.8 thousand hectares in 144 districts across six of the major regional maize growing states, namely, Benishangul-Gumuz, Amhara, Tigray, Gambella, Oromia, and SNNPs.

FAW was first identified in May 2018 in the southwest Indian state of Karnataka (Sharanabasappa *et al.* 2018a). By late 2018, the pest outbreaks were detected in Bangladesh, Myanmar, and Thailand (Guo *et al.* 2018) and Sri Lanka, adversely affecting large-scale maize mono-cropping systems. In Nepal, FAW was discovered for the first time in the Nawalparasi district on May 9, 2019 (NPPO 2019). Early in 2019, FAW bugs were discovered in maize crops in Sumatra, Indonesia (Herlinda *et al.* 2022). It was thought to have migrated naturally from Jordan to the Middle East, where it was detected in 2020 in Israel (EPPO 2021), Jordan (IPPC 2021), and Syria (IPPC 2021, Heinoun *et al.* 2021) (Fig.1).

### **Management strategies against fall armyworms**

It is crucial to identify FAW before the pest causes financial harm. According to Fernandez (2002), control techniques should only be used in maize when 20% of whorls of tiny plants (during the first 30 days) are infested with this pest or 5% of seedlings are clipped. According to Assefa and Ayalew (2019), its larval stage is the most effective time for the pest's correct treatment.

### **Pest scouting and monitoring**

The success of applying effective IPM practices

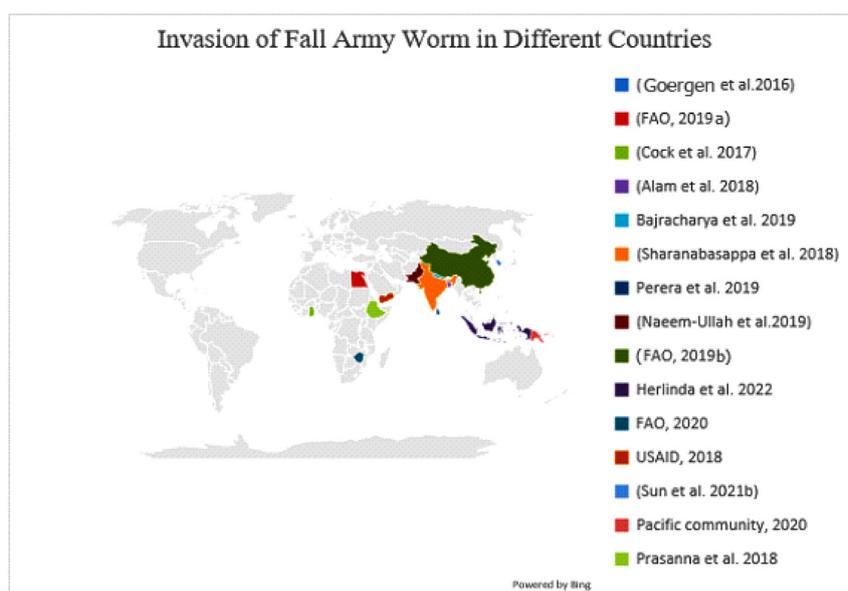


Fig. 1. Worldwide distribution of fall armyworm.

to FAW begins with efficient field scouting and monitoring. This aids in accurate field diagnosis on the amount and distribution of pests, as well as the damage inflicted. Farmers identify pest damage on the farm as holes in the leaves and frass on the stem. Pitfall, sticky, light, and pheromone traps are all methods for monitoring and determining pest presence and density on farms (Prasanna *et al.* 2018). Farmers with smaller farms used handpicking for scouting and monitoring in the field, but this is not practicable for large acreage. FAW can be trapped easily in the night with the use of light trap because it is a nocturnal insect for monitoring purpose. The moth can be monitored with black light trap due to the nocturnal behavior of the moth (Bhusal & Chapagain 2020).

### Cultural control

Cultural measures can be important strategy for controlling fall armyworm. Avoiding late planting is part of the cultural control since a higher FAW infection would severely destroy the maize ears compared to those of the early plantings. Early plantation or the use of early maturing types (greater armyworm densities occur later in the season) are found to be useful in controlling FAW (Prasanna *et al.* 2018). Additionally,

it might be helpful to rotate and intercrop maize with non-host crops like beans and sunflower in order to reduce the invasion of FAW (FAO 2018). Kumela *et al.* (2019) demonstrated how smallholder farmers in Ethiopia and Kenya have succeeded with a dry sand and trichlorfon mixture prepared as granules or powder and placed into whorls. According to a study, climate-adapted push-pull plantings showed 2.7 times higher grain yields of maize and 82.7% decrease in the average number of larvae per plant and 86.7% less plant damage per plot than maize grown in a plot as a sole crop (Midega *et al.* 2018). The cultural approach to pest control is more economical and secure as it does not have any unfavorable effects on food, human health, or the environment. According to Firake *et al.* (2019), one method of controlling FAW is to manually pick and eliminate egg clusters and newly hatched larvae by crushing them or submerging them in kerosene water. According to FAO (2017), pheromone traps that attract male armyworm moths are recommended for widespread deployment due to their user-friendly design.

### Use of pheromone

Effective FAW management necessitates timely

**Table 1.** Predators of fall armyworm.

Sl. No.	Scientific name	Description	References
1	<i>Doru luteipes</i>	Very significant FAW parasitoids. studies using bioecological methods on FAW larvae have shown that there are 25–30 eggs per oviposition, with an incubation period of roughly one week.	Frizzas <i>et al.</i> (2014)
2	<i>Euborellia annulipes</i>	FAW larvae are also consumed by a significant parasitoid of <i>Spodoptera frugiperda</i> .	Barros <i>et al.</i> (2018)
3	<i>Orius insidiosus</i>	In most cases, biological control methods involve extremely abundant species	Ferkovich <i>et al.</i> (2007)
4	<i>Calo somacalidum</i>	The females lay their eggs either directly on top of the soil or right underneath it after mating. The immature stage goes through three instars before pupating on Earth.	Knutson (2008)
5	<i>Podisus maculiventris</i>	It punctures its prey and delivers a toxin that quickly induces paralysis.	Kneeland <i>et al.</i> (2012)
6	<i>Orius sauteri</i>	An important parasitoid. Moth eggs, aphids, and small Lepidoptera larvae are all prey for <i>O. sauteri</i> .	Jaraleño <i>et al.</i> (2020)

Source: (Prasanna *et al.* 2018).

identification of the pest to enable implementation of suitable crop protection measures. Pheromone-trapping used in monitoring, surveillance, and scouting is a critical method for identifying pests at an early stage and making timely and suitable management decisions (Hendrichs *et al.* 2021). Pheromones, specifically sex pheromones produced by female FAWs to attract male FAWs for mating, are used to monitor population growth on the farm. While pheromone traps provide early warning of moth activity in a location (Meagher and Mitchell 2001). Monitoring pest-infested plants provides information on field infestation levels, which guides judgments about whether to apply control methods. The presence and accumulation of FAW in a certain location can be detected using pheromone traps. Synthetic substances that replicate natural FAW pheromones, also known as lures, are used to attract and catch male moths. The trapped moths are then recorded. Farmers can use these numbers to confirm the presence of FAW in their fields and whether additional reconnaissance is required (FAO 2019a). Amongst various *S. frugiperda*'s female pheromone chemical components viz. (Z)-9-tetradecen-1-ol acetate (Z9-14:OAc), (Z)-9-dodecen-1-ol acetate (Z9-12:OAc), (Z)-7-dodecenyl acetate (Z7-12:OAc), (Z)-11-dodecenyl acetate (Z11-12:OAc), (Z)-11-hexadecenal (Z11-16:Ald), and (Z)-11-hexadecenyl acetate (Z11-16:OAc), (Z)-9-tetradecenyl acetate (Z9-14:Ac) and (Z)-7-dodecenyl acetate (Z7-12:Ac) are the major and the minor component, respectively. Regarding pest

management, it is crucial to understand that FAW is made up of two strains (corn and rice) with different pheromones (Kenis *et al.* 2022).

### Biological control

In addition to providing a more cost-effective and eco-friendly option than the commonly employed synthetic insecticides, biological control can lessen environmental damage. Bio control refers to the advantageous role that competitors, pathogens, parasitoids, and predators play in reducing pests and the harm they cause (Nafiu *et al.* 2014). To maintain control over FAW populations, insect predators for both eggs and larvae must be present. Predators *Picromerus lewisi* and *Arma chinensis* mostly target FAW larvae in their sixth instar (Tang *et al.* 2019a, b), while earwigs *Doru lineare* and *D. luteipes* prey on FAW eggs and larvae (Pasini *et al.* 2007, Sueldo *et al.* 2010). The entomo-pathogen resources or possible bio-pesticide choices of FAW and their current state of use have been compiled in some reviews (Bateman *et al.* 2018, Chen *et al.* 2019). Natural enemy populations are impacted by the prevalence of parasitism variation (Kogan *et al.* 1999). According to reports, parasitoids are the most frequently employed natural enemies as part of biological pest management spodopterans. The two primary egg parasitoids of FAW are *Telenomusremus nixon* (Hymenoptera: Platygasteridae) and *Trichogramma* spp. (Hymenoptera: Trichogrammatidae), which are already employed in augmentative

**Table 2.** Parasitoids of fall armyworm.

Sl. No.	Parasitoids	Type of parasitoids	Description	References
1	<i>Trichogramma pretiosum</i>	Egg parasitoids	It has a 7.2-fold longer lifespan when the host and a food source (pure honey) are both present.	Bleicher and Parra (1991)
2	<i>Telenomus remus</i>	Egg parasitoid	Demonstrates over 45% incidence of parasitism (Sisay <i>et al.</i> 2019). <i>Telenomus remusi</i> it completes its development in 12 to 13 days at 25°C, with each female capable of parasitizing over 250 eggs (Bueno <i>et al.</i> 2014).	Bueno <i>et al.</i> (2010)
3	<i>Chelonus insularis</i>	Egg-larval parasitoids	The female <i>Chelonus</i> deposits its eggs within those of the fall armyworm (FAW), and the parasitized larva gradually reduces its feeding activity until it eventually dies.	Jourdie <i>et al.</i> (2010)
4	<i>Chelonus bifoveolatus</i>	Egg-larval endo-parasitoid	They primarily target insects from the Pyralidae and Noctuidae families, with the parasitoid laying its eggs directly inside the host's eggs. (Murua <i>et al.</i> 2009).	Koffi <i>et al.</i> (2020)
6	<i>Drino quadrizonula</i>	Larval parasitoids	Parasitized members of the Noctuidae family	Crosskey (1970)
7	<i>Lespesia archippivora</i>	Larval parasitoids	<i>Lespesia archippivora</i> progresses through three larval instars that consume the host caterpillar and upon reaching maturity, the parasitoid exits the host and undergoes pupation in the soil.	Delfin <i>et al.</i> (2007)

Source: Abbas *et al.* (2022).

biological management (Ferrer 2001). However, since parasitoids don't always make their hosts eat less, more parasitism does not necessarily translate into decreased herbivory (Tables 1–3).

In addition to being acknowledged as comprehensive bio-pesticides aimed at suppressing numerous destructive pests, entomo-pathogenic fungi (EPFs) have demonstrated effectiveness against a range of insect pests (Hussain *et al.* 2018, Waqas *et al.* 2021) and may be incorporated as a crucial element of integrated pest management (IPM) strategies aimed at suppressing FAW populations (Shah and Pell 2003, Inglis *et al.* 2001). Only a small number of the many pathogens linked to *S. frugiperda*, nematodes, viruses, fungi, and protozoa cause illness in the pest. The most notable pathogen is the nuclear polyhedrosis virus (NPV) of *S. frugiperda*, which fatally affects both the pest and the entomo-pathogenic fungus species "Erynia radicans, *Nomuraea rileyi*, and *Entomophaga aulicae*. Because their immune responses and body functions are still maturing, early developmental phases of insect larvae are more susceptible to fungal infections

in early instars than in advanced stages (Perumal *et al.* 2023a, Perumal *et al.* 2023b). Fall armyworm eggs and second-instar larvae are effectively combated by fungi such as *Beauveria bassiana* and *Metarhizium anisopliae*. *M. anisopliae* produced egg mortalities ranging from 79.5 to 87.0% in a lab setting, while *B. bassiana* recorded mortality rates of 30% for larvae in their second instar. With certain fungal isolates,

**Table 3.** Entomopathogens of fall army worm.

Entomopathogens	% mortality	References
<i>Metarhizium anisopliae</i>	97%, 87%, 77% and 72% mortality in the second, third, fourth and fifth instar larvae, respectively at nine days post-treatment	Akutse <i>et al.</i> (2019)
<i>Spodoptera litura</i>	74-78%	Javed <i>et al.</i> (2022)
<i>Heterorhabditis</i> spp.	77% using 100 IJs/Larva	Shinde <i>et al.</i> (2023)
<i>Aspergillus flavus</i>	Able to substantially suppress haemocyte levels in <i>S. litura</i> larvae at minimal doses (4×10 <sup>8</sup> conidia/ml) over a span of three days	Karthi <i>et al.</i> (2018) Balumahendhiran <i>et al.</i> (2019)

**Table 4.** Different botanical extracts used to control fall armyworm.

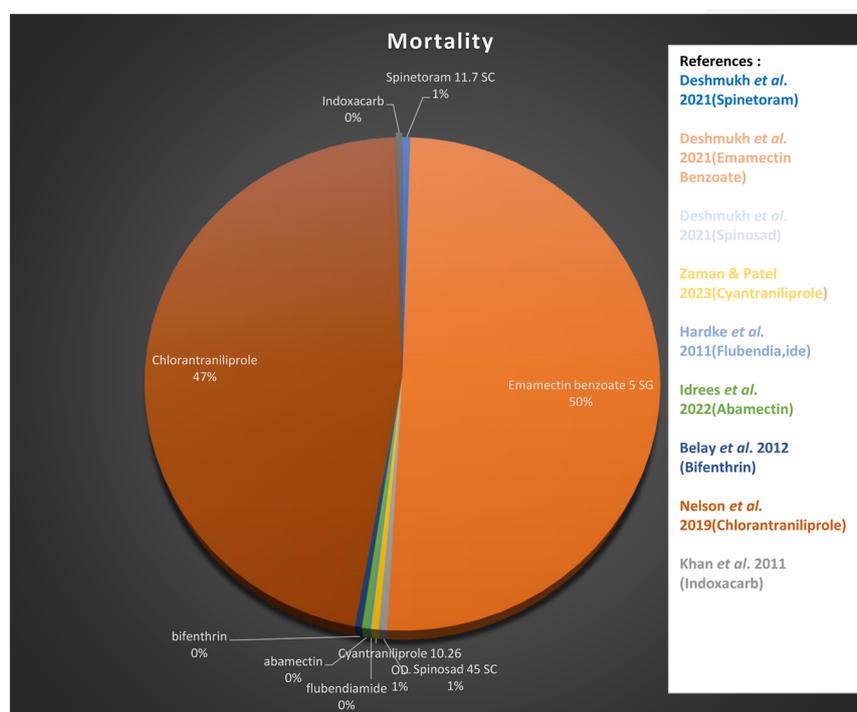
Extract	Mode of action	References
<i>Moringa oleifera</i>	It shows antifeedant activity	Kamel (2010)
Hexane and ethanol extracts of meliaceous seeds	Achieves complete larval mortality in lab trials	Mikolajczak <i>et al.</i> (1989)
Essential oil from <i>Piper hispidinervum</i> seeds	Are effective against spermatogenesis and egg laying	Alves <i>et al.</i> (2014)
Ethanolic extracts of <i>Jatropha gossypifolia</i> leaves	Give larval antifeedant effects and enhances pesticide efficacy through synergistic interaction	Bullangpoti <i>et al.</i> (2012)
Castor oil and Ricinine (seed extracts)	Inhibits growth and larval mortality	Ramos-López <i>et al.</i> (2010)

the overall egg mortality and early-stage larval death rates with *M. anisopliae* reached 96% (Akutse *et al.* 2019). On *S. frugiperda* larvae gathered from the maize fields in Karnataka, India, Shylesha *et al.* (2018) documented the egg parasitoids, namely, *Telenomus* sp., *Trichogramma* sp., *Glyptapanteles creatonoti*,

*Campoletis chlorideae*, and *Cotesia ruficrus*.

### Use of biopesticides

Local farmers have asserted the advantages of botanical extracts derived from their plants. Instead of synthetic insecticides, which may be more detrimental to the environment, raise consumer costs, and postpone recovery, botanical pesticides are preferable (Shah *et al.* 2020, Ullah *et al.* 2022). *Chrysanthemum cinerariifolium*, *Jatropha curcas*, *Nicotina tabacum*, *Milletia ferruginea*, *Phytolacca docendra*, and *Croton macrostachyus* are a few plant extracts that may be utilized to manage insect pests (Jimma 2014). In lab settings, 80% of deaths were caused by botanical pesticides (Tavares *et al.* 2010). Several reports and studies indicate that these botanicals are effective against FAW (Babendreier *et al.* 2020). Unlike chemical pesticides, botanical insecticides are harmless for natural enemies, target-specific, and environmentally benign (Mora and Blanco-Metzler 2018). Comparing their application to areas treated with pesticides, FAW natural parasitism is thereby promoted by up to 60% (Meagher *et al.* 2016) (Table 4).

**Fig. 2.** Chemical showing mortality against fall armyworm.

## Chemical control

Synthetic pesticides reveal the main risk to sustainable agriculture. It is preferable to use cultural and natural resources to improve plant health. Chemical control is the application of synthetic pesticides to manage the growth of insect populations. Pesticides are typically utilized as the final line of defense in the deployment of IPM when other methods have failed or are limited in their ability to reduce population growth. This is because synthetic pesticides produce immediate consequences as knockdown or ingestion poisons, and they are widely classified into contact and system mode-of-actions. Control of FAW is mainly performed with the spraying of synthetic pesticides (Assefa and Ayalew 2019), but it involves significant costs, potential environmental contamination. Several insecticides including Spinetoram, Emamectin benzoate + Profenofos, Isocycloseram, Isocycloseram, Chlorantraniliprole, Broflanilide have registered across various regions globally to control this pest.

Chemical pesticides are utilized in extreme situations, nevertheless, and prompt action is required (Tumlinson *et al.* 1986). Several pesticides, including esfenvalerate, carbaryl, chlorpyrifos, malathion, permethrin, emamectin benzoate, and others, are advised for *Spodoptera* species. To combat autumn armyworm, 92% of Rwandan farmers and 88% of Ugandan farmers used a combination of emamectin benzoate and cypermethrin (Tambo *et al.* 2020). According to a recent study conducted in China, abamectin and broflanilide, which are members of the avermectin and diamides group, reduced the population of second-instar of *S. frugiperda* larvae by 87.3 and 91.3% after 72 hrs of treatment (Idrees *et al.* 2022). Emamectin benzoate, chlorpyrifos, and chlorantraniliprole have been shown in numerous prior studies based on socio-economic surveys and laboratory and field bio-assays to be effective against various *Spodoptera* species (Deshmukh *et al.* 2020, Zhao *et al.* 2020). According to Bhusal & Bhattarai (2019), the implementation of spinosad and the novel pesticide flubendiamide and chlorantraniliprole caused "over 90% of larval death," and it was found that spinetoram outperformed the conventional pesticides novaluron and lambda-cyhalothrin (Hardke *et al.* 2011). Following seven days of emamectin

benzoate therapy, the larvae's full mortality was noted (Khan *et al.* 2011) (Fig. 2).

## CONCLUSION

FAW (fall armyworm) feeds on a wide range of host plants, affecting over 350 plant species from 42 families. Its invasion has caused significant reduction in maize production fields globally, prompting the need for effective management strategies. Cultural, biological, and chemical control measures have been labeled as crucial for managing FAW infestations, focusing on early identification and targeted treatments to minimize financial impact and keep crops healthy and productive.

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