Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 9 Issue 12 December 2025

Review Article

# Towards Sustainable Control of Fall Armyworm in Maize: An Overview of Management Practices

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**Received:** November 11, 2025

**Published:** November 29, 2025



## Abstract

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith), has rapidly emerged as a formidable invasive pest, posing a significant threat to global food security, particularly maize production. Originating from the Americas, its aggressive spread across Africa and Asia necessitates a comprehensive evaluation of management strategies to mitigate its devastating impact, with yield losses ranging from 20% to over 70%. This review synthesizes current knowledge on effective and sustainable practices for managing FAW in maize. We critically examine a spectrum of control measures, beginning with foundational, cost-effective cultural practices such as early planting, intercropping, and residue management. The paper further explores biological and botanical methods, highlighting the efficacy of biopesticides like Bacillus thuringiensis and Metarhizium anisopliae, the conservation of natural enemies, and the use of botanical extracts. While chemical control offers rapid pest suppression, we address significant challenges of insecticide resistance, environmental contamination, and non-target impacts, advocating for its judicious use within an Integrated Pest Management (IPM) framework. The review underscores critical challenges hindering sustainable FAW control, including resistance management, climate change impacts on pest dynamics, and research gaps. We conclude by emphasizing the urgent need for robust IPM strategies, supportive government policies, and effective extension services to empower farmers with tools for long-term, resilient FAW management.

**Keywords:** *Spodoptera frugiperda*; Integrated Pest Management (IPM); Biopesticides; Cultural Control; Insecticide Resistance; Sustainable Agriculture

## Introduction

The fall armyworm *Spodoptera frugiperda* (J.E. Smith), a highly destructive invasive insect of the family Noctuidae, has emerged as one of the most serious agricultural pests in recent decades. Native to tropical and subtropical regions of the Americas, it was first identified in Africa in 2016 and within two years had spread across more than 44 countries in sub-Saharan Africa [5,14]. The pest was subsequently detected in Asia, with India reporting the first infestation in Karnataka in 2018, followed by its rapid expansion into several other states such as Bihar, Chhattisgarh, Gujarat, Odisha, Tamil Nadu, and West Bengal [8,29]. By 2019, the ability of this pest to establish globally was further demonstrated with its confirmation in Nepal and other South Asian countries [1,6,21,26].

The invasive success of *S. frugiperda* is largely attributed to its biological characteristics. The moth is capable of long-distance migration, traveling up to 500 km within a single generation aided by wind currents [23]. Though maize (*Zea mays* L.) is its most favored host and also the most severely affected crop, the species is highly polyphagous, infesting more than 80 plant species worldwide, including rice, sorghum, millet, cotton, and multiple vegetables [1,8,9]. Larval feeding severely damages both vegetative and reproductive structures, resulting in characteristic whorl injury, defoliation, and direct cob damage [10,14].

The impact of FAW on crop productivity is alarming, with yield losses typically ranging between 20–70%, and in some cases leading to complete crop failure [11,17]. In regions such as India and Nepal, where maize serves as both a staple food and a critical input for livestock and poultry feed, the pest poses a direct threat to food security, farmer livelihoods, and national economies [6,26].

Given its rapid spread, broad host range, and devastating impact, reliance solely on chemical insecticides is not a sustainable option due to resistance development and environmental concerns [1,10]. Hence, there is an urgent need to adopt integrated pest management (IPM) strategies that encompass cultural practices, mechanical and biological interventions, botanicals, and judicious use of chemical pesticides. Environmentally sustainable approaches such as biopesticides, push-pull technology, and the conservation of natural enemies offer promising solutions for managing FAW while safeguarding food security [20,26].

## Symptoms of fall armyworm damage and its economic effects

The fall armyworm *(Spodoptera frugiperda)*, particularly during its larval instar stages, causes extensive damage to host crops. Early instars typically scrape the leaf surface, leaving behind characteristic "pin-hole" and "window-pane" patterns. As the larvae mature, they feed more aggressively, resulting in ragged whorls and skeletonized leaves [1,14]. Fully developed larvae predominantly target the plant's growth points, including whorls, tassels, and ears, and they frequently bore into cobs and kernels. This feeding behavior leads to both quantitative and qualitative losses [6,10].

The symptoms visible according to the crops stages is that the caterpillars feed inside the whorls of young maize plants. Early instar larvae scrape the leaf surface, forming white, semi-transparent patches. As the larvae mature, they cause extensive damage, giving the leaves a torn or ragged appearance. The presence of moist, sawdust-like frass near the whorls or upper leaves is a typical sign of infestation. Severe feeding within the whorl can destroy developing tassels, while older larvae may bore into the cobs and feed on developing kernels. Such damage not only reduces plant vigor but also obstructs insecticide penetration, making pest management even more challenging [8].

The economic consequences of fall armyworm outbreaks are considerable. Maize production losses have been reported to range from 20% to 70%, with severe infestations occasionally leading to total crop failure [11,17]. On a national scale, yield reductions of 20% to 50% have also been recorded. The threat is equally alarming in South Asia. Within a year of its initial detection, fall armyworm outbreaks were reported across more than 170,000 hectares in ten Indian states [28,30]. In Nepal, unchecked infestations pose the risk of a near-total collapse of maize production [6,26].

In addition to being a staple crop for millions of smallholder farmers, maize is also essential to the production of feed for animals and poultry. Severe infestations put household nutrition at risk, raise feed and food prices, and make smallholders more economically vulnerable. These smallholders are already limited by their inability to obtain inputs and pest management resources [1,26]. In order to lessen FAW's threat to agricultural systems and livelihoods, it is imperative that ecologically sound and farmer-friendly integrated management strategies be developed.

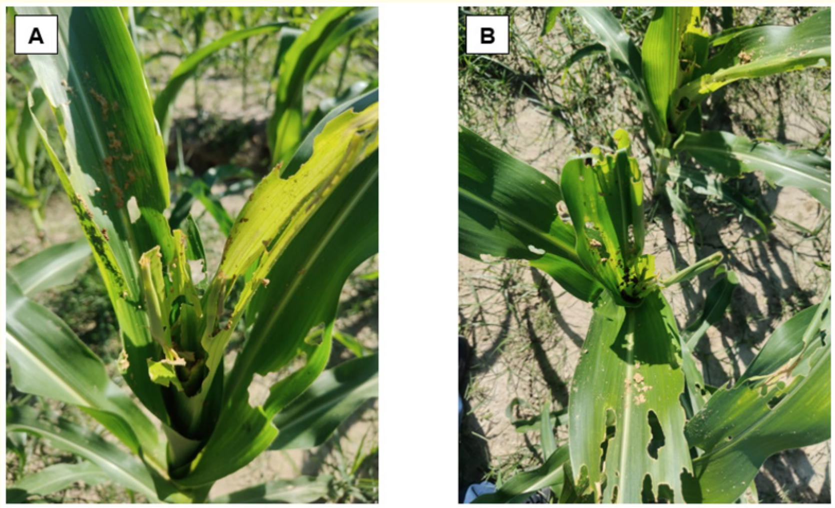


**Figure 1:** Photos showing fall army worm infected damages on maize (a) Excreta present on the leaves as a sign of the larvae of the fall army worm (b) Shot holes on the leaves.

## Management of fall army worm

It is important to detect Fall Army Worm in the field before the pest causes economic damage. Integrated Pest Management (IPM) is a set of methods that includes monitoring, cultural, biological, botanical, and chemical methods that are specific to an area. The larval stage of fall armyworm is the most effective phase for pest management and the timing of the management action (morning, afternoon, evening) is crucial [26].

## Cultural practices

Fall armyworm (FAW) control is significantly contingent upon cultural practices that are sustainable, environmentally benign, and cost-effective, particularly for smallholder farmers. Early planting is a crucial tactic because it minimizes damage by allowing crops to mature before pest population peaks later in the season [23]. In addition, FAW feeding patterns have been disrupted and infestation levels reduced by intercropping maize with non-host crops like sunflower, beans, pigeon pea, black gram, or green gram [13]. Crop diversity and rotation increase the population of natural enemies, which further reduces the number of pests. However, it is reported that in highly infested fields, it might also be necessary to burn crop residues and deep plough in order to destroy eggs, larvae, pupae, and adults [32]. Regular weeding lowers the number of Graminaceae host weeds available for FAW breeding grounds. This approach's low cost and quick results make it especially helpful in small-scale farming systems. Overall, these cultural practices are advantageous because they are affordable and pose no residual risks to human health and the environment; however, they require long-term planning and sustained effort for maximum effectiveness, and their pest control efficiency is generally lower compared to other interventions [19].

## Mechanical control method

Mechanical and Physical management is the most effective and rapid way to manage biological pests [3]. One method of controlling fall armyworms is the hand collecting and destruction of egg masses, as well as the mass crushing or soaking of neonate larvae in kerosene water [13]. Regular field visits (twice weekly) to crush egg masses and larvae, Hand picking and destruction of egg masses and neonate larvae in mass by crushing or immersing in kerosene water. Application of dry sand in to the whorl of affected maize plants soon after observation of FAW incidence in the field.

Application of Sand + lime in 9:1 ration in whorls in first thirty days of sowing. Mass trapping of male moths using FAW specific pheromone traps @ 15/acre. To catch fall armyworm moths, a traditional bucket trap featuring a yellow funnel, white bucket and green canopy has proven to be the most effective [16]. In Benin, pouring ash, sand, sawdust or dirt into whorls to dry out and control larvae; pouring water in the maize whorl to drown larvae. The FFS farmers in Benin picked larvae to feed them to chicks for poultry production. FAW can be considered a good complementary source of protein in countries where insects are consumed [12].

### Biological method

Biological control of fall armyworm can be enhanced by protecting natural enemies in situ through habitat management and increasing plant diversity using intercropping with pulses and ornamental flowering plants [13].

- **Microbial Control:** The bacterial formulation *Bacillus thuringiensis* var. kurstaki @ 2g/litre or 400g/acre is effective for FAW control. It is recommended to use *Metarhizium anisopliae* as a talc formulation (1x10^8 cfu/g) at 5g/litre applied through whorl spraying 15-25 days after, with 1-2 sprays at 10-day intervals based on pest damage for effective management of FAW [13]. FAO highlighted that biopesticides, including *Bt, Beauveria bassiana*, and baculoviruses have significant efficacy in reducing FAW infestations and leaf defoliation [12].
- **Parasitoids:** FAW control has been identified in 53 parasitoid species from 43 genera and 10 families worldwide [4]. Among the different natural enemies reported for FAW, the egg parasitoid *Telenomus remus* and *Trichogramma* spp. are the most studied and used species, both showing great potential for augmentative biological control (ABC) of FAW and other armyworms that often attack maize [7,15]. The wasp *Chelonus insularis* Cresson is a key egg parasitoid of the fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), one of the main insect pests of maize (*Zea mays* L.) [25].

Eggs parasitoids such as *Trichogramma pretiosum* and *Telemonus remus* can be released for destroying the egg stage of FAW @ 50000 per acre at weekly intervals, avoid spraying chemical pesticides for few days during the time of release in the field.

Biological controls do not lead to pest resistance, are safe for humans and the environment, target specific pests without affecting non-target species, and are cost-effective over the long term. However, initial management costs are high, the process is slow, and pest control percentages are generally lower than with chemical pesticides. Botanical pest management employs locally available resources such as plant extracts, oils, soil, sand, lime, wood ash, and soaps. The highest larval mortalities in contact toxicity and feeding bioassays were observed with *Nicotiana tabacum* and *Lippia javanica* extracts [22]. Botanical pesticides are favored for their availability, low cost, safety, and environmental friendliness [24]

### Chemical method

The timing of chemical application is essential for effective fall armyworm management. To maximize pesticide use, it is necessary to understand the lifecycle of the pest, as spraying is ineffective when larvae are deeply embedded inside maize ears and whorls, or when applied during the day, as larvae primarily feed at night, dawn or dusk [10]. Several insecticides belonging to different chemical groups, including Methomyl, Pyrethroids, Cyfluthrin, and organophosphates like Methyl parathion, are recommended for FAW control. High larval mortality (>90%) has been reported with spinosad, chlorantraniliprole, flubendiamide, and spinetoram, in comparison with conventional insecticides like lambda-cyhalothrin and novaluron [6]. Chemical control methods provide higher and faster pest suppression but pose significant risks such as residual toxicity to human beings and the environment and also cause harm to beneficial insects. Monomehypo exhibited the maximum control (36%) followed by chlorpyrifos (29%), lambdacyhalothrin (26%), carbofuran (18%) and the lowest by emamectin benzoate (10%) (2). Furthermore, accumulation of frass may reduce the penetration of insecticides, limiting their efficacy, which is why chemical control is considered costly and less economical and is usually reserved for sever infestations [10]. Despite their efficacy, indiscriminate use of insecticides without threshold monitoring can lead to resistance and environmental hazards [31].

| SN | Common name of Pesticide | Recommended dose | Application method |
|---|---|---|---|
| 1 | Imidaclorprid 48% FS | 4 ml per kg of seed | Seed treatment |
| 2 | Azadiractin 1500 ppm | 5 ml per lit of water | Foliar spray against early stage |
| | Spinetoram 11.7% SC | 1 ml per 2 lit of water | Foliar spray |
| | Emamectin benzoate 5% SG | 1 ml per 2.5 lit of water | Foliar spray |
| | Chlorantraniliprole 18.5% SC | 1 ml per 2.5 lit of water | Foliar spray |
| | Spinodad 45% SC | 1 ml per 3 lit of water | Foliar spray |

Source: [27].

Several biochemical mechanisms may contribute to the evolution of insecticide resistance. Resistance has been reported in the following groups: Carbamates (1A), Organophosphates (1B), Pyrethroids (3), Bt's (11A) [18].

### Challenges and future prospective

Resistance management remains a significant challenge in fall armyworm control primarily resulting from the over-reliance and misuse on chemical pesticides and insecticides. This accelerates the development of resistance in FAW populations. Integrated resistance management strategies that rotate insecticides and incorporate biological and cultural control measures are essential in delaying the development of resistance [4]. The spread and effects of Fall army worm are significantly impacted by climate change. The varying temperature and precipitation patterns influence FAW migration, abundance, and outbreak timing, frequently resulting in increased generations per season and higher infestation risks. In order to mitigate these effects adaptation through climate-smart agricultural practices and early warning systems is required There still exist research gaps in understanding the ecology of FAW in new environments, development of resistant crop varieties that are adapted locally, validating effective biological control agents, and development of reliable integrated pest management (IPM) models for different agro-ecological zones. There is also a need for development and field validation of biopesticides and digital pest monitoring tools. For effectively coordinated FAW management, policy support and extension services are indispensable. It is essential to have strong policies that support funding for research, safer biopesticide registration and adoption, and extension programs that educate farmers. Extension services should prioritize capacity building, encouraging the adoption of IPM, and providing timely advisories for pest monitoring and control [4,26].

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