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The fall armyworm, *Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae)* on maize: A review

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Abstract
The Fall Armyworm (*Spodoptera frugiperda*) has spread rapidly and has a significant impact on maize/corn production in several parts of the world. The pest was discovered in India in 2018 and has since become a significant risk to maize/corn cultivation, resulting in severe economic losses. This review aims to assess the status of Fall Armyworm in India, focusing on its biology and behaviour, impact on maize crops, management strategies, and ongoing research efforts. Despite various control actions being implemented, the pest continues to pose challenges for both farmers and researchers. The review concludes with a discussion of how to manage invasive pests with integrated pest management (IPM) strategies and future directions.

Keywords: Fall armyworm**,** maize, management strategies, biology and behaviour

Introduction

Maize/corn (*Zea mays* L.), the third most significant grain and nicknamed the "Queen of Cereals," has the greatest genomic yield potential. The traditional use of maize is for food, feed, and fodder. During summer seasons (Paudyal KR, Poudel SK, 2001) [20], it is commonly grown in a single crop. India cultivates around 9-10 million acres of maize every year. India's annual maize production is approximately 28-30 million metric tons. The demand for maize crops is increasing every year because of its nutritional benefits. The Fall armyworm, *Spodoptera frugiperda* is a main reason for maize yield losses ranging from 20-50% (Annual Report, 2023) [1].

The Fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) infects maize/corn plants at all stages of development, from sowing to tasseling, producing defoliation, killing the young plant, resultant in grain loss, & reducing yield quality and quantity (Chimweta *et al*., 2019) [5]. The FAW is a polyphagous insect pest native to subtropical and tropical regions of America (FAO, 2017) [9]. The preliminary report came from southern states Karnataka, Tamil Nadu, and Andhra Pradesh in 2018, and it quickly spread to other maize-growing regions in India. The first invasion of this pest in India was found on maize/corn crops in Karnataka between May and June 2018 (Sharansabasappa *et al*., 2018). The FAW's preference for maize was higher than those of additional crops (Prasanna BM *et al*., 2018) [21]. Young maize/corn plants with heights of 30 to 60 cm. are ideal by gravid females of FAW for oviposition. The small caterpillars eat on the leaves of young corn/maize plants (Belay D, 2011) [3]. The larvae of FAW could attack maize/corn plants during reproductive or flowering or vegetative phases. It could also bore into the maize/corn ears, cobs, and stems (Dhar T, *et al*. 2019) [8]. Its ability to rapidly develop resistance to chemical pesticides, coupled with the challenge of timely pest detection, makes its management a critical issue for Indian agriculture.

Current status of fall armyworm in India

Fall Armyworm (FAW) native to the tropical regions of South and North America (Clark PL, 2007) [7]. It was observed for the first time in the African continent in early 2016. Initial reports were from West Africa: Nigeria, Togo, Benin and Sao Tome' and Principe (IIPC, 2016 and IITA, 2016) [14]. By May 2017 the pest has been observed in almost all Sub-Saharan African countries. In 2019 pest have been reached diverse new boundaries *viz*., Myanmar, Bangladesh, Sri Lanka, Thailand, Lao, Nepal, China, Viet Nam and, more recently, in the Republic of Korea in Asia (FAO, 2019) [10].

Fall Armyworm (FAW) continues to breakout into new territory, moving further north and east in India. Severe occurrences of fall armyworm were observed from across diverse Indian states. In India, it was first recorded in mid-May 2018 in Shivamogga, Karnataka by (Sharanabasappa *et al*. 2018) [24]. The FAW was observed at maize/corn crop fields in Ranga Reddy, Nalgonda, and Warangal, erstwhile districts of Telangana state, India during the 2021–2022 Rabi and Kharif seasons by (Mallesh, Modala, *et al*. 2023) [17]. Till now, FAW is observed from Telangana, Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu, Gujarat. Massive investigations on war footing are undergoing.

Biology and behavior of fall armyworm

The Fall Armyworm has a distinct lifecycle with several developmental stages: egg, larva, pupa, and adult. The adult moth is nocturnal and migratory, with females laying eggs on the undersides of maize leaves. The larvae are the primary damaging stage, feeding on both the leaves and the developing ears of maize. The pest exhibits high reproductive potential, with a single female capable of laying up to 1,000 eggs in her lifetime. The larvae undergo six instars, with the first three being the most destructive as they feed on the plant tissue, resulting in defoliation, ear damage, and, in severe cases, plant death. P Aarthi Helen *et al*. 2021 [22] were investigated to know biology of FAW on maize/corn under laboratory conditions (650 C and 25 %

RH). The mean life span of male and female moths was 36.2 and 38.2 days, respectively. Fecundity ranged between 957 and 1289 eggs per female. 96 percent of eggs hatched on average. Mean egg hatching was 96 percent. Three to four days was the range of the incubation period. The Larval period ranged from 16-18 days, wherein first, second, third, fourth, fifth, and sixth instars were 2.8, 2.5, 2.1, 2.2, 2.6, and 4.4 days, respectively. Pupal period varied from 8 to 12 days. The longevity of males and females varied from 11 to 13 and 10 to 11 days, respectively.

Li, Y.-P *et al*. 2023 [16] observed FAW behaviour in corn fields in China, larval dispersal is an important life strategy that impacts FAW population spreading in maize/corn fields and subsequent plant damage. Cheng, Y *et al*. 2024 [4] explored the feeding behavior, plant part favorites, and damage symptoms of FAW larvae on peanuts also throughout the larval period, considering changes in population densities and the passage of time over the number of investigations. The results Cheng, Y *et al*. 2024 [4] showed that FAW larvae often inhabited peanut leaves, mainly the undersides of the leaves. Larvae moved from the leaves to the soil in the seedling pot to complete development. Furthermore, FAW larvae tended to feed on peanut leaves rather than stems regardless of population densities. Recent studies on the behavior of the fall armyworm (*Spodoptera frugiperda*) in maize fields in India highlight significant insights into its lifecycle and patterns. In Tamil Nadu, dedicated research plots were established to observe its behaviors such as egg-laying, larval development, and flight activity. Data revealed that FAW infestation often begins at the seedling stage, peaking during the vegetative and reproductive growth phases of maize. This pattern aligns with broader observations that indicate higher pest populations during warm, dry conditions, contributing to rapid proliferation. Seasonal studies in 2019-20 noted minimal damage at the season's onset, with infestations increasing until the crops matured. Additionally, observations showed that late-planted maize fields tend to suffer more severe attacks compared to those sown early. The pest's lifecycle and its correlation with crop phenology suggest that managing planting schedules and environmental monitoring are critical to mitigating FAW impact in maize cultivation.

Impact of fall armyworm on maize production

The economic impact of Fall Armyworm on maize production in India has been substantial. Maize is one of India's key food and fodder crops, with an estimated production of around 30 million tonnes annually. Fall Armyworm has caused a significant decline in yields, with reports of losses ranging from 20% to 80% in severely affected areas. In some cases, entire maize fields have been rendered unharvestable. Baudron *et al*. (2019) [2] have reported that maize infestation was found to be 26.4 and 55.9% with an impact on yield of 11.57%. Other authors have reported leaf, silk, and tassel damage levels ranging between 25 and 50%, and grain yield has decreased to 58% (Chimweta *et al*., 2019) [5].

The pest's feeding damage results in reduced photosynthesis, stunted growth, and compromised grain fill. Infestation is particularly devastating during the early stages of maize development and during flowering when ear damage occurs. The economic strain on farmers has been exacerbated by rising pest management costs, particularly with the extensive use of chemical pesticides.

Management strategies

Various management strategies have been employed to combat Fall Armyworm infestations in India, including chemical, biological, cultural, and genetic approaches.

Chemical Control: In the initial stages of infestation, farmers have relied heavily on chemical pesticides, particularly broad-spectrum insecticides. However, the efficacy of chemical control has diminished over time, as *S. frugiperda* has developed resistance to several classes of insecticides. This has led to an over-reliance on pesticide applications, with concerns over environmental contamination and pesticide residues in food. In India, there is currently no licensed pesticide to combat FAW; nevertheless, monocrotophos and chloropyriphos are advised for early-season lepidopteran insects such as shoot borer (Ramasubramanian and Srikanth, 2015). [23]

Biological Control: Biological control agents, including natural predators and parasitoids (e.g., *Trichogramma* spp., *Telenomus* spp.), have shown promise in controlling Fall Armyworm populations. The FAW also controlled by few coccinellid predators (Mallesh M *et al*. 2023) [18]. Additionally, microbial biopesticides such as *Bacillus thuringiensis* (Bt) have been explored as an alternative to chemical control. Earlier application of neem oil/azadirachtin can prevent oviposition and early larval feeding (ICAR-ADVSIORY, 2018) [11]. These agents target the larvae and are considered more environmentally sustainable.

Cultural Control: Cultural practices such as crop rotation, intercropping, and planting pest-resistant maize varieties have been advocated to reduce the risk of Fall Armyworm outbreaks. Timely planting, proper spacing, and removal of infected plant material are also part of cultural control measures track and limit the spread of FAW (Padhee, 2019) [19]. Seedlings introduced for planting should be examined for the presence of FAW and treated with insecticide (ICAR-SBI, 2018) [12]. If the seedlings originate from a FAW prone area, prophylactic or quarantine treatment may be resorted to (ICAR-ADVSIORY, 2018) [13]. Clean cultivation should be practiced, as it can survive on grasses. Intercropping with pulses reduces incidence and attack of FAW, as enhanced biodiversity enhances natural populations (ICAR-NBAIR 2018b).

Genetic Resistance: The development of genetically modified (GM) maize varieties with built-in resistance to Fall Armyworm has been a key area of research. Bt maize, which expresses a protein toxic to *S. frugiperda*, has been successfully developed and adopted in many countries. However, the commercial availability of Bt maize in India is still limited, and regulatory challenges remain.

Integrated Pest Management (IPM): An IPM approach, which combines chemical, biological, and cultural control methods, is widely recommended as the most effective and sustainable way to manage Fall Armyworm. Farmers are encouraged to use pheromone traps for early detection, monitor pest populations, and apply treatments in a targeted manner. IPM modules have been formulated for the pest management and evaluated during Rabi and Kharif 2019 in the farmers field comparing with the farmers practice (Non

IPM). During the on-farm trials conducted by KVK, Srikakulam, it was resulted that pest occurrence was 11-12% in IPM plots in Kharif and 4-5% during Rabi. Whereas, the pest occurrence was 30-32% in Kharif and 16-17% during Rabi in non IPM followed fields. There was 8-10% yield increase recorded and incremental cost benefit ratio was 1: 5.2 (Chitti Babu G *et al*. 2020) [6].

Ongoing research and future directions

Ongoing research on Fall Armyworm in India focuses on understanding its biology, ecology, and behavior, as well as developing sustainable control methods. Key areas of research include:

Pest Resistance Monitoring: Given the growing concern about resistance to chemical pesticides, researchers are investigating the mechanisms behind resistance and exploring new insecticides with different modes of action.

Biopesticide Development: There is a growing interest in developing environmentally friendly biopesticides, including entomopathogenic fungi, bacteria, and natural predators, which could help reduce dependence on chemical pesticides.

Climate Change and Pest Behavior: Studies are exploring the impact of climate change on the spread and intensity of Fall Armyworm infestations. Rising temperatures and changing rainfall patterns could potentially exacerbate pest outbreaks.

Farmer Education and Extension Services: Increasing awareness and providing farmers with accurate, timely information about pest monitoring and management is crucial. Extension services play a key role in disseminating knowledge about IPM practices and the judicious use of pesticides.

Conclusion

The Fall Armyworm has developed as a major threat to maize production in India, causing significant economic losses and posing challenges to farmers and researchers alike. Despite the various management strategies in place, including chemical, biological, and cultural controls, the pest continues to be a serious problem. Integrated Pest Management (IPM) offers the most promising approach to control, as it combines multiple methods to manage the pest sustainably. Ongoing research into pest biology, resistance mechanisms, and alternative control methods will be crucial in the long-term management of Fall Armyworm in India. Furthermore, the involvement of farmers, extension services, and policymakers will be key in implementing effective control measures at the ground level.

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