Environment and Ecology 42 (2B) : 780—789, April—June 2024
Article DOI: https://doi.org/10.60151/envec/NDRG4974
ISSN 0970-0420

Spodoptera frugiperda (JE Smith) in India: Pervasiveness, Host Range, and Management

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Received 15 September 2023, Accepted 16 March 2024, Published on 3 June 2024

ABSTRACT

The Fall Army Worm (FAW), scientifically referred to as *Spodoptera frugiperda*, originally emerged in the tropical and subtropical regions of the Americas. Its migration to Africa in 2016 and subsequent spread to Asia, reaching India in May 2018, raised significant concerns about the adaptable pest's expansion. Karnataka was the first state in India to report FAW, and by 2018 and early 2019, it had spread throughout peninsular India and the North and North East regions. This highly resilient insect has the ability to infest over 100 different plant species, making it a formidable pest. FAW has two dominant strains: The corn strain 'C,' affecting maize, sorghum, and cotton, and the rice strain 'R,' affecting rice and other grasses. The damage caused by FAW varies, posing a substantial threat to agriculture. The use of Integrated Pest Management (IPM) strategies has been shown to be effective in controlling FAW. Bio-rational pesticides, including *Metarrhizium rileyi* and *Nomuraea rileyi*, along with parasitoids like *Telenomus* sp., *Trichogramma* sp., *Glyptapanteles creatonoti*, and *Campoletis chloridae*, play a crucial role in managing the pest. Semiochemicals such as (Z)-9-tetradecenyl acetate and habitat management methods like Push-Pull technology also contribute to successful control. Chemical insecticides like chlorantraniliprole, spinetoram, thiamethoxam, and lambda cyhalothrin can be utilized to combat FAW. However, it is essential to note that early larval chemical control is more effective than late-stage intervention. The goal of this report is to emphasize the prevalence of FAW and to demonstrate the effective management techniques that have been used to minimize its effects.

Keywords Fall Armyworm, Distribution, Host preference, Integrated pest management.

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INTRODUCTION

Spodoptera frugiperda, commonly known as the Fall Army Worm (FAW), is a significant agricultural pest originating from tropical and subtropical America (FAO 2019). It poses a substantial threat to maize and other crops within the Gramineae family (Andrews 1980). In 2016, the species migrated across

continents, reaching Africa (Keerthi *et al.* 2023). Its remarkable adaptability allowed it to successfully invade Asia, making notable appearances in India in May 2018 (Sharanabasappa *et al.* 2018). The rapid proliferation of this pest, initially identified in Karnataka, has now extended to the northern and north-eastern regions of India, indicating its unwavering expansion. Moreover, the Fall Army Worm has been noted in Myanmar, Thailand, and several other Asian nations, resulting in notable harm to maize crops. In January 2019, the Fall Army Worm had penetrated Yunnan province in China and quickly disseminated throughout various provinces known for maize production within just ten months. This rapid spread presented a significant menace to China's agricultural sector and food production systems. It is imperative to tackle the difficulties presented by this invasive pest to protect worldwide food security and ensure the sustainability of agriculture.

The Fall Army Worm, aptly named for its tendency to march through fields, possesses the capability to infest a diverse range of plants, affecting over 100 different species. The larvae of *Spodoptera frugiperda* exhibit a particular attraction to plants within the Poaceae or Graminae family, earning them the moniker "Pest of cereals." They are frequently present on cultivated grasses like maize, sorghum, sugarcane, and rice (CABI 2018). In addition to its broad host range, this species is known for its adaptability to diverse habitats, high reproductive rate, and resistance to conventional pesticides. The Fall Army Worm has evolved into a super pest, with two dominant strains, 'C' and 'R.' The corn strain 'C' influences maize, sorghum, and cotton, whereas the rice strain 'R' specifically targets rice and other grasses (Pogue 2002). The consequences of the Fall Army Worm on maize have been thoroughly documented. Baudron *et al.* (2019) noted a range of yield losses from 26.4 to 55.9 percent due to the Fall Army Worm. Furthermore, damage to maize affects the leaf, silk, and tassel, with levels reaching 25 to 50%, leading to a notable grain yield loss of up to 58%, as reported by Chimweta *et al.* (2019). These findings emphasize the considerable risk posed by the Fall Army Worm to agricultural crops, especially maize.

The international concern about FAW stems from its potential to threaten the food security and livelihoods of numerous small-scale farmers in Asia and India. This essay aims to delve into the distribution in India, the variety of hosts impacted, and the implementation of effective management strategies to mitigate the threats posed by this relentless pest.

Distribution status of Fall Armyworm

Global distribution

The Fall Armyworm (FAW) poses a notable threat to agricultural crops on a global scale, having extended its reach from the Americas to Africa, Asia, and Europe. There is particular concern among pest management professionals about its adverse effects on African maize crops. Scientifically identified as *Spodoptera frugiperda*, the Fall Armyworm (FAW) was initially detected in western Africa in January 2016 (Goergen *et al*. 2016). By January 2018, it had invaded almost 40 African nations, reflecting a marked expansion of its range.

The initial detection of FAW was reported in Karnataka, a southern state of India, in May 2018, and it rapidly disseminated to maize-producing states across the country (Table 1) (Sharanabasappa *et al.* 2018, Shylesha *et al*. 2018, Suby *et al.* 2020). Moreover, instances of FAW outbreaks have been documented in various other nations, such as Thailand, Yemen, Bangladesh, Myanmar, and China (Yee *et al*. 2019).

In 2019, researchers from Sri Lanka (Perera *et al.* 2019), Nepal (Bajracharya *et al.* 2019), the Philippines (Navasero *et al.* 2019), Vietnam (Hang *et al.* 2020) and Indonesia (Trisyono *et al.* 2019) documented incidents of Fall Armyworm (FAW) invasions. The FAW's impact was not limited to Asia, as it also spread to Oceania, as demonstrated by studies conducted by Ma *et al.* (2019), Prasanna *et al.* (2021), and Tambo *et al.* (2023). In 2020, FAW outbreaks were reported in several countries, including Australia, South Korea, Cambodia, Papua New Guinea, New Caledonia, Jordan, Syria, and the UAE, emphasizing the need for comprehensive strategies to manage and mitigate the consequences of this destructive pest.

Table 1. Fall Armyworm infestation in Indian states.

Name of the states	Year of introduction	Host crop	References
Karnataka	2018	Maize	Sharanabasappa *et al.* 2018
Tamil Nadu Telengana Andhra Pradesh West Bengal	2018	Maize	Bhosale 2018
Maharashtra	2018	Sugarcane, Maize	Chormule *et al.* 2019
Gujarat	2018	Maize	Sisodia et al. (2018)
Bihar	2018	Maize	Sarfaraz *et al*. (2018)
Madhya Pradesh	2019	Maize	Vishwakarma *et al.* (2020)
Mizoram	2019	Maize	Sarma *et al*. 2023
Nagaland, Tripura, Manipur, Meghalaya	2019	Maize	
Rajasthan	2019	Maize	Babu *et al*. 2019
Goa	2019	Fodder Maize	Maruthadurai and Ramesh 2019
Odisha	2019	Maize	Kerketta *et al.*2020
Kerala	2020	Banana	Ragesh and Balan 2020
Himachal Pradesh	2020	Maize	Sharma 2021
Assam	2020	Maize	Sarma *et al*. 2023
Uttarakhand	2020	Maize	Paschapur *et al.* (2021)

Distribution status in India

In 2018, the southern Indian state of Karnataka experienced the emergence of *Spodoptera frugiperda* (JE Smith) (Sharanabasappa *et al.* 2018). The extent of this pest's presence in Karnataka was discovered to fluctuate considerably, with percentages spanning from 9.0% to 62.5% according to a study conducted by Shylesha *et al.* (2018). In multiple Indian states, such as Tamil Nadu, Telangana, Andhra Pradesh, Maharashtra, and West Bengal, the pest was identified in both maize and sugarcane crops over a period of five months (Bhosale 2018). In 2018, Tamil Nadu was the first Indian state to report the presence of FAW in sugarcane (Srikanth *et al.* 2018). This pest was subsequently detected for the first time in Maharashtra on sugarcane in September of that same year (Chormule *et al.* 2019). In Gujarat, Sisodia *et al.* (2018) documented FAW on maize, while Ali *et al.* (2018) discovered its presence in multiple locations across Bihar's Magadh region during a study conducted between September and November 2018.

A study conducted by Vishwakarma and colleagues in 2019 revealed the existence of FAW in maize crops in Madhya Pradesh. Specifically, on March 3, 2019, FAW was identified in Ngasih, a location in the Lunglei district of south Mizoram, where it damaged several maize cultivations. By May 2020, FAW had spread to maize crops in several states, including Nagaland, Tripura, Manipur, and Meghalaya, as reported by Naganna *et al.* (2020). In April, Babu *et al.* (2019) reported the initial presence of FAW in Southern Rajasthan. Additionally, Maruthadurai and Ramesh's research in the same year revealed FAW in fodder maize in North Goa for the first time. In, Kerketta *et al.* (2020) noted the detection of FAW in *rabi* maize in Koraput, Odisha, where it displayed significant prevalence.

In the Indian state of Kerala, an orchard consisting of 5,000 banana plants experienced a 20% infestation of Fall Armyworm (FAW), as reported by Ragesh and Balan (2020). FAW was first detected in Himachal Pradesh during the 2020 *kharif* season, causing damage to a maize crop in Una with a reported damage percentage of 47.29%, according to Sharma and Sharma (2020). In the Biswanath district of Assam, FAW was first detected in 2020-2021 and infested maize crops at levels ranging from 15.2% to 64.3%, as Sarma *et al.* (2023) reported.

During the *kharif* season of 2020 in the Himalayan region of Uttarakhand, a report of FAW was made for the first time. The pest rapidly expanded from the foothills and reached an altitude of 2174 meters, where maize was grown. The extent of the pest infestation varied between 15% in Nainital (Majhera) and 60% in Almora, Bageshwar, and Dehradun (Paschapur *et al.* 2021).

The initial discovery of FAW infestation in Gujarat's finger millet crop took place in October 2020, resulting in damage levels ranging from 26.22% to 46.82% (Damasia *et al.* 2020). According to Krishnarao *et al.* (2021), Telangana had the highest incidence of infestation, followed by Andhra Pradesh and Odisha.

Host preference

The Fall Armyworm is widely recognized as a polyphagous pest due to its tendency to feed on a broad

spectrum of plant species, including more than 300 distinct types, as per scientific investigation. Two main types of Fall Armyworm have been identified: The corn strain "C," which affects maize, sorghum, and cotton, and the rice strain "R," which targets rice and other grasses, resulting in varying degrees of destruction. The feeding habits of this pest are quite comprehensive and have a significant impact on plant growth at all stages, particularly focusing on the whorl of young plants that are up to 45 days old. This makes it a significant global pest for maize, as reported by Montezano *et al.* (2018), who also noted damage to crops belonging to the Poaceae, Asteraceae, and Fabaceae families.

FAW displays a diverse array of preferred host plants, which includes a range of significant cereal crops such as maize, rice, sorghum, wheat, and millet, as well as all leguminous crops (Fabaceae), as reported by Gahatraj *et al.* (2020). Furthermore, FAW has also been observed to feed on peanuts and Bermuda grass, as noted by Sparks (1979).

According to Bortolotto *et al.* (2014), in countries with tropical climates and the practice of multiple cropping systems, such as India, polyphagous pests like FAW exhibit a notable ability to adapt swiftly to new agro-ecosystems . In these areas, the "green bridge effect" enables pests to continue thriving even when their preferred hosts are not present, causing frequent pest outbreaks across a wide range of agricultural and climatic conditions (Kennedy and Storer 2000, Pedigo 2002, Saeed *et al.* 2017). This phenomenon has the potential to elevate secondary polyphagous pests to the status of "key pests," a term used to describe pests that can have substantial economic implications (Pedigo 2002). In such situations, pests that were initially of lesser concern or considered secondary in importance can become major threats to crops and agricultural systems, leading to increased economic losses and challenges for pest management.

In India, Fall Armyworm has been reported to impact a range of crops, including maize, sugarcane, paddy, ginger, bajra, sorghum, cotton, Johnson grass, sunflower, banana, fodder grass, and grain amaranth (Sharanabasappa *et al.* 2018, Srikanth *et al.* 2018, Chormule *et al.* 2019, Ali *et al.* 2018, Shankar and Adachi 2019, Venkateswarlu *et al*. 2018, Bharadwaj *et al.* 2020, Ragesh and Balan 2020, Maruthadurai and Ramesh 2019).The research conducted by Bharadwaj *et al.* (2020) uncovered that maize was the crop most severely impacted in five regions of Maharashtra, with bajra, cotton, sunflower, and Johnson grass experiencing sporadic damage.

Management strategies of Fall Armyworm

Biological control

Given the fact that Fall Armyworms are naturally gregarious, identifying infestations early is essential to avoid crop losses. To minimize the risk of damage, it is suggested that appropriate management measures be put in place if even a small number of seedlings show signs of injury or if a significant portion of the small plant whorls are infested with Fall Armyworms within 30 days of planting, as suggested by Fernandes *et al.* (2012). Dealing with FAW in the early stages of infestation is more effective than attempting to manage them in the later stages, when they become more resistant to control measures and can cause more extensive damage. Combining pest management practices is an efficient and sustainable way to address the challenges posed by the FAW.

Biological control methods can serve as a cost-effective alternative for farmers who may face financial constraints and are unable to invest in chemical insecticides or expensive seeds. Research has indicated that microbial formulations, derived from pathogens and natural enemies of arthropods, prove to be effective in agricultural systems and boast lower production costs, especially as they are predominantly produced in a liquid medium (Mahmoud 2016, Kenis *et al.* 2022).

The consistent employment of artificial pesticides in agricultural settings presents several potential hazards, including the possibility of harming human health and the environment, rising input expenses, and the emergence of resistance and resurgence. Moreover, the larvae of the FAW, hidden within leaf curls and corn ears, can render pest control efforts ineffective. Nevertheless, given the nocturnal feeding habits of FAW, occurring mainly during the night or at dawn and twilight, biological control strategies

can still be implemented to manage the pest. This approach avoids exacerbating environmental and health risks associated with synthetic pesticides.

Bio-rational pesticides

Biological agents, including bacteria, viruses, fungi, and nematodes, have demonstrated potential in reducing Fall Armyworm (FAW) populations. Among these, the Multiple Nucleopolyhedrosis Virus (SfMNPV) has been highlighted in studies (Garcia *et al.* 2011, Gomez *et al.* 2013, Komivi *et al* 2019). *Metarrhizium rileyi* has demonstrated the capability to induce larval mortality, with rates ranging from 1.87% to 18.30% in Karnataka (Mallapur *et al.* 2018). Additionally, the entomopathogenic fungus *Nomuraea rileyii* was reported to cause a larval infection rate of 10-15% in 2019 (Sharanabasappa *et al.* 2019). FAW is more vulnerable to *Bt aizawai* and *Bt thuringiensis* than *Bt kurstaki*, which is typically effective against a range of lepidopteran pests. This range of biological control options highlights the diverse mechanisms available for managing Fall Armyworm infestations, as illustrated in Fig. 1.

Predator and parasitoids

Natural enemies, including predators and parasitoids, play a key role in regulating Fall Armyworm (FAW) populations. In a study conducted by Molina Ochoa *et al.* (2003), several parasitoids from 14 different families, such as 9 Hymenoptera and 4 Diptera, were identified as parasitizing FAW. Additionally, intercropping has been acknowledged as a technique to enhance the growth and effectiveness of natural enemies in controlling FAW (FAO 2017).

According to Sharanabasappa *et al.* (2019), specific instances have shown that larval parasitoids and predators, including *Coccygidium melleum, Eriborus* sp., and *Exorista sorbillans*, are effective against Fall Armyworm (FAW). Additionally, egg parasitoids such as *Telenomus* sp., *Trichogramma* sp., *Glyptapanteles creatonoti,* and *Campoletis chloridae* have evolved in

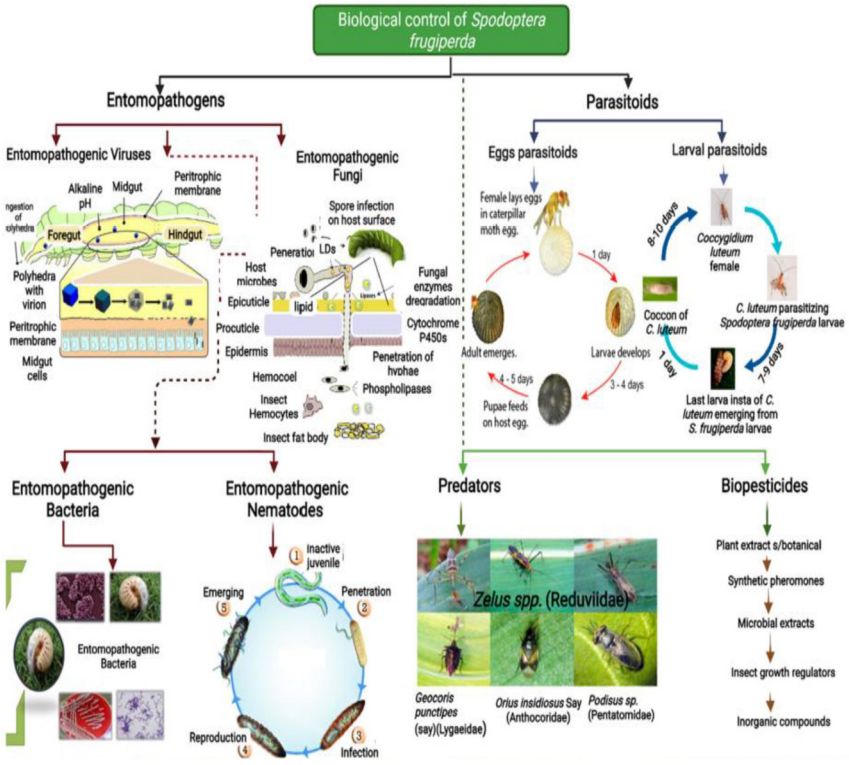

Fig. 1. Biological Control classification for *S. frugiperda* (Abbas *et a*l.,2022)

Table 2. Predators and parasitoids of *Spodoptera frugiperda* within the Indian ecosystem.

Sl. No.	Scientific name	Family	Host stage	References
1	*Telenomus* sp.	Hymenoptera: Platygastridae	Egg parasitoid	
2	*Trichogramma* sp	Hymenoptera: Trichogrammatidae	Egg parasitoid	Shylesha *et al*. (2018)
3	*Glyptapanteles creatonoti* (Viereck)	Hymenoptrea: Braconidae	Larval parasitoid	
4	*Coccygidium melleum* (Roman)	Hymenoptera: Braconidae	Endo larval parasitoid	
5	*Campoletis chlorideae* Uchida	Hymenoptera: Ichneumonidae	Endo larval parasitoid	Sharanabasappa *et al*. (2019)
6	*Eriborus* sp	Hymenoptera: Ichneumonidae	Endo larval parasitoid	
7	*Odontepyris* sp.	Hymenoptera: Bethylidae	Larval parasitoid	
8	*Exoristasorbillans* (Wiedemann)	Diptera: Tachinidae	Endo larval parasitoid	
9	*Forficula* sp.	Dermaptera: Forficulidae	Predator	
10	*Harmonia octomaculata* (Fabricius)	Coleoptera: Coccinellidae	Predator	
11	*Coccinella transversalis* Fabricius	Coleoptera: Coccinellidae	Predator	

response to FAW, as documented by Shylesha *et al.* (2018). Moreover, FAW larvae can produce isolated endo-parasitoids like *Cotesia marginiventris* and *Chelonus insularis*, as per Robert (2019). *Chelonus* sp., which acts as a primary egg and larval parasitoid, has been found to contribute to the control of FAW populations. Prior to the emergence of the Fall Armyworm (FAW) in maize ecosystems, several predators, such as pentatomid bugs, spiders, predatory wasps, ladybird beetles, mirid bugs, earwigs, and rove beetles, were frequently observed (ICAR-NBAIR 2019). These natural enemies contribute to the ecological balance and management of FAW populations. Some of these natural enemies found in the Indian ecosystem are listed in Table 2. Figure 1 depicts the mechanism of a parasitoid attacking a pest.

Botanical control

Various plant species, including *Phytolacca dodecandra, Azadirachta indica, Milletia ferruginea, Croton macrostachyus, Jatropha curcas, Nicotiana tabacum,* and *Chrysanthemum cinerariaefolium,* have been utilized for the control of insect pests. Research conducted by Silva *et al.* (2015) revealed that the extract from *Azadirachta indica* (neem) seed cake elevated the mortality rate of Fall Armyworm (FAW) larvae. In a different investigation, Martinez *et al.* (2017) uncovered that the ethanolic extract taken from *Argemone ochroleuca* (Papaveraceae) decreased the feeding and larval growth of FAW larvae, which ultimately resulted in their demise. Although numerous plants exhibit insecticidal properties against FAW, only a few have been commercialized. In North America, azadirachtin and pyrethrins are among the most commonly utilized botanicals for pest control. Numerous products containing rotenone, garlic, nicotine, ryania, quassia, and various other natural extracts have received global approval (Isman 1997). A study conducted by Viana and Prates (2003) demonstrated that the mortality rate in *S. frugiperda* caterpillars increased from 5% after three days of feeding to 10% by the tenth day.

Semio-chemicals

Pheromone traps are frequently employed to capture and monitor the FAW in substantial quantities. These traps rely on pheromones to disrupt mating and attract moths for mass trapping and pest monitoring. Studies conducted by Malo *et al.* (2004) and Batista-Pereira *et al.* (2006) have demonstrated the effectiveness of pheromones in tracking male Fall Armyworm (FAW) populations on a global scale.

The primary components of the sex pheromone produced by female Fall Armyworms primarily consist of (Z)-9-tetradecenyl acetate (Z9-14:OAc), along with two minor components. This primary component has also been detected in Indian moths. Employing FAW pheromones for mass trapping and monitoring is suggested. However, it's crucial to recognize that these pheromone lures only remain effective for 20–30 days, necessitating frequent replacement, which increases both cost and labor.

Agro-ecological approach

According to Harrison *et al.* (2019), the control of

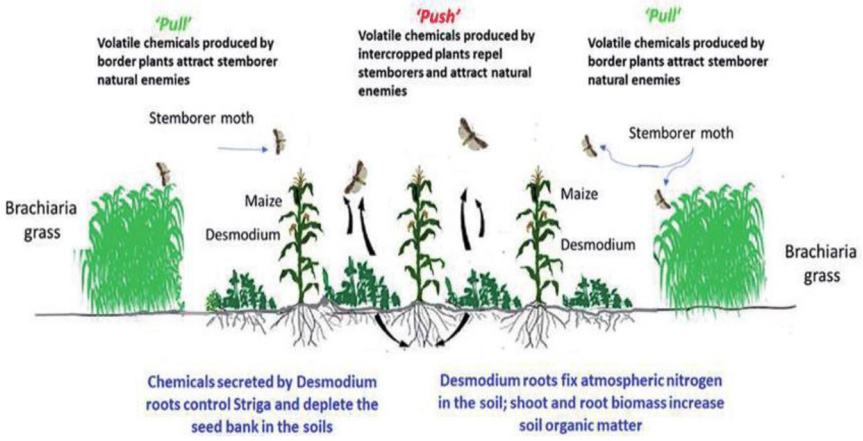

Fig. 2. Push-pull technology: Intercropping maize with repellent green leaf Desmodium and Brachiaria grass as border crops (Otim *et al.* 2021).

FAW using agroecological methods emphasizes biodiversity, soil fertility management, and targeted strategies to prevent or reduce outbreaks. One such approach is intercropping, which increases plant diversity in the field, making it difficult for FAW to locate host plants such as maize. Intercropping utilizes the "push-pull mechanism," which employs pest-repellent plants to push FAW away from maize and pull them away from the crop, thereby hindering or delaying oviposition.

Desmodium intortum (Mill) operates as a push intercrop and trap plant, while *Brachiaria* serves as a pull crop, encircling the intercropped region, as illustrated in Fig. 2. As per reports, this approach has led to an 82.7% reduction in larvae per plant and an 86.7% decrease in plant damage per plot (Midega *et al.* 2018). Furthermore, research has shown that intercropping with *Tephrosia* and *Desmodium* can decrease the egg production of FAW on maize (Harrison *et al*. 2019).

Adapting intercropping techniques to suit the unique agro-ecological and climatic conditions in India could be a sustainable solution for smallholder farmers, offering effective measures to combat FAW.

Chemical control

In the context of managing FAW, chemical control is often the primary method employed when pest populations exceed an acceptable level. To ensure effective FAW management, continuous monitoring and targeted pesticide application are necessary. Chemical control tends to be most successful when implemented during the early stages of larval development. Research conducted by Cruz *et al.* (2012) revealed that spinosad was particularly effective in controlling FAW, resulting in a significant number of larval deaths.

Advanced insecticides, including Cholarantraniliprole, flubendiamide, and spinetoram, have shown greater effectiveness against FAW in controlled laboratory experiments, as compared to traditional options like lambda-cyhalothrin and novaluron, as reported by Hardke *et al.* (2014). To reduce the harm inflicted on maize crops by FAW, the Central Insecticide Board and Registration Committee (CIB and RC) advises using specific chemical mixtures. These include thiamethoxam 12.6% + lambda cyhalothrin 9.5% ZC at a rate of 0.25 ml/l, spinetoram 11.7% SC at 0.5 ml/l, and chlorantraniliprole 18.5% SC at 0.4 ml/l. Additionally, the Government of India has recently endorsed the use of cyantraniliprole 19.8% + thiamethoxam 19.8% FS at 6 ml/kg seed for treating Fall Armyworm (FAW) seeds. These recommendations provide guidance for farmers and pest management professionals in utilizing chemical measures to control FAW infestations.

CONCLUSION

The appearance of the FAW in India constitutes a

substantial threat to the agricultural sector, given the widespread presence of suitable host plants and favorable climatic conditions across multiple regions. These conditions have allowed the pest to flourish, potentially resulting in the production of numerous generations in a single season and leading to its establishment as an endemic species in certain regions. To address this critical issue, the Indian government has taken proactive measures to educate farming communities and implement effective management strategies.

The government's extensive initiatives to promote pest awareness and management underscore its commitment to providing farmers with the essential knowledge to confront the challenges presented by the FAW. Considering the pest's capability to infest a diverse array of crops and its potential for rapid multiplication, it is crucial for farmers to possess knowledge about various aspects of the FAW, including its behaviour, life cycle, and sustainable treatment approaches.

To develop and implement effective and sustainable strategies to manage Fall Armyworm (FAW) in India, close collaboration among agricultural experts, policymakers, and farming communities is essential. Such collaboration can help mitigate the adverse effects of FAW on agricultural produce and maintain the financial stability of rural farmers in affected areas.

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