



## Microbial Pest Management Options for Fall Armyworm, *Spodoptera frugiperda* in India

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Agricultural production in India is greatly threatened by biotic stresses such as insect pests and diseases. The recent spread of fall armyworm, *Spodoptera frugiperda* in India has emerged as a major challenge for maize. Although synthetic insecticides are widely used for its management, their excessive and repeated application can adversely affect the environment, non-target organisms and human health. Microbial control agents offer an environmentally safer, sustainable, and effective alternative for fall armyworm management. This review highlights the potential of entomopathogenic fungi, bacteria, viruses, and nematodes against *S. frugiperda* in India, with emphasis on their efficacy and application strategies for integration into pest management programmes. Despite considerable research, the availability and adoption of effective and farmer-friendly microbial formulations remain limited. Strengthening research on mass production, formulation, field validation, application technology, and regulatory support is essential for wider adoption. Integration of microbial agents with compatible management tactics can contribute to sustainable and environmentally responsible management of fall armyworm in India.

### Introduction

Maize (*Zea mays* L.) is the “Queen of Cereals”, which has a greater yield potential than other cereal crops. In 70 countries, including 53 developing nations like India, maize is produced on more than 100,000 hectares, and the number of acres sown each year is growing. India produced approximately 28.75 million tonnes of maize in 2017–18, comprising 20.12 million tonnes during the Kharif season and 8.63 million tonnes during the Rabi season. Following the detection and spread of fall armyworm, *Spodoptera frugiperda* (J.E. Smith, 1797) (Lepidoptera: Noctuidae), maize production declined to approximately 27.72 million tonnes in 2018–19, with 19.41 million tonnes produced during Kharif and 8.30 million tonnes during Rabi (Kumar et al., 2020). The entry of *S. frugiperda* during 2018-19 resulted in yield losses in maize of around a thousand metric tonnes. *S. frugiperda* is a pest that can attack more than 300 different hosts. In addition, it is said to severely affect 23 horticulture crops, including cabbage, beet, tomato, potato, and onion, in addition to cotton, pasture grasses, peanut, soybean, alfalfa, and millets, as well as economically significant cultivated grasses like rice, sorghum, and sugarcane (CABI, 2019; Pogue, 2002; Chapman et al., 2000). The destructive stage of this insect is the caterpillar. The caterpillar was seen eating on the middle (Leaf whorl) of the maize crop from 4-6 leaf stages with infestation rates of 25–30 and 30–35%, knee high stage rates of 65–70%, and tassel stage rates, respectively. After that, pupation occurs at a depth of 6-7 cm in the soil. It takes 30-35 days to successfully complete its life cycle. The dark head of the caterpillar has a white inverted "Y" mark on the front. The moth has a powerful flight and can travel more than 100 kilometres to find its host plants (Painkra, 2019).

## History of *S. frugiperda* in India

In India, Sharanabasappa et al. firstly reported it near Shivamogga, Karnataka, in mid-May 2018. Subsequently the *S. frugiperda* was reported in many other states like Telangana, Andhra Pradesh, Maharashtra, Gujarat, Tamil Nadu, Rajasthan, Chhattisgarh, and West Bengal; and caused crop losses in fields of maize and other vegetable crops. The timeline of invasion by *S. frugiperda* in different Indian states is presented in Table-1.

**Table-1: *S. frugiperda* infestation in Indian states**

| S. No. | Name of the state                              | Host plant                      | Year | Reference                          |
|--------|------------------------------------------------|---------------------------------|------|------------------------------------|
| 1      | Karnataka                                      | Maize                           | 2018 | Sharanabasappa et al., 2018        |
| 2      | Chhattisgarh                                   | Maize                           | 2018 | Deole and Paul, 2018               |
| 3      | Gujarat                                        | Sweet corn                      | 2018 | Sisodiya et al., 2018              |
| 4      | Tamil Nadu                                     | Sugarcane                       | 2018 | Srikanth et al., 2018              |
| 5      | Odisha and West Bengal                         | Maize                           | 2018 | Anonymous, 2019b                   |
| 6      | Andhra Pradesh                                 | Bajra and sorghum               | 2018 | Venkateswarlu et al., 2018         |
| 7      | Maharashtra                                    | Sugarcane                       | 2019 | et al., 2019                       |
| 8      | Telangana                                      | Maize                           | 2019 | FAO, 2019                          |
| 9      | Mizoram, Nagaland, Tripura, Manipur, Meghalaya | Maize                           | 2019 | Anonymous, 2019b                   |
| 10     | Arunachal Pradesh                              | Maize                           | 2019 | Kumar et al., 2019                 |
| 11     | Uttar Pradesh                                  | Maize                           | 2019 | Anonymous, 2019a                   |
| 12     | Assam                                          | Maize                           | 2019 | Anonymous, 2019b                   |
| 13     | Sikkim                                         | Maize                           | 2019 | Anonymous, 2019b                   |
| 14     | Rajasthan                                      | Maize                           | 2019 | Babu et al., 2019                  |
| 15     | Jharkhand                                      | Maize                           | 2019 | Raghav and Choudhary, 2021         |
| 16     | Uttarakhand                                    | Maize                           | 2019 | Maurya et al., 2019                |
| 17     | Bihar                                          | Maize                           | 2019 | Reddy et al. 2020                  |
| 18     | Madhya Pradesh                                 | Maize                           | 2020 | Vishwakarma et al., 2020           |
| 19     | Goa                                            | Fodder crops and green amaranth | 2020 | Maruthadurai and Ramesh, 2020      |
| 20     | Kerala                                         | Banana                          | 2020 | Gavas Ragesh and Sanju Balan, 2020 |
| 21     | Punjab                                         | Maize                           | 2020 | Jindal et al., 2021                |
| 22     | Haryana                                        | Maize                           | 2020 | Kumar et al., 2024                 |
| 23     | Himachal Pradesh                               | Maize                           | 2020 | Sharma, 2021                       |
| 24     | Jammu and Kashmir                              | Maize                           | 2022 | Ahad et al., 2025                  |

## Pest management options for *S. frugiperda*

For the management of the *S. frugiperda* in maize, a number of control strategies, including cultural methods, the use of chemical pesticides, and natural plant products, are popular. Because of pest pesticide resistance, cost-effectiveness, effects on natural enemies, and environmental and health problems, the use of chemical pesticides is not sustainable. As a result, it's critical to reduce the usage of pesticides and create long-term IPM techniques to control *S. frugiperda* in India for secured, environmental friendly management practises (Yu et al. 2003). In the management of pests sustainably, biological plant protection using entomopathogens is essential. When compared to chemical pesticides, entomopathogens as

biocontrol agents have several benefits. They include low cost, excellent effectiveness, safety for beneficial organisms, and reduced residues (Lacey et al, 2001).

### Available microbial control agents in India

Entomopathogenic microorganisms like bacteria, fungi, nematodes, viruses, and protozoa can cause harm to *S. frugiperda* larvae (Molina-Ochoa et al., 2003; Ríos-Velasco et al., 2010). Recently, there have been some microbial agents discovered in India that are effective against the maize fall armyworm, such as the following:

**Entomopathogens fungi-** It is required for evaluation of native strains of entomopathogenic fungi against *S. frugiperda* as an alternative to chemical pesticides. Similar to bacteria and viruses, fungal pathogens have a unique method of infection such that they can directly infect their host through the cuticle without needing to be ingested. Because of this, entomopathogenic fungus can infect insects' non-feeding stages like eggs and pupae (Anand et al., 2009, Nguyen et al, 2007). The entomopathogenic fungi have two main modes of action: first, the spores land on the insect cuticle, and second, they germinate and penetrate the cuticle by forming aspirator. The development of hyphae in the hypodermis leads to their continued growth in the blood cells and body of the insect, where they ultimately kill it (Glare and Milner, 1991). Mallapur et al. (2018) conducted a field survey and published the first report on entomopathogenic fungi, *Nomuraea rileyi*, from India during the kharif season 2018. According to the studies, *N. rileyi* infect *S. frugiperda* naturally, with infection rates ranging from 1.87 percent in Vijaypur to 18.30 percent in Dharwad district. Meanwhile, *S. frugiperda* damage to maize ranged from 12.42 percent in Uttar Kannada to 65.73 percent in Dharwad district. The results also indicated that after 15 days of spraying *N. rileyi*, the reduction in larval and leaf damage ranged from 62.50 to 66.46 and 66.84 to 73.05%, respectively. Moreover, Patel et al. (2020) discovered that laboratory tests were undertaken to assess the bio-efficacy of various strains of entomopathogenic fungi, including *Beauveria bassiana*, *Metarhizium anisopliae*, and *Nomuraea rileyi*, against the *S. frugiperda*. The strain of *M. anisopliae* at  $2 \times 10^9$  conidia/ml performed better than other entomopathogenic fungi in terms of larval mortality, killing 2<sup>nd</sup> and 3<sup>rd</sup> instar larvae with 57.56% and 50.63%, respectively. In addition, during May 2018 in Karnataka, Ramanujam et al. (2021) conducted surveys on maize infested by the *S. frugiperda* and the survey's results showed that white fungal growth infections had a negative impact on *S. frugiperda*. This fungus infected approximately 20–30% of the 4th and 5th instar larvae of the *S. frugiperda*. The fungus was identified as *Beauveria felina* after further molecular analysis using the ITS region. This is the first report of *B. felina* being found on maize pest *S. frugiperda*. Ramanujam et al. (2020) also tested entomofungal strains of *Beauveria bassiana*, *Metarhizium anisopliae*, and *Metarhizium rileyi* against *S. frugiperda* 2nd instar larvae in a lab setting. *M. anisopliae* ICAR-NBAIR Ma-35 produced the highest mortality rate of the ten strains tested (67.8%), followed by *B. bassiana* ICAR-NBAIR Bb-45 (64.3%), and ICAR-NBAIR Bb-11 (57.1%).

**Entomopathogenic bacteria-** Entomopathogenic bacteria, multiply and release poisons in the midgut lumen after being consumed by an insect with a sensitivity to them. The insect vomits, loses its appetite, develops diarrhoea, and releases watery faeces. Septicemia and the insect's mortality are caused by the bacteria's entry into the hemocoel (Kumar et al., 2020b). Patel et al. (2020) conducted a lab experiment to evaluate the *Bacillus thuringiensis* bio-efficacy against *S. frugiperda*. After tested against 2nd and 3rd instar larvae using a spore-crystal mixture, the *B. thuringiensis* strain caused larval mortality rates of 64.65% and 59.01%, respectively. Again Patel et al. (2022) conducted field trial experiment during kharif, 2019 and rabi, 2019-20 at Biological control farm, Anand Agricultural University, Anand to determine the effectiveness of various entomopathogens and microbial biopesticides against *S. frugiperda* infesting maize. The findings showed that among the tested entomopathogens, *B. thuringiensis* AAU Strain - 1% AS was the most effective in both seasons, and that treatment was comparable to *B. thuringiensis* 3.5% ES (Commercial formulation), with the lowest populations of larvae (1.11 larvae/10 plants and 1.22 larvae/10 plants), plant damage (11.47% and 13.10%), and cob damage (11.45% and 13.01%), respectively. The natural

enemies, chrysopids, coccinellids, and spiders, were found to be unaffected by any of the evaluated entomopathogens or microbial biopesticides over the experiment period.

**Entomopathogenic nematodes-** Lalramnghaki *et al.* (2021) reported that potential candidates for *S. frugiperda* biological control include entomopathogenic nematodes (EPNs). According to the findings, all isolated EPN species showed a significant rate of larvicidal and pupicidal activity against the pest. Following exposure to the EPN species, it was discovered that 3rd and 5<sup>th</sup> larval instar mortality ranged from 43.75-100.00% and 25.00-100.00%, respectively (at concentrations of 10-800 IJs/larva), while pupa mortality ranged from 37.50-68.75% (at concentrations of 200-1600 IJs/pupa). After that Patil *et al.* (2022) studied to choose virulent entomopathogenic nematode (EPN) isolates based on the laboratory testing, and to assess the efficacy of virulent isolates in the field alongside the widely used chemical insecticide emamectin benzoate against *S. frugiperda*. According to laboratory findings, *Steinernema carpocapsae* NBAIRS59 and *Heterorhabditis indica* 1 NBIIH38 both induced 100% mortality in the third and fourth instars of *S. frugiperda* larvae while causing 85% and 72% mortality in the pupae, respectively. Shinde *et al.* (2022) studied to identify, describe, and analyse in a lab environment the reproductive capacity of natural strains of the entomopathogenic nematode *H. indica* against larval instars of *S. frugiperda*. When compared to the 4<sup>th</sup> and 5<sup>th</sup> instar larvae, the *S. frugiperda* instar-wise mortality data revealed that the 3rd instar was substantially more sensitive. A bacterial symbiont of the genera *Photorhabdus* and *Xenorhabdus* is carried in the intestinal tract by the obligatory pathogens *Steinernematidae* and *Heterorhabditidae*, respectively. The non-feeding third stage infective juvenile is the only stage that can endure outside of a host. After identifying a suitable host, IJs enter it naturally through openings like the mouth, spiracles, anus, or thin sections of the host cuticle. Once within the host hemocoel, they release their symbionts and work with bacteria and nematodes to suppress the host immune system. Usually within 48 hours, the insect host is killed by toxins produced by nematodes and growing bacteria in the body cavity (Kumar et al. 2020b).

**Nuclear Polyhedrosis Virus-** Gunda *et al.* (2020), studied that natural occurrence of SpfrNPV among *S. frugiperda* larvae in Meghalaya may provide additional opportunity to the farmers of the region to utilize this potential biocontrol agent against invasive *S. frugiperda*. One of the most thoroughly investigated and widely utilised baculovirus groups for pest management is entomopathogenic viruses, particularly NPVs. S. Basically, two different baculovirus species, namely F. NPVs, the majority of which are multicapsid forms, and granulovirus. As a result, it is also anticipated that SpfrNPV from Meghalaya will contain several nucleocapsids in the virion of occlusion bodies (OBs), but this cannot be verified until thorough characterization. Worldwide, several NPVs have been isolated from *S. frugiperda* and several isolates have been used for the control of the pest with >80% efficacy, indicating its role as a potent biopesticide against this notorious pest. Field observations of *S. frugiperda* in maize crop revealed that the SpfrNPV infected larvae stopped feeding and came out from the whorl on the leaf surface of maize plants. In certain cases, dead caterpillars were found. Several NPVs from *S. frugiperda* have been isolated throughout, and several of these isolates have been employed to suppress the pest with >80% efficiency, demonstrating its significance as an effective biopesticide against this notable pest. The SpfrNPV-infected larvae on the leaf surface of maize plants stopped eating and emerged from the whorl, according to field observations of *S. frugiperda* in maize crops. In several situations, dead caterpillars with characteristic NPV attack symptoms were discovered hanging on maize plants. Other diagnostic signs include lethargy, a body's initial brighter colour that eventually turns darker, regurgitation, and body liquefaction. From the maize fields, *S. frugiperda* caterpillars that had died had been gathered. They displayed the typical signs of NPV infection. During the second and third generations of *S. frugiperda* that were created from the original field-collected larvae, early instar mortality of second to fourth was recorded at a total of 39.33% and 48.67%.

## Conclusion

Agriculture has continued to face massive damage from weeds, viruses, nematodes, fungi, insect pests, animals, and birds since the beginning of history, which has resulted in a decrease in crop production. According to estimates, weeds, illnesses, and insects have caused considerable damage to crop productivity. There were numerous solutions to this issue in use. Use of chemical/synthetic pesticides is one of the most popular methods for getting rid of insect pests (e.g. carbamates, chlorinated hydrocarbons, organophosphates, etc.). The use of chemical pesticides can increase productivity, but there are also possible hazards to health and the environment. These chemical pesticides are persistent for a long time. In the same way, careless and continuous application of these chemical treatments results in adverse residual issues, insect pest resistance, and the loss of some beneficial species. Using a systematic and environmentally responsible strategy is crucial to overcoming the risks connected with chemical pesticides. The formation of biopesticides, which are derivatives of naturally occurring material such as plants, animals, microorganisms, or their products, is one such improvement in pest control strategy. They are less harmful to the environment, effective, and decomposable. The term "biopesticides" is incorrect in that it is not necessary for microbiological agents for pest control to completely eliminate the pest; instead, they suppress the insect and allow the crop to adequately develop a harmful effect on the pest so that crop output is unaffected.

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