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Bio-agents for sustainable management of Fall Armyworm *Spodoptera frugiperda* (J.E. Smith)

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Introduction:

The interconnected linkages among plants, herbivores, carnivores, parasites, and pathogenic agents that govern and balance the bio-ecosystem are responsible for the equilibrium of living organism populations (Szwabiski et al. 2010). Unfortunately, human activities that generate everyday disturbances perpetually threaten this balance (Ruppert et al. 2018). Increased agricultural pest populations can cause to food and economic losses (Zamagni et al. 2012; Sala et al. 2013). In order to avoid these losses, crop protection strategies against phytopathogens and crop pests from mammals, birds, reptiles, and arthropods have been developed (Berny et al. 2010; Roger et al. 2014). Pesticides have been the most widely used way of pest management. Unfortunately, certain insect species have developed resistance mechanisms to distinct pesticide families (Anderson et al. 2018; Tay and Gordon 2019), while others have escaped and migrated to new areas. In the absence of consistent pest control measures or indigenous natural enemies, successful pest invasions are typically followed by rapid population growth and movement, resulting in severe plant injury and potentially significant yield and economic losses (De Barro et al. 2011; Haile et al. 2021).

The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is a well-known invasive pest that has spread from its original habitat in the Neotropical Americas to many regions of Asian countries. This polyphagous insect has been found on over 350 host plants, including many economically important crops. Insecticides are primarily utilized by millions of farmers with the backing of numerous governments to prevent food and economic losses . However, indiscriminate insecticide usage not only endangers human health and the environment (O'Dowd *et al*., 2003), but also disrupts the natural interdependence of diverse species by killing non-target organisms such as natural enemies of pests.

Bio-agents to overcome the infestation of FAW

Over a hundred different species of

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natural biocontrol agents for FAW have already been identified. Many indigenous entomopathogens, parasitoids, and predators of FAW have been identified in India. The Fall Armyworm has many naturally-occurring 'natural enemies' or 'farmers' friends'. These biological control agents are organisms that feed on FAW.

A major difficulty is to develop conditions that allow these beneficial creatures to reach their full potential. Many of the farmers' acquaintances are killed by broad-spectrum pesticides. Farmers must recognise the pest at all phases of growth, identify natural antagonists, identify potential gaps in local natural enemy guilds, and sustain their action through appropriate management techniques in an IPM context.

Parasitoids:

Parasitoids are organisms whose adults lay eggs inside or on a single host. The resulting larvae feed on the host's tissues to grow until they are fully grown and pupate. These co-evolved parasitoids can have a significant impact on FAW populations and are hence appropriate choices for use in biological control efforts.

During Western Hemisphere inventory, around 150 distinct parasitoid species were discovered to be related with the FAW in various crops.

Parasitoid larvae inevitably kill their hosts as a result of their growth. Hymenopteran parasitoids viz., *Telenomus* sp. (Platygastridae), *Trichogramma* sp. (Trichogrammatidae), *Chelonus* sp., *Glyptapanteles creatonoti* (Viereck) and *Cotesia* sp. of Braconidae, *Phanerotoma* sp. and *Campoletis chlorideae* Uchida of Ichneumonidae and Nuclear polyhedrosis virus (NPV of Sf) and *Nomuraea rileyi* of *S. frugiperda* larvae have been documented to have good biocontrol potential on FAW. FAO's web-based FAW portals (FAO 2020); CABI-based news, research, practical extension materials, videos, and other resources; a mobile app on FAW Monitoring and Early Warning System (FAMEWS); the Global Action for Fall Armyworm Control' in 2020 and the ASEAN Action Plan on FAW Control are recently established systems for FAW detection and management.

Egg parasitoid, *Telenomus remus* parasitizing fall armyworm eggs

Chenonus blackbruni

Predators:

3 predator species associated with FAW in maize fields in South India in 2018. The predators were *Forficula* sp., *Harmonia octomaculata* and *Coccinella transvirsalis* (Sharanabasappa *et al*., 2019). The dermapteran predator, *Forficula* sp. associated with *S. frugiperda* in maize fields in Tamil Nadu (Shylesha *et al*., 2018). The nymphs and adults of *Eocanthecona furcellata* (Wolf) and *Andrallus spinidens* (Fabr.) (Hemiptera: Pentatomidae) were found to associate with *S. frugiperda* in maize fields in India (Shylesha and Sravik, 2018). *E. furcellata* as an important predator of *S.frugiperda* in maize fields in India. The pentatomids, *Arma chinesis* (Fallou) (Tang *et al*., 2019) and *Picromorus lewisi* Scott (Tang *et al*., 2019) were recorded as predators of *S. frugiperda* in maize fields in China. In China, reported the earwig, *Doru luteipes* (Scudder) as a predator of *S. frugiperda* in maize fields (Abbas *et al*., (2022). Zeng *et al*. (2021) reported the anthocorid, Orius similis Zeng (Hemiptera: Anthocoridae) as a native predator of *S. frugiperda* in China.

Entomopathogenic nematode:

The researchers reported the pathogenicity of *Heterorhabditis indica* and *Steinernema carpocapsae* against all phases of *S. frugiperda* development. Both tested EPNs demonstrated a high rate of ovicidal, larvicidal, and pupicidal effects on *S. frugiperda*, according to the data. The EPNs also had a substantial impact on adults, resulting in deformity and death. *H. indica* demonstrated higher invasion efficiency and reproduction rates than *S. carpocapsae* on different larval stages and pupae, according to EPN invasion efficiency and reproduction assays. EPNs were also found in adult cadavers of *S. frugiperda* that had been treated with EPNs. Pre-releasing third instar larvae to whorls of maize plants was used to conduct a preliminary study on the effect of EPN application on *S. frugiperda* under semi-field conditions.

Pathogens:

Pathogens (microorganisms that can cause disease) are everywhere. In agriculture, plant pathogens (e.g. fungi, bacteria, viruses, nematodes) affect plants, reducing yield or quality. Also very important, but less perceived by farmers, are entomopathogens – those pathogens that affect insects (‘entomo-‘).

The Fall Armyworm is naturally affected by several different types of pathogens:

Fungi, in particular

- ✓ *Metarhizium anisopliae*
- ✓ *Metarhizium rileyi*
- ✓ *Beauveria bassiana*

Viruses, in particular Nuclear Polyhedrosis Virus (NPVs) such as the Spodoptera Frugiperda Multicapsid Nucleopolyhedrovirus (SfMNPV)

- ✓ Bacteria, such as the *Bacillus surigensis* (Bt)
- ✓ Protozoa

In the field, FAW larvae spontaneously demolished by viruses and fungi are easily detected. Larvae that have been virus-killed become floppy and many dangle from leaves, eventually dripping viroid particles and fluids (picture 2). As the fungal spores mature, fungalkilled larvae become hard and appear "frozen" on the leaves, finally appearing white or light green (picture 1). These are the two most common entomopathogen groups that spontaneously kill FAW larvae in the field.

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