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Article

Resistance and Integrated Management: Current Challenges in the Control of Spodoptera frugiperda in Brazil

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RESUMO

A cultura do milho (*Zea mays*) possui grande importância econômica e social no Brasil, terceiro maior produtor mundial, mas enfrenta desafios significativos devido à lagarta-do-cartucho *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae), praga-chave que pode causar perdas de até 60% em infestações severas. Dessa forma, o presente estudo teve como objetivo revisar, por meio de revisão narrativa, as principais estratégias de controle da *S. frugiperda*, abordando os tipos de controle atualmente disponíveis, discutindo suas limitações e impactos. O manejo tradicional da praga baseia-se principalmente no controle químico e no cultivo do milho Bt (*Bacillus thuringiensis*). No entanto, o uso intensivo de inseticidas, aliado à sobreposição de culturas hospedeiras ao longo do ano, tem acelerado a evolução de resistência, resultando em falhas no controle. O manejo integrado de pragas surge como abordagem fundamental, combinando métodos biológicos, químicos e culturais. Entre os agentes de controle biológico, destacam-se vírus como SfMNPV, fungos entomopatogênicos (*Beauveria bassiana* e *Metarhizium anisopliae*), bactérias (Bt) e parasitoides (*Trichogramma* spp.). Práticas culturais, como rotação de culturas e monitoramento constante da lavoura, complementam as estratégias. Para garantir a eficácia e a sustentabilidade no manejo da lagarta-do-cartucho, é essencial capacitar os agricultores e adotar práticas integradas que reduzam a pressão de seleção sobre as populações da praga. Dessa forma, é possível minimizar perdas de produtividade, prolongar a eficácia das tecnologias disponíveis e promover um manejo mais equilibrado e sustentável da cultura.
Palavras-chave: Inseticidas; lagarta-do-cartucho; milho; monitoramento.

ABSTRACT

Corn (*Zea mays*) cultivation is of great economic and social importance in Brazil, the world's third-largest producer, but faces significant challenges due to the fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), a key pest that can cause losses of up to 60% in severe infestations. Therefore, this study aimed to review, through a literature review, the main control strategies for *S. frugiperda*, addressing currently available control strategies and discussing their limitations and impacts. Traditional pest management is mainly based on chemical control and the cultivation of Bt corn. However, the intensive use of insecticides, coupled with the overlapping of host crops throughout the year, has accelerated the evolution of resistance, resulting in control failures and cases of resistance to Bt corn, often due to the incorrect or non-existent adoption of refuge areas. Integrated Pest Management (IPM) emerges as a fundamental approach, combining biological, chemical, and cultural methods. Among the biological control agents, viruses such as SfMNPV, entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium anisopliae*), bacteria (*Bacillus thuringiensis*), and parasitoids (*Trichogramma* spp.) stand out. Cultural practices, such as crop rotation and continuous crop monitoring, complement the strategies. To ensure the effectiveness and sustainability in the management of the fall armyworm, it is essential to train farmers and adopt integrated practices that reduce the selection pressure on pest populations. In this way, it is possible to minimize productivity losses, prolong the effectiveness of available technologies, and promote a more balanced and sustainable management of corn.
Keywords: Insecticides; fall armyworm; corn; monitoring.

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Introduction

Maize (Zea mays) is widely cultivated throughout Brazil and is one of the country's major grain crops, standing out for its versatility and significant economic importance in human and animal nutrition, industry, and biofuel production (Filho, 2015; CNA, 2023). Brazil is the third-largest maize producer worldwide, behind only the United States and China, with these three countries collectively accounting for more than 60% of global production (Boschiero, 2025).

Brazil's favorable climatic conditions have contributed significantly to the expansion of maize cultivation. However, when the production system was restricted to a single annual crop, pest and disease control was more effective. With the adoption of the second-crop maize system, the crop began to remain in the field for longer periods, intensifying phytosanitary challenges, such as the increased occurrence of insect pests and plant diseases, resulting in significant economic losses due to reduced yield (Sabato, 2017; Hernández-Trejo *et al*., 2019).

Among the major pests affecting maize, the fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), stands out as it causes significant damage throughout the crop cycle, compromising maize quality and yield in the field (Cruz *et al*., 2010; Medyk *et al*., 2025). Other reported pests that can also cause significant damage include the corn earworm (*Helicoverpa zea*), corn rootworm (*Diabrotica speciosa*), Old World bollworm (*Helicoverpa armigera*), lesser cornstalk borer (*Elasmopalpus lignosellus*), corn leafhopper (*Dalbulus maidis*), and the green-belly stink bug (*Diceraeus* [=*Dichelops*] *furcatus* and *D. melacanthus*) (Gallo *et al*., 2002; Valicente, 2015; Filho *et al*., 2016).

The management of *S. frugiperda* in maize is primarily based on chemical control and the use of genetically modified cultivars that express insecticidal proteins derived from the microorganism *Bacillus thuringiensis* (Bt). Despite the widespread adoption of Bt maize technology in Brazil, chemical control remains the most widely used method for reducing pest populations (Burtet *et al*., 2017).

Considering that the improper use of chemical control can result in environmental impacts and the selection of resistant populations, it is essential to seek sustainable alternatives, such as biological control (BC). Biological control constitutes one of the main pillars of integrated pest management (IPM), playing a strategic role alongside behavioral and chemical control. This control measure is essential for management strategies, as it helps maintain pest populations below the economic injury level (Parra *et al*., 2021).

From this perspective, biological control using entomopathogens, including *Bacillus thuringiensis* (Bt), *Metarhizium anisopliae*, *Beauveria bassiana*, *Trichoderma asperellum*, and *Spodoptera frugiperda* multiple nucleopolyhedrovirus (SfMNPV), has proven to be highly effective against *S. frugiperda* (Pomari *et al*., 2013; Abbas *et al*., 2022; Afandhi *et al*., 2022).

Therefore, the present study aimed to review the main control strategies for *S. frugiperda*, addressing both conventional methods, such as chemical control, and sustainable alternatives, such as biological control, while discussing their limitations and impacts.

Methodology

The present narrative review aimed to gather, analyze, and discuss the main control strategies for *S. frugiperda*. The theoretical framework was developed based on the survey and synthesis of scientific studies indexed in recognized databases, such as ScienceDirect, Web of Science, SciELO, and Google Scholar, as well as consultations of technical publications from reference institutions, such as Embrapa.

For material selection, descriptors in Portuguese and English were used, combining the terms "*Spodoptera frugiperda*," "maize crop," "chemical control," "biological control," "integrated pest management," and "innovations in pest control," associated with the Boolean operators "AND" and "OR." The identification of duplicates, screening, and selection of studies were performed manually, without the use of reference management or screening software.

Original articles, reviews, books, and technical reports published within the last 20 years in Portuguese, English, and Spanish were included. Given this temporal window, studies published more than 10 years ago were considered when they described biological or behavioral aspects of the pest that remain relevant in the current literature, whereas management strategies and innovations in pest control were prioritized based on publications from the last 10 years. As exclusion criteria, studies whose full texts were not available for access and studies presenting duplicated content in relation to another study already included were excluded, retaining only the most complete or most recent version, in addition to updated studies addressing management tactics.

After applying the inclusion and exclusion criteria through title and abstract screening, 122 studies were selected for full-text reading. Following this refinement, studies with the greatest relevance and adherence to the topic were filtered and selected. The number of studies identified and screened in the previous stages was

not quantitatively recorded. The data obtained were analyzed qualitatively, and the discussion was structured around the main control categories (chemical, biological, cultural, and integrated management), with emphasis on recent innovations and their implications for the sustainable management of the pest in the Brazilian agricultural context.

Literature Review

Maize Crop

Maize (*Zea mays*) is a species belonging to the Poaceae family and originated in Central America. It is widely cultivated in Brazil and worldwide due to its significant economic and social importance, as well as its close relationship with agricultural and livestock production. It is one of the most widely produced cereals in the world because of its versatility and is cultivated throughout most of the country. In Brazil, maize production is divided into first and second crops, which is an advantage compared with other countries. The state of Mato Grosso is the leading maize-producing state in Brazil (Duarte *et al*., 2021; IBGE, 2024).

Maize stands out as one of Brazil's main agricultural commodities. National production for the 2025/26 crop season is estimated at 138.4 million tons, with expectations of growth in both exports and domestic consumption, projected at 46.5 million and 94.5 million tons, respectively. Favorable climatic conditions in the main producing regions have contributed significantly to the good development of the crops, which are currently predominantly at the flowering and grain-filling stages (CONAB, 2026).

Maize productivity is influenced by several factors, including soil characteristics, climate, topography, the presence of living organisms, and the management practices adopted. The interaction among these factors causes different genotypes to respond differently to environmental conditions. Thus, the performance of a variety depends not only on its genetic characteristics but also on the conditions under which it is cultivated. For this reason, it is essential to correctly determine the planting date, taking into account all stages of the crop cycle and the environmental conditions expected at each stage (Guimarães *et al*., 2021).

In Brazil, maize is cultivated under a wide diversity of environmental conditions, ranging from warm regions to colder areas and encompassing different altitudes and latitudes, resulting in distinct yield potentials. In recent years, the Central-West and Southern regions have achieved high production and productivity. This progress is attributed to several improvements, including management practices, soil preparation, fertilization, genetically modified seeds, sowing methods, pest and disease control, weed management, and harvesting technologies, in addition to the expansion of areas allocated to maize cultivation (Artuzo *et al*., 2022).

Due to favorable climatic conditions, pests occur throughout the entire development of maize, from seed germination to the physiological maturity of the grains. The initial problems commonly arise from the presence of caterpillars in crop residues and soil-dwelling insects, followed by aboveground pests that damage seedlings. At more advanced stages, leaf- and ear-feeding caterpillars become particularly important, followed by sap-sucking insects that affect both leaves and developing grains (Ávila, 2015).

Morphology and Biology of Spodoptera frugiperda

Spodoptera frugiperda, commonly known as the fall armyworm, is a holometabolous insect that undergoes complete metamorphosis, meaning that its life cycle comprises the egg, larval, pupal, and adult stages (Cruz, 1995). It is considered a polyphagous species and can feed on at least 353 host plants belonging to 76 families, including the most widely recognized crops such as maize, soybean, sorghum, wheat, sugarcane, and cotton (Montezano *et al*., 2018).

Immediately after oviposition, the eggs are light green, becoming orange after approximately 12 to 15 hours and darkening as hatching approaches. Newly hatched larvae are whitish and become greenish after feeding begins. During the first instar, larvae measure approximately 1.9 mm in length; in the second instar, 3.5 to 4 mm; and in the third instar, 6.3 to 6.5 mm, with a light-brown coloration on the dorsal surface and a greenish coloration on the ventral surface. During the fourth and fifth instars, the body becomes darker and can reach up to 18 mm in length. In the final instar, the larva exhibits a brownish-gray coloration dorsally and greenish coloration on the ventral and subventral regions, with reddish-brown spots also present in the latter region. The head displays an inverted "Y"-shaped marking, an important characteristic for identifying the species (Cruz, 1995).

In maize, younger larvae preferentially scrape the younger leaves, whereas more developed larvae create holes and consume large portions of leaf tissue, leaving the whorl severely damaged. Due to their cannibalistic behavior, usually only one larva is able to develop within a single whorl. However, larvae at different instars may be observed within the same whorl, separated by the leaf blades. At the end of larval development, the

larvae burrow into the soil and transform into reddish pupae, which become darker as adult emergence approaches (Gallo *et al*., 2002; Valicente, 2015).

The adult insect is a moth with a wingspan of approximately 35 mm, characterized by dark-brown forewings and grayish-white hindwings. Adults are nocturnal and are more active during warm nights. During the day, *S. frugiperda* moths remain sheltered beneath the foliage, close to the soil surface, or between the folded leaves of the maize whorl (Gallo *et al*., 2002; Cruz *et al*., 2010).

Damage and Losses Caused by Spodoptera frugiperda

Under severe infestations, the fall armyworm can cause significant losses in maize crops, with yield reductions of up to 60%, depending on the intensity of the infestation and the plant's developmental stage. Maize is most susceptible between the 8- and 10-leaf stages. Control measures should be initiated when approximately 10% of the plants exhibit characteristic symptoms, such as leaf scraping, indicating the onset of infestation (Cruz *et al*., 2021).

The larvae can penetrate the stalk through the whorl, forming downward galleries that reach the growing point and result in the symptom known as "dead heart." Another type of damage occurs when the base of the stalk is partially or completely severed, potentially leading to plant death. The ear insertion point may also be attacked, causing complete production loss due to the failure of grain formation or the dropping of the developing ear. In addition, direct damage to developing grains within the ear is common and is caused by larval feeding, while indirect damage results from the penetration of microorganisms such as fungi and bacteria, thereby reducing grain quality (Cruz, 2008).

After the formation of the whorl, the larvae move into the interior of the maize plant, where they remain protected. This location makes it difficult for crop protection products, particularly chemical insecticides, to reach and act effectively on the larvae (Carvalho *et al*., 2013; Barcelos; Angelini, 2018). The characteristic feeding behavior and rapid development of the larvae are likely among the main factors reducing insecticide efficacy under field conditions. Therefore, understanding how resistance mechanisms are distributed and how frequently they occur is of great importance (Berg; Plessis, 2022).

Chemical Control

The control of maize pests is carried out using a variety of insecticides. Early-season pests that attack seeds, roots, and seedlings are generally controlled through seed treatment, a method that offers advantages such as ease of use, lower consumption of active ingredient per area, and lower cost. Pests that attack vegetative and reproductive plant parts, on the other hand, are primarily controlled through spraying, whether using backpack sprayers, tractor-mounted equipment, aerial application, or irrigation systems. Successful control depends on the compatibility of the insecticide formulation with the application equipment and the target pest, as well as on factors such as application timing, nozzle type, flow rate, and water quality, all of which directly influence control efficacy (Viana *et al*., 2012).

Chemical control of *S. frugiperda* can be effectively carried out at different developmental stages of the maize crop. Insecticides enter the insect's body through three main routes: through the cuticle, via contact or dermal action; through inhalation into the tracheal system; or through oral ingestion into the digestive system (Gullan; Cranston, 2017).

Currently, 335 phytosanitary products are registered for the control of *S. frugiperda*. The most relevant chemical group is the pyrethroids, with 91 registrations (Figure 1), either as the primary active ingredient or in combination with other compounds. This is followed by benzoylureas, with 59 registrations; oxime methylcarbamates, with 45; organophosphates, with 30; and anthranilic diamides, with 29 registrations (Agrofit, 2026).

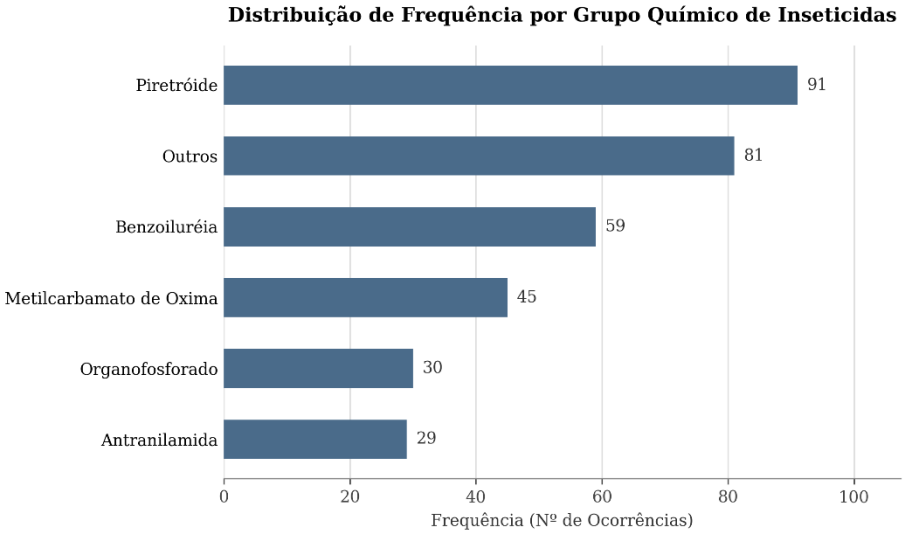


Figure 1. Insecticides registered in the Agrofit system for the control of *S. frugiperda* in maize crops. Source: Prepared by the authors (2026).

The selection of an insecticide molecule for pest control should consider the required level of control, avoiding damage from exceeding economic thresholds. In addition to cost, factors such as efficacy, toxicity, selectivity, environmental persistence, and the possibility of rotating insecticides with different modes of action should be evaluated to reduce the risk of resistance (Viana *et al.*, 2012).

In Brazil, chemical insecticides remain an essential tool in the management of *S. frugiperda*, particularly in areas where the pest exhibits resistance to Bt maize. The intensive use of these products has been widely reported, with ten to fourteen applications per crop cycle, depending on infestation levels and local resistance conditions (Valicente; Tueller, 2009; Fatoretto *et al.*, 2017; Berg; Plessis, 2022).

In general, insecticide application for the management of *S. frugiperda* is recommended when infestation reaches the control threshold (CT), which may vary according to the crop developmental stage. At a more advanced stage, approximately 20% of plants exhibit scraping symptoms and/or the beginning of holes in the leaves, corresponding to levels 3 and 4 on the Davis scale (Table 1). However, to achieve greater control efficacy and yield gains, intervention may be initiated when 10% of plants reach a score of 3. At this stage, small circular lesions and some elongated, rectangular lesions, up to 1.3 cm in length, can be observed on the whorl leaves. This CT criterion is widely used as a technical basis for deciding when to apply chemical insecticides (Davis *et al.*, 1992).

Table 1. Damage rating scale (0 to 9) for assessing damage caused by *S. frugiperda* in the maize whorl (Davis *et al.*, 1992; Fernandes *et al.*, 2003).

Note	***Description of the damage***
0	Plant with no damage
1	Plant with spots (more than one spot per plant)
2	Plant with spots; 1 to 3 small circular lesions (up to 1.5 cm)
3	Plant with 1 to 5 small circular lesions (up to 1.5 cm); plus 1 to 3 elongated lesions (up to 1.5 cm)
4	Plant with 1 to 5 small circular lesions (up to 1.5 cm); plus 1 to 3 elongated lesions (larger than 1.5 cm and smaller than 3.0 cm)
5	Plant with 1 to 3 large elongated lesions (larger than 3.0 cm) on 1 to 2 leaves; plus 1 to 5 holes or elongated lesions up to 1.5 cm
6	Plant with 1 to 3 large elongated lesions (larger than 3.0 cm) on 2 or more leaves; plus 1 to 3 large holes (larger than 1.5 cm) on 2 or more leaves
7	Plant with 3 to 5 large elongated lesions (larger than 3.5 cm) on 2 or more leaves; plus 3 to 5 large holes (larger than 1.5 cm) on 2 or more leaves
8	Plant with many elongated lesions (more than 5) of all sizes on most leaves. Many medium to large holes (more than 5) larger than 3.0 cm
9	Plant with many leaves, almost all of them destroyed

Source: Davis *et al.*, 1992; Fernandes *et al.*, 2003.

The efficacy of insecticides in controlling caterpillars depends on their mode of action, which can influence the speed at which they cause insect mortality. While neurotoxic insecticides act rapidly, chitin synthesis inhibitors, such as lufenuron, have a slower effect because they act only during the molting process (Busato *et al.*, 2006). Among the different insecticide options studied for the control of *S. frugiperda*, even though some do

not yet have specific registration for this pest, products belonging to the diamide, insect growth regulator, spinosyn, and organophosphate groups stand out (Teodoro *et al.*, 2013; Oliveira; Nunes, 2017).

Biological Control

Biological control is defined as a natural phenomenon that plays a fundamental role in regulating plant and animal populations through the action of their natural enemies, which act as biotic mortality agents. These agents are highly diverse and include macroorganisms, such as insects and mites, as well as microorganisms, including fungi, viruses, bacteria, nematodes, and protozoa. Larger predators, such as spiders, amphibians, fish, reptiles, birds, and mammals, also play a role (Parra *et al.*, 2021).

The current biological control market includes a total of 98 registered control (Figure 2). The predominant group is bacteria, represented by *B. thuringiensis*, with 48 registrations. Viruses follow, with 20 registrations. Parasitoids and fungi have fewer registrations, with 13 and 8, respectively (Agrofit, 2026).

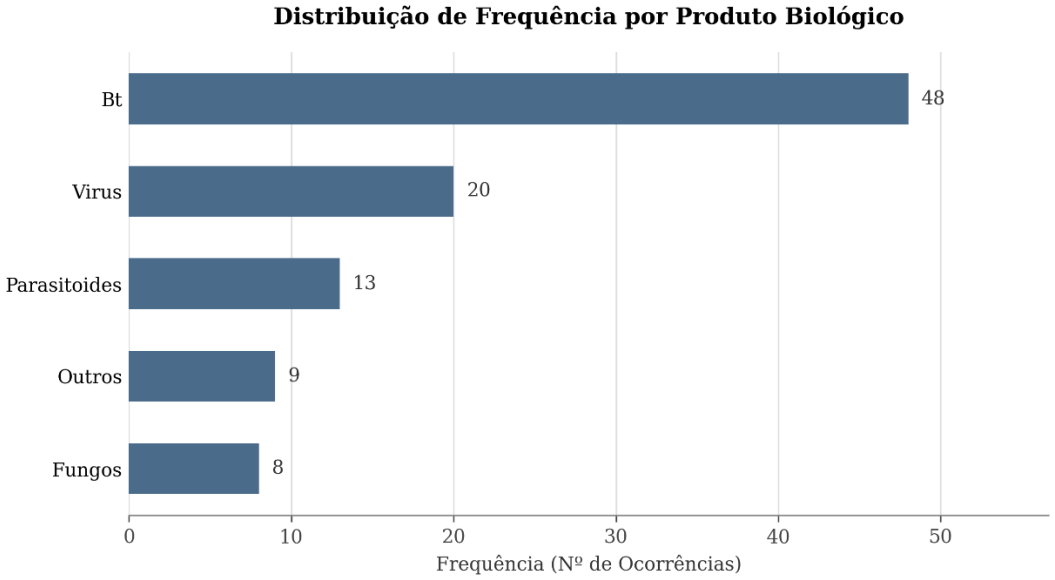


Figure 2. Biological insecticides registered in the Agrofit system for the control of *S. frugiperda* in maize crops. Source: Prepared by the authors (2026).

Entomopathogenic Fungi

Entomopathogenic fungi primarily infect aphids, whiteflies, grasshoppers, flies, beetles, caterpillars, thrips, and mites, exhibiting a broad spectrum of activity and the ability to colonize various insect and mite species. In addition, they differ from other groups of pathogens in their ability to infect all developmental stages of their hosts (Alves *et al.*, 2008).

Fungi invade insects through different routes, the main one being penetration through the cuticle or integument. Following infection, the fungus rapidly multiplies inside the host, causing death through tissue destruction and the action of fungal toxins. After the insect dies, the fungus often emerges from the body and produces spores, which are dispersed by wind, rain, or contact with other insects, potentially leading to epizootics. Infected insects exhibit reduced feeding and movement, becoming sluggish and generally dying within a short period, often remaining attached to leaves or branches in an upright position (Valicente, 2009).

M. anisopliae and *B. bassiana* have demonstrated efficacy in controlling *S. frugiperda* during its early developmental stages, exhibiting ovicidal activity. Studies indicate that both fungal species act rapidly on the pest's eggs, with significant mortality observed 96 hours (four days) after the eggs were immersed in two fungal suspensions, one containing *M. anisopliae* and the other *B. bassiana* (Maddalena *et al.*, 2024). Therefore, these fungi represent a promising alternative for more sustainable pest management in agroecosystems.

Fungal isolates of *B. bassiana* and *M. anisopliae* selected from collections at Unioeste, the Biological Institute of São Paulo, and ESALQ/USP demonstrated pathogenicity against *S. frugiperda*. Some *B. bassiana* isolates (Unioeste 26 and Unioeste 64) stood out by promoting the highest confirmed mortality rates, followed by other isolates with intermediate performance. Overall, *B. bassiana* isolates demonstrated greater virulence compared with *M. anisopliae* isolates, with only one isolate of the latter species (CB 417) showing mortality similar to that of the most effective *B. bassiana* isolates (Thomazoni *et al.*, 2009).

A study conducted in Indonesia found that *B. bassiana s.l.* and *Trichoderma asperellum s.l.* were effective in controlling *S. frugiperda*, causing larval mortality rates of 71% and 62%, respectively. The results indicated that *T. asperellum s.l.* has greater potential as a biocontrol agent against this pest. Furthermore, the study represents the first report of the direct lethality of a *Trichoderma* isolate against *S. frugiperda* larvae, contributing to the advancement of knowledge regarding the use of this fungus in the biological management of insect pests (Afandhi *et al.*, 2022).

In their study, Xu *et al.* (2025) investigated the immune responses of *S. frugiperda* to infection by the fungus *Metarhizium rileyi* using RNA sequencing and microscopic analyses. The results showed that the immune response varies according to the progression of infection. During the initial phase (0–48 h), the fungus penetrates the cuticle and the larva activates defense mechanisms, including metabolic while immune pathways. Between 48 and 96 h, the fungus disseminates through the hemolymph, accompanied by an intensified cellular response, including phagocytosis and the production of reactive oxygen species. In the final phase (96–120 h), immune activity decreases. At this stage, the larva dies and the fungus emerges through the cuticle, producing new conidia (Xu *et al.*, 2025).

A bioinsecticide formulated based on the fungus *Cordyceps javanica* (syn. *Isaria javanica*), such as Izaturbo®, has also been registered. It is indicated for use on various crops and has demonstrated efficacy in controlling the fall armyworm, being applied through foliar spraying at regular intervals (Vitiia, 2025).

Entomopathogenic Viruses

Currently, most viruses registered for use as biopesticides are baculoviruses, which cause infections primarily in lepidopteran insects (Gullan; Cranston, 2017). For the control of the fall armyworm, research has focused on two specific types of baculoviruses: granuloviruses (GV) and nucleopolyhedroviruses (NPV) (Cruz, 2000).

The *S. frugiperda* nucleopolyhedrovirus (SfNPV) is specific to the fall armyworm, with the larval stage being the most susceptible to infection. Infection generally occurs through the ingestion of contaminated food, but it can also occur through eggs, spiracles, or parasitoids. After ingestion, the alkaline pH of the intestine dissolves the viral occlusion bodies, allowing the virus to multiply in the internal cells and tissues, ultimately causing larval death within 6 to 8 days after ingestion. The larva releases a liquid containing occlusion bodies through its mouthparts, which acts as an inoculum and contaminates the plant whorl, facilitating the spread of infection to new hosts (Cruz, 2000).

The main symptoms of baculovirus infection begin with the appearance of spots on the integument, reduced feeding activity, yellowing, and an oily appearance of the epidermis. As the disease progresses, the caterpillars lose mobility and become darker due to the disintegration of their internal organs. They typically move toward the upper parts of the plant and hang from the foliage, a characteristic symptom of viral infection. Larvae of the fall armyworm exhibit a consistent pattern of infection, with the internal organs being completely destroyed and, at the time of death, the integument exhibiting a light-pink coloration and complete liquefaction (Weinzierl; Henn, 1989; Cruz, 2000; Barreto *et al.*, 2005).

Some studies indicate that an increase in larval population density favors infection by the microorganism, as a higher concentration of hosts enhances viral replication and increases the number of viable infections. Higher mortality rates of 83.5% and 85% were observed at densities of 10 and 5 second-instar larvae, respectively, whereas mortality decreased to 50% in fifth-instar larvae, demonstrating that more advanced developmental stages are less susceptible to the virus (Bolonheiz *et al.*, 2010).

In 2017, Embrapa developed the first commercial product registered based on *Baculovirus spodoptera*, CartuchoVIT, which is considered an effective biological control agent due to its safety and ease of handling. The product is economically advantageous because it generally requires only two applications, resulting in lower costs associated with agricultural machinery and labor. In terms of efficacy, field evaluations have demonstrated that the bioinsecticide achieves mortality rates ranging from 75% to 95% in fall armyworm larvae up to five days old (Embrapa, 2017).

Entomopathogenic Bacteria

The bacterium *Bacillus thuringiensis* (Bt) is a microbial bioinsecticide produced industrially for pest control, particularly against lepidopteran insects, in agricultural crops and forests. Its importance stems from its ability to produce protein inclusions known as crystals, resulting in a highly selective mode of action. When ingested, the bacterium releases crystalline delta-endotoxins (protoxins), which are activated by proteases in the larva's alkaline midgut. This activation enables the toxins to bind to receptors in the intestinal epithelium, disrupting cellular integrity and ultimately causing insect death. Compared with older larvae or adults, larvae in the early

instars are more susceptible to Bt, while the bacterium remains harmless to mammals and humans (Gullan; Cranston, 2017).

A scientific review analyzed the role of the gut bacteria of *S. frugiperda* in its adaptation, reproduction, and pesticide resistance. Microorganisms such as *Enterococcus* and *Enterobacter* contribute to the digestion of toxic compounds, vitamin synthesis, and metabolic regulation, in addition to increasing insecticide tolerance. The composition of the microbiota varies according to factors such as diet, developmental stage, sex, and environment. The study also indicates that manipulation of these microorganisms may represent a promising strategy for pest control. Among the alternatives are the incompatible insect technique (IIT), the use of genetically modified microorganisms, and the application of antimicrobial peptides (Yan *et al.*, 2025).

A study conducted by Gomes *et al.* (2018) using bacterial strain 358.1 demonstrated effects on the development of *S. frugiperda*, causing an increase in the duration of the larval stage and alterations during metamorphosis. These effects were observed mainly during the pupal stage and adult emergence, with adults exhibiting deformed wings, indicating impairment of normal development.

The development of Bt-based biological control was driven by the coding of the Cry protein (delta-endotoxin) by a single *cry* gene, facilitating biotechnological manipulation. At the end of the 20th century, this led to the strategic diversification of Bt, either through increased toxin production, the prospecting of new strains with an expanded spectrum of activity, or, primarily, through genetic engineering, which enabled the development of transgenic plants (Bt crops) (Capalbo *et al.*, 2005). Bt maize is a genetically modified crop that has received genes from the bacterium Bt and provides control of caterpillars, such as those belonging to the order Lepidoptera (Díaz *et al.*, 2024).

However, to preserve the efficacy and durability of Bt maize, growers need to establish a refuge area. In Brazil, refuge implementation requires planting non-Bt maize hybrids on 10% of the area cultivated with Bt maize, using hybrids with similar plant height and vegetative cycles. The distance between the refuge and transgenic maize is limited to 800 meters, which corresponds to the maximum dispersal distance of adult fall armyworms. The main objective is to synchronize mating between potentially resistant insects surviving in the Bt area and susceptible insects emerging from the refuge. In large fields exceeding this distance, internal refuge strips are required to ensure mating between the two populations (Carneiro *et al.*, 2009; Díaz *et al.*, 2024).

Bt maize provides a significant advantage by reducing insect damage to ears by up to 90%. Due to the reduced incidence of feeding injuries, it also decreases the likelihood of fungal growth entering through plant damage. Consequently, Bt maize suffers less pest damage than conventional maize, resulting in higher productivity (Carneiro *et al.*, 2009).

Parasitoids and Predators

Several parasitoids and predators are important natural regulators of fall armyworm populations. Among them, the predator *Doru luteipes* (Dermaptera: Forficulidae) and the parasitoids *Trichogramma* spp. (Hymenoptera: Trichogrammatidae), *Telenomus* sp. (Hymenoptera: Scelionidae), *Chelonus insularis* (Hymenoptera: Braconidae), and *Campoletis flavicincta* (Hymenoptera: Ichneumonidae) stand out. These natural enemies are essential because they act on eggs and/or larvae up to approximately 1.5 cm in length, eliminating the pest before it causes significant damage to the crop (Cruz, 1995).

Species of the genus *Trichogramma* are important egg parasitoids. They are small wasps whose females lay their eggs inside the eggs of the host, where they complete their life cycle. The most widely used and commercially available species is *Trichogramma pretiosum*. Its application in crops is carried out through mass releases shortly after the appearance of egg masses or adult moths. This release method is preferred because it does not cause damage to the plant. *Trichogramma* wasps preferentially parasitize lepidopteran eggs, which include some of the most important agricultural pests (Figueiredo *et al.*, 2015).

The efficacy of parasitoids released in the field depends on several factors, including the number of insects released, pest density, *Trichogramma* species, number and timing of releases, distribution method, crop phenology, presence of natural enemies, and climatic conditions. Evaluations before and after releases are essential to understand parasitoid behavior and efficacy, allowing adjustments to the management strategy. Assessment may include the distribution of eggs at strategic points and the analysis of leaf damage through sampling and damage-rating scales (Cruz, 1995).

The egg parasitoid *Telenomus remus*, which is highly specific to *S. frugiperda*, is widely used in the biological control of this pest because it is capable of parasitizing eggs throughout all layers of the egg mass. The appropriate implementation of this strategy consists of releasing the parasitoid for three consecutive weeks, ensuring greater efficacy in controlling pest eggs in maize crops (Ivan *et al.*, 2016).

Challenges Encountered

Pest control has faced major difficulties, particularly with regard to chemical control. Reports of insect resistance to insecticides are not a recent problem. However, with the advancement of the pesticide industry, the frequency of these cases has increased, leading to the emergence of multiresistant species that exhibit multiple resistance mechanisms against different chemical groups (Rosa; Martins, 2011).

In Brazil, reports of unsuccessful control of *S. frugiperda* through the application of certain insecticides in maize crops have been observed in recent years. This lack of efficacy is particularly notable for traditional products such as pyrethroids and organophosphates. In response to this difficulty, some farmers have resorted to independently increasing product dosages beyond the levels recommended on labels or package inserts, or to using inappropriate mixtures in an attempt to restore satisfactory pest control. Consequently, these practices have contributed to the development of insect resistance to chemical products and the reduction of natural enemy populations, in addition to increasing production costs (Valicente; Cruz, 1991; Poletti; Omoto, 2003; Rosa; Martins, 2011).

One of the main challenges in controlling *S. frugiperda* is precisely related to its bioecological characteristics, which favor rapid adaptation and the development of resistance to available management methods. Its high reproductive potential, short biological cycle, and polyphagous behavior allow the pest to maintain large populations throughout the year, particularly in regions where the overlapping or succession of host crops occurs. This scenario results in continuous exposure to insecticides and Bt proteins, intensifying selection pressure and accelerating the evolution of resistance (Omoto *et al.*, 2013).

With regard to Bt maize, many growers are reluctant to properly implement refuge areas, highlighting the need for more effective communication strategies. It is essential to guide farmers to continuously monitor their crops in order to identify control failures and the increasing incidence of secondary pests (Leite *et al.*, 2011).

One of the main obstacles to the adoption of biological control on farms is farmers' lack of knowledge regarding how to distinguish pests from beneficial insects, such as natural enemies and pollinators, including bees. Therefore, there is an urgent need to train and educate producers. Effective strategies for increasing awareness of the importance of biodiversity include the use of visual materials and practical training courses conducted directly on farms (Cruz, 2022).

Conclusions

Effective control of *S. frugiperda* requires the adoption of Integrated Pest Management (IPM) principles, which aim to maintain the efficacy and sustainability of management strategies. Among the main recommended practices are the preservation of natural enemies, continuous monitoring of pest populations, and the integration of different control tactics, including biological, cultural, chemical, and biotechnological methods.

The survey of registered phytosanitary products, with a predominance of pyrethroids and organophosphates, reflects the continued strong dependence on chemical control. However, the intensive and often inappropriate use of these products has accelerated the emergence of resistant populations, compromising the medium- and long-term efficacy of this management tool.

In this context, biological control, cultural practices, and integrated management represent promising alternatives. The integration of these approaches is essential to address control challenges and ensure the sustainability of *S. frugiperda* management.

References

Abbas AF, Ullah M, Hafeez M, Han X, Dara MZN, Gul H, Zhao CR 2022. Biological Control of Fall Armyworm, *Spodoptera frugiperda*. *Agronomy* 12(11):2704. https://doi.org/10.3390/agronomy12112704

Afandhi A, Fernando I, Widjayanti T et al. 2022. Impact of the Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith), Invasion on Maize and the Native *Spodoptera litura* in East Java, Indonesia, and Evaluation of the Virulence of Some Indigenous Entomopathogenic Fungus Isolates for Controlling the Pest. *Egypt J Biol Pest Control* 32:48. https://doi.org/10.1186/s41938-022-00541-7

Agrofit [homepage on the Internet]. Brasília: Ministério da Agricultura, Pecuária e Abastecimento (MAPA); c2026 [cited 2026 Apr 13]. Available from: https://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons.

Alves SB, Lopes RB, Vieira SA, Tamai MA 2008. Fungos entomopatogênicos usados no controle de pragas na América Latina. In SB Alves, RB Lopes (eds.). *Controle microbiano de pragas na América Latina: avanços e desafios*. FEALQ, Piracicaba, p. 69-110.

Artuzo FP, Foguesatto CR, Machado JAD, Oliveira L, Souza ÂRL 2019. O potencial produtivo brasileiro: uma análise histórica da produção de milho. *Rev Agroneg Meio Amb* 12(2):515-540. https://doi.org/10.17765/2176-9168.2019v12n2p515-540

Ávila CJ. Proteção de plantas: manejo integrado das principais pragas que atacam a cultura do milho no país. *Revista Visão Agrícola* [serial on the Internet]. 2015 Jul/Dec [cited 2025 Oct 5];(13). Available from: https://www.esalq.usp.br/visaoagricola/sites/default/files/VA_13_Protecao_plantas-artigo2.pdf.

Barcelos PHS, Angelini MR 2018. Controle de *Spodoptera frugiperda* (Smith, 1797) em diferentes tecnologias Bt (*Bacillus thuringienses*) na cultura do milho. *Rev Agric Neotrop* 5(1):35–40. https://doi.org/10.32404/rean.v5i1.1824

Barreto MR, Guimaraes CT, Teixeira FF, Paiva E, Valicente FH 2005. Effect of Baculovirus spodoptera isolates in *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) larvae and their characterization by RAPD. *Neotrop Entomol* 34(1):67-75.https://doi.org/10.1590/S1519-566X2005000100010

Bolonheiz H, Oliveira NC, Balan MG 2011. Eficiência de Baculovirus spodoptera e lufenuron no controle de diferentes ínstares e densidades populacionais da lagarta do cartucho em milho. *Rev Campo Digital* 5(1). Available from: https://revista2.grupointegrado.br/revista/index.php/campodigital/article/view/594.

Boschiero BN [homepage on the Internet]. 5 Maiores produtores de milho do mundo em 2025: produção e exportação. Blog Agroadvance [updated 2025; cited 2026 Jun 06]. Available from: https://agroadvance.com.br/blog-5-maiores-produtores-de-milho-do-mundo/.

Burtet LM, Bernardi O, Melo AA, Pes MP, Strahl TT, Guedes JVC 2017. Managing fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), with Bt maize and insecticides in southern Brazil. *Pest Manag Sci* 73(12):2569-2577. https://doi.org/10.1002/ps.4660

Busato GR, Grützmacher AD, Garcia MS, Zotti MJ, Nörnberg SD, Magalhães TR, Magalhães JB 2006. Susceptibilidade de lagartas dos biótipos milho e arroz de *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae) a inseticidas com diferentes modos de ação. *Cienc Rural* 36(1):15-20. https://doi.org/10.1590/S0103-84782006000100003

Capalbo DMF, Arantes OMN, Suzuki MT 2005. Bacillus thuringiensis. Brasília, DF: Empresa Brasileira de Pesquisa Agropecuária. Available from: https://www.embrapa.br/busca-de-publicacoes/-/publicacao/15480/bacillus-thuringiensis. Acesso em: 26 out. 2025.

Carneiro AA, Guimaraes CT, Valicente FH, Waquil JM, Vasconcelos MJV, Carneiro NP, Mendes SM 2009. *Milho Bt: teoria e prática da produção de plantas transgênicas resistentes a insetos-praga*. Circular técnica 135, Embrapa Milho e Sorgo, Sete Lagoas, 25 pp. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/748936. Acesso em: 30 out. 2025.

Carvalho RA, Omoto C, Field LM, Williamson MS, Bass C 2013. Investigating the molecular mechanisms of organophosphate and pyrethroid resistance in the fall armyworm *Spodoptera frugiperda*. *PLoS ONE* 8(4):e62268. https://doi.org/10.1371/journal.pone.0062268.

Companhia Nacional de Abastecimento (CONAB) [homepage on the Internet]. Brasília: CONAB; c2025 [updated 2025; cited 2026 Apr 11]. Produção de grãos é estimada em 353,4 milhões de toneladas em 2025/26.

Available from:https://www.gov.br/conab/pt-br/assuntos/noticias/producao-de-graos-e-estimada-em-353-4-milhoes-de-toneladas-em-2025-26-com-inicio-da-colheita-das-culturas-de-primeira-safra.

Confederação da Agricultura e Pecuária do Brasil (CNA) [homepage on the Internet]. Brasília: CNA; c2023 [updated 2023 Apr 24; cited 2025 Oct 4]. Milho é um dos cereais mais nutritivos e versáteis do mundo. Available from: https://www.cnabrasil.org.br/noticias/milho-e-um-dos-cereais-mais-nutritivos-e-versateis-do-mundo.

Cruz I 1995. *A lagarta-do-cartucho na cultura do milho*. Circular Técnica 21, Embrapa-CNPMS, Sete Lagoas, 45 pp. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/475779. Acesso em: 10 out. 2025.

Cruz I 2000. Utilização do baculovírus no controle da lagarta-do-cartucho do milho, *Spodoptera frugiperda*. In IS Melo, JL Azevedo (eds.). *Controle biológico*. Embrapa Meio Ambiente, Jaguariúna, cap. 8, p. 201-230. Available from: http://www.alice.cnptia.embrapa.br/alice/handle/doc/484158. Acesso em: 16 out. 2025.

Cruz I, Figueiredo ML C, Silva RB 2010. Monitoramento de adultos de Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae) e Diatraea saccharalis (Fabricius) (Lepidoptera: Pyralidae) em algumas regiões produtoras de milho no Brasil. Documentos 93, Embrapa Milho e Sorgo, Sete Lagoas, 42 pp. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/879462. Acesso em: 06 out. 2025.

Cruz I, Waquil JM, Santos JP, Viana PA, Salgado LO 1986. *Pragas da cultura do milho em condições de campo: métodos de controle e manuseio de defensivos*. Circular técnica 10, EMBRAPA-CNPMS, Sete Lagoas, 75 pp. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/475356. Acesso em: 13 out. 2025.

Cruz I, Viana PA, Waquill JM [homepage on the Internet]. Sete Lagoas: Embrapa Milho e Sorgo; c2021 [cited 2025 Oct 10]. Pragas da Fase Vegetativa e Reprodutiva. Available from: https://www.embrapa.br/agencia-de-informacao-tecnologica/cultivos/milho/producao/pragas-e-doencas/pragas/pragas-da-fase-vegetativa-e-reprodutiva.

Cruz JC, Karam D, Monteiro MAR, Magalhães PC (eds.) 2008. *A cultura do milho*. Embrapa Milho e Sorgo, Sete Lagoas, 517 pp.

Davis FM, Ng SS, Williams WP 1992. Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. *CABI Agric Biosci* [serial on the Internet]. [cited 2025 Oct 20]. Available from: https://www.cabidigitallibrary.org/doi/full/10.5555/19931170718.

Díaz AS, Leal GN, Silva NF, Venâncio MG S, Figueiredo KG, Oliveira JAC, Lopes NJ [homepage on the Internet]. Santa Maria: Revista Cultivar; c2024 [updated 2024 Jul 31; cited 2025 Oct 26]. *Spodoptera frugiperda*: uma ameaça significativa para a agricultura brasileira. Available from: https://revistacultivar.com.br/artigos/spodoptera-frugiperda-uma-ameaca-significativa-para-a-agricultura-brasileira.

Duarte JO, Mattoso MJ, Garcia JC [homepage on the Internet]. Sete Lagoas: Embrapa Milho e Sorgo; c2021 [cited 2025 Oct 10]. Importância socioeconômica do milho. Available from: https://www.embrapa.br/agencia-de-informacao-tecnologica/cultivos/milho/pre-producao/socioeconomia/importancia-socioeconomica.

EMBRAPA [homepage on the Internet]. Brasília: Empresa Brasileira de Pesquisa Agropecuária; c2017 [updated 2017 May 9; cited 2025 Oct 26]. Pesquisa cria primeiro inseticida à base de vírus contra lagarta-do-cartucho. Available from: https://www.embrapa.br/busca-de-noticias/-/noticia/22266550/pesquisa-cria-primeiro-inseticida-a-base-de-virus-contra-lagarta-do-cartucho.

Fatoretto JC, Michel AP, Silva Filho MC, Silva N 2017. Adaptive potential of fall armyworm (Lepidoptera: Noctuidae)) limits Bt trait durability in Brazil. *J Integr Pest Manag* 8(1):17.https://doi.org/10.1093/jipm/pmx011.

Fernandes OD, Parra JRP, Neto AF, Pícoli R, Borgatto AF, Demétrio CGB 2003. Efeito do milho geneticamente modificado MON810 sobre a lagarta-do-cartucho, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae). *Rev Bras Milho Sorgo* 2(2):25–35. Available from: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/104589/1/Efeito-milho.pdf. Acesso em: 15 out. 2025.

Figueiredo MLC, Cruz I, Silva RB, Foster JE 2015. Biological control with *Trichogramma pretiosum* increases organic maize productivity by 19.4%. *Agron Sustain Dev* 35:1175-1183. https://doi.org/10.1007/s13593-015-0312-3.

Gallo D et al. 2002. *Entomologia agrícola*. 2. ed., FEALQ, Piracicaba.

Gomes JM, Godoy MS, Barreto RVG, Lira AG, Lima AG 2018. Controle biológico de *Spodoptera frugiperda* Smith, 1797 (Lepidoptera: Noctuidae) por bactérias. *Rev Verde Agroecol Desenv Sustent* 13(2):156-162. doi.org/10.18378/rvads.v13i2.5826

Guimarães DP, Sans LMA, Landau EC [homepage on the Internet]. Sete Lagoas: Embrapa Milho e Sorgo; c2021 [cited 2025 Oct 10]. Zoneamento agropecuário. Available from: https://www.embrapa.br/agencia-de-informacao-tecnologica/cultivos/milho/pre-producao/caracteristicas-da-especie-e-relacoes-com-o-ambiente/zoneamento-agropecuario.

Gullan PJ, Cranston PS 2017. *Insetos: fundamentos da entomologia*. 5. ed., Editora Roca, Rio de Janeiro, 912 pp.

Hernández-Trejo A, Drouaillet BE, Herrera RR, Giron JMG, Arellano SAP, Hernández EO 2019. Importancia del control biológico de plagas en maíz (*Zea mays* L.). *Rev Mex Cienc Agríc* 10(4):803–813. https://doi.org/10.29312/remexca.v10i4.1665

Instituto Brasileiro de Geografia e Estatística (IBGE) [homepage on the Internet]. Rio de Janeiro: IBGE; c2025 [cited 2025 Oct 10]. Produção de milho em grão no Brasil. Available from: https://www.ibge.gov.br/explica/producao-agropecuaria/milho-em-grao/br.

Ivan IAF, Silva KR, Loboschi DL, Araújo-Junior LP, Santos AJPS, Pinto AS 2016. Número de liberações de *Telenomus remus* no controle de ovos de *Spodoptera frugiperda* em milho de segunda safra. In *Anais do 31º Congresso Nacional de Milho e Sorgo*. Associação Brasileira de Milho e Sorgo, Bento Gonçalves, RS, p. 289-293. Available from: https://www.abms.org.br/cnms2016_trabalhos/docs/1153.pdf. Acesso em: 19 out. 2025.

Leite NA, Mendes SM, Waquil JM, Pereira EJG 2011. *O milho Bt no Brasil: a situação e a evolução da resistência de insetos*. Documentos 133, Embrapa Milho e Sorgo, Sete Lagoas, 46 pp. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/920730. Acesso em: 30 out. 2025.

Maddalena A, Abreu KG, Brito CH, Santana RF, Santos JPO, Salustino AS, Morais MM, Ribeiro LS, Silva RB 2024. Avaliação do efeito de *Metarhizium anisopliae* e *Beauveria bassiana* sobre ovos de *Spodoptera frugiperda* (Smith, 1797). *J Environ Anal Progress* 9(1):060–064. https://doi.org/10.24221/jeap.9.1.2024.6577.060-064

Medyk MA, Ferreira LG, Waureck A 2025. Controle biológico e químico de pragas na cultura do milho. *Scientia Rural* 29(1).

Montezano DG, Specht A, Sosa-Gómez DR, Roque-Specht VF, Sousa-Silva JC, Paula-Moraes SV, Peterson JA, Hunt TE 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. *Afr Entomol* 26:286–300. https://doi.org/10.4001/003.026.0286

Oliveira HF, Nunes J 2017. Eficiência de inseticidas no controle de *Spodoptera frugiperda* na cultura da soja. *Cultivando o Saber* (Edição Especial):162-176.

Parra JRP et al. 2021. Controle biológico com parasitoides e predadores na agricultura brasileira. FEALQ, Piracicaba, 592 pp.

Pereira Filho IA 2015. *Cultivo do milho*. 9. ed., Sistema de Produção 1, Embrapa Milho e Sorgo, Sete Lagoas.

Poletti M, Omoto C 2003. Resistência de inimigos naturais a pesticidas: Exploração de inimigos naturais a pesticidas em programas de manejo integrado de pragas. *Biotecnol Cienc Desenv* 6(30):16-26.

Pomari AF, Bueno AF, Bueno RCOF, Menezes Junior AO, Fonseca ACPF 2013. Releasing number of *Telenomus remus* (Nixon) (Hymenoptera: Platygastridae) against *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in corn, cotton and soybean. *Cienc Rural* 43:377-382. https://doi.org/10.1590/S0103-84782013005000013

Rosa APSA, Martins JFS 2011. Manejo da resistência de Spodoptera frugiperda a inseticidas na cultura do milho: situação atual. Documentos 334, Embrapa Clima Temperado, Pelotas, 18 pp.

Sabato EO 2017. Enfezamentos e viroses no milho. In *Construindo sistemas de produção sustentáveis e rentáveis: livr de palestras*. Associação Brasileira de Milho e Sorgo, Sete Lagoas, cap. 7, p. 196-219. Available from:http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1081658. Acesso em: 04 out. 2025.

Teodoro AV, Procopio S, Bueno AF, Negrisoli Junior AS, Carvalho HWL, Negrisoli CRC B, Brito LF, Guzzo EC 2013. *Spodoptera cosmioides* (Walker) e *Spodoptera eridania* (Cramer) (Lepidoptera: Noctuidae): novas pragas de cultivos da região Nordeste. Comunicado Técnico 131, Embrapa Tabuleiros Costeiros, Aracaju, 7 pp. Available from:http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/977625. Acesso em: 15 out. 2025.

Thomazoni D, Mamprim AP, Di Francisco L, Martinelo L, Marchese LPC, Formentini MA, Fanti ALP, Alves LFA 2009. Seleção de isolados de *Beauveria bassiana* e *Metarhizium anisopliae* visando o controle da lagarta-do-cartucho, *Spodoptera frugiperda* (Smith, 1797) (Lepidoptera: Noctuidae). *Cad Agroecol* 4(1). Available from: https://revista.aba-agroecologia.org.br/cad/article/view/4418. Acesso em: 06 nov. 2025.

Valicente FH 2009. Controle biológico de pragas com entomopatógenos. *Inf Agropec* 30(251):48-55. Available from: http://www.alice.cnptia.embrapa.br/alice/handle/doc/574316. Acesso em: 03 nov. 2025.

Valicente FH 2015. *Manejo Integrado de Pragas na cultura do milho*. Circular Técnica 208, Embrapa Milho e Sorgo, Sete Lagoas, 13 pp. Available from: https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1017489/1/circ208.pdf. Acesso em: 10 out. 2025.

Valicente FH, Cruz I 1991. *Controle biológico da lagarta-do-cartucho, Spodoptera frugiperda, com o baculovírus*. Circular Técnica 15, EMBRAPA-CNPMS, Sete Lagoas, 14 pp. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/471750. Acesso em: 30 out. 2025.

Valicente FH, Tuelher ES 2009. *Controle biológico da lagarta-do-cartucho, Spodoptera frugiperda, com baculovírus*. Circular Técnica 114, Embrapa Milho e Sorgo, Sete Lagoas, 14 pp. Available from: https://www.infoteca.cnptia.embrapa.br/bitstream/doc/660134/1/Circ114.pdf. Acesso em: 22 out. 2025.

Van Den Berg J, Du Plessis H, Reisig D 2022. Chemical control and insecticide resistance in *Spodoptera frugiperda* (Lepidoptera: Noctuidae). *J Econ Entomol* 115(6):1761-1771. https://doi.org/10.1093/jee/toac108

Viana PA, Mendes SM, Cruz I 2012. *Guia de inseticidas para a cultura do milho*. Comunicado Técnico 204, Embrapa Milho e Sorgo, Sete Lagoas. Available from: http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/954465. Acesso em: 13 out. 2025.

Vittia [homepage on the Internet]. São Joaquim da Barra: Vittia; c2025 [cited 2026 Apr 13]. Izaturbo®: inseticida microbiológico à base de *Cordyceps javanica*. Available from: https://vittia.com.br/produto/izaturbo/.

Weinzierl R, Henn T 1989. *Inseticidas microbianos*. Circular 1295, Faculdade de Agricultura, Universidade de Illinois, 11 pp.

Wordell Filho JA, Ribeiro LP, Chiaradia LA, Madalóz JC, Nesi CN 2018. *Pragas e doenças do milho: diagnose, danos e estratégias de manejo*. Boletim Técnico 170, Epagri, Florianópolis, p. 84.

Xu P, He Z, Gao X, Zeng X, Wei D, Long X, Yu Y 2025. Research on the expression of immune-related genes at different stages in the third-instar larvae of *Spodoptera frugiperda* infected by *Metarhizium rileyi*. *Insects* 16(2):199. doi.org/10.3390/insects16020199

Yan XR, Li JN, Sun ZY, Yan CC 2025. An insight into biology, function and pest management guidance of gut microbiota in *Spodoptera frugiperda*. *Insects* 16(12):1237. doi.org/10.3390/insects16121237