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Editorial
Trends in Bioinputs: Challenges and Opportunities

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Bioinputs encompass a diverse array of products, processes, or technologies derived from animal, plant, or microbial sources that effectively enhance agricultural production. These inputs are typically employed to bolster both the productivity and protection of agroecosystems, thereby promoting sustainability and facilitating a transition from conventional chemical-based inputs (Barbosa *et al.*, 2025; Vidal & Dias, 2023).

In Brazil, the adoption of bioinputs in agriculture reached two major milestones. In 2000, when the Ministry of Agriculture and Livestock (MAPA) approved the registration of a botanical extract from *Azadirachta indica* (commonly known as neem) for use as an insecticide, repellent, and growth regulator (Campos *et al.*, 2016). This approval spurred the creation of targeted legislation governing the production, distribution, and application of bioinputs. The second paradigm shift in favor of bioinputs occurred after 2013, following the outbreak of the exotic pest *Helicoverpa armigera* (Lepidoptera: Noctuidae) which caused multibillion-dollar losses to Brazilian agriculture. At that time, only the bacterium *Bacillus thuringiensis* provided satisfactory control of this pest (Dourado et al. 2016).

In 2020, Decree No. 10,375 established the National Bioinputs Program, providing the requisite regulatory framework and fostering sector expansion (Ramalho & Lopes, 2022). As one of the world's largest agricultural producers, Brazil's primary sector was expected to play a pivotal role in developing innovative bioinputs technologies on a short timeline. Consequently, these alternatives for the agribusiness sector gained momentum nationwide, resulting in the production of beneficial microorganisms, plant extracts, biological derivatives, and related products. Bioinput development stands out particularly for replacing agrochemicals, thereby mitigating the negative environmental impacts of agricultural production, preserving biodiversity, and enhancing soil health and fertility (Corrêa *et al.*, 2025).

The utilization and development of natural products (NPs) derived from plant secondary metabolism as agricultural bioinputs hold paramount importance. This relevance stems from the diverse classes of natural compounds, such as essential oils, triterpenes, alkaloids, naphthoquinones, flavonoids, and others, that function in plants as pollinator attractants, natural predator repellents, and secondary metabolic adaptations promoting species perpetuation (Duran-Lara *et al.*, 2020). When extracted from plants via various feasible methods, these natural products can be applied in bioprospecting, that is, their viable utilization in alternative applications, such as phytosanitary control in crops (Souza *et al.*, 2025). The extract of *A. indica*, one of the most prominent examples previously cited herein, exhibits well-documented biochemical activity attributable to azadirachtin, a tetranortriterpenoid isolated from the plant's seeds through liquid-liquid extraction, followed by fractionation and purification using chromatographic techniques (Silva *et al.*, 2024). Diverse hotspots, including natural products from Brazilian Cerrado plants, are regarded as highly promising for developing novel technologies in this field.

Beneficial microorganisms have been used in seed treatment before sowing. Studies indicate yield increases when used at the recommended dose (Costa *et al.*, 2019). However, research demonstrates potential negative impacts on the physiological quality of treated seeds (Feliceti *et al*., 2023). These effects are dependent on the cultivar, seed physiological quality (Lima *et al*., 2021) and the laboratory test conditions, such as absence of substrates and organic compounds, high humidity, and lack of pathogens, as well as product features such as metabolite production by each strain, dose, and formulation ingredients (Faria *et al*., 2025).

Reducing the use of synthetic insecticides in agriculture has become a global demand. Excessive use of synthetic insecticides has selected resistant insects that have become a significant challenge to integrated pest management - IPM (Almeida et al. 2025). Also, pesticides can add toxic residues to food crops, eliminate natural enemies, contribute to pest resurgence and present risks to the applicator and cause environmental contamination (Bueno et al. 2010).

Efficient and environmentally control strategies are needed to be developed to use as a strategy in IPM. In this sense, the use of biological agents has increased in recent years, in Brazil. For example: the use of entomopathogenic fungi *Beauveria bassiana* (Hypocreales: Cordycipitaceae), *Metarhizium anisopliae* (Hypocreales: Clavicipitaceae), *Cordyceps* (Isaria) *fumosorosea*, *Cordyceps javanica* (Hypocreales: Cordycipitaceae) have been used in the control of agricultural pests (Boaventura and Quintela, 2025). *M. anisopliae* is used in the control of *Euschistus heros* (Hemiptera: Pentatomidae) in soybean. *B. bassiana* in the control of *Anthonomus grandis* (Coleoptera: Curculionidae) in cotton, *Hypothenemus hampei* (Coleoptera: Scolytidae) in coffee, several genera of termites, *Helicoverpa armigera* (Lepidoptera: Noctuidae), and whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae) in many crops. *C. javanica* presented efficacy in controlling *Dalbulus maidis* (Hemiptera: Cicadellidae) in maize, whitefly and citrus psyllid (Sousa et al. 2023; Almeida et al. 2025).

Another useful tool in IPM is the bacterium *Bacillus thuringiensis* (Bt). The cry proteins from Bt as biological pesticide used in pest control against insects from the orders Lepidoptera, Coleoptera, Hemiptera, Neuroptera, Orthoptera, Siphonaptera, Thysanoptera, and Isoptera (Glare and O'Callaghan, 2000). In Brazil, Bt toxins has been widely used to control lepidopteran caterpillars in several agricultural crops (Valicente, 2019).

Entomopathogenic viruses from the Baculovidae family have been used efficiently in the control of caterpillars in important agricultural crops such as: *Anticarsia gemmatalis* and *Chrysodeixis includens* (Lepidoptera: Noctuidae) in soybean, *S. frugiperda* in corn, and *H. armigera* in several crops. Another biological control program is the use of entomopathogenic nematodes from the Heterorhabdidiidae and Steinernematidae families, mainly in sugarcane for the control of *Sphenophorus levis* (Coleoptera: Curculionidae) and other pests such as *S. frugiperda* and *Conotrachelus psidii* in guava. However, this program is incipient, with the advances in research, these control agents will be promising for use in IPM (Andaló et al. 2019)

Other biological control program in Brazil involves the control of lepidopteran pests using parasitoid insects. Among the main species used are *Trichogramma pretiosum* (Hymenoptera: Trichogrammatidae) to control *Spodoptera frugiperda*, *Chloridea virescens*, *Helicoverpa armigera*, *Helicoverpa zea*, and *Trichogramma galloi* (Hymenoptera: Trichogrammatidae) to control *Diatraea saccharalis* (Lepidoptera: Crambidae), and *Cotesia flavipes* (Hymenoptera: Braconidae) to control larvae of *D. saccharalis* (Silveira et al. 2019).

Beyond direct mortality, Oliveira et al. (2025) demonstrated that entomopathogenic fungi can significantly impair pest feeding behavior, providing an additional mechanism of biological control, reducing the frequency and duration of feeding activities of *Euschistus heros*, particularly stylet penetration and seed ingestion. Subtle changes in plant or pest status—such as stress and feeding behavior dynamics can be detected with the adoption of real-time acquisition of data, such as thermal imaging (Oliveira et al., 2026).

However, these advancements would be futile if such technologies were not developed in a viable manner for Brazilian farmers. In this regard, initiatives such as the Center of Excellence in Bioinputs were established to drive economic, social, and environmental development through innovations in the field, fostering practical technologies for agriculture and livestock production. Bioinput technology development currently encompasses multiple stages beyond the mere production of technical products to address field challenges. It also involves business management, training of skilled labor, and engagement of researchers to ensure the feasibility of solutions. For effective technology development and transfer, it is essential to consider factors such as soil health, sustainability, food security and agricultural productivity, institutionally structuring this rapidly expanding productive sector, which is currently underway.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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