BIOINPUTS REVOLUTION BY BRAZILIAN FRUIT PRODUCTION: BIOLOGICAL AGENTS, MECHANISMS, AND MARKET GROWTH

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Abstract: The Brazilian market has seen growing government support for biological inputs—natural or bio-based products used in agriculture. These inputs are becoming key alternatives in **Integrated Fruit Production (IFP),** promoting sustainability. This study compiles information on **bioinput applications in fruit farming,** including their main biological agents, mechanisms of action, and market trends in Brazil. Research highlights **biostimulants, biofertilizers, biodefenses, and postharvest coatings** as major bioinput categories. These products enhance crop growth, improve stress resistance, and support eco-friendly pest and disease management. Their adoption aligns with Brazil's push for **sustainable agriculture**, reducing reliance on synthetic chemicals while maintaining productivity. The Brazilian bioinput market is expanding rapidly, driven by demand for **higher yields and environmentally safe practices.** Technologies based on plant extracts and microorganisms help improve soil health and reduce toxicity risks for workers and ecosystems. Additionally, bioinputs boost the **competitiveness of Brazilian fruits in global markets** by ensuring high-quality, residue-free produce. Future research should focus on **optimizing bioinput efficiency**, exploring their effects on different fruit varieties, and refining sustainable practices to enhance crop performance from growth to postharvest. This approach supports Brazil's agricultural innovation while meeting global sustainability standards.
Index Terms: biological products; biostimulant; biofertilizers; biodefensive.

REVOLUÇÃO DOS BIOINSUMOS NA FRUTICULTURA BRASILEIRA: AGENTES BIOLÓGICOS, MECANISMOS E CRESCIMENTO DE MERCADO

Resumo: O mercado brasileiro tem recebido crescente apoio governamental para bioinsumos — produtos naturais ou de base biológica utilizados na agricultura. Esses insumos estão se tornando alternativas essenciais na Produção Integrada de Frutas (PIF), promovendo sustentabilidade. Este estudo compila informações sobre a aplicação de bioinsumos na fruticultura, incluindo seus principais agentes biológicos, mecanismos de ação e tendências de mercado no Brasil. A pesquisa destaca biostimulantes, biofertilizantes, biodefensivos e revestimentos pós-colheita como as principais categorias de bioinsumos. Esses produtos melhoram o crescimento das culturas, aumentam a resistência a estresses e auxiliam no manejo ecológico de pragas e doenças. Sua adoção está alinhada com os esforços do Brasil por uma agricultura sustentável, reduzindo a dependência de químicos sintéticos sem comprometer a produtividade. O mercado brasileiro de bioinsumos está em rápida expansão, impulsionado pela demanda por maior produtividade e práticas ambientalmente seguras. Tecnologias baseadas em extratos vegetais e microrganismos ajudam a melhorar a saúde do solo e reduzem riscos de toxicidade para trabalhadores e ecossistemas. Além disso, os bioinsumos aumentam a competitividade das frutas brasileiras no mercado global, garantindo produtos de alta qualidade e livres de resíduos. Futuras pesquisas devem focar em otimizar a eficiência dos bioinsumos, investigar seus efeitos em diferentes variedades frutíferas e aprimorar práticas sustentáveis para melhorar o desempenho das culturas — desde o crescimento até a pós-colheita. Essa abordagem fortalece a inovação agrícola brasileira, alinhando-se aos padrões globais de sustentabilidade.
Termos para Indexação: Produtos Biológicos; Bioestimulantes; Biofertilizantes; Biodefensivos.

INTRODUCTION

Over the past years, significant growth has occurred in government initiatives promoting research and commercialization of Bioinputs - biological substances (including fungi, bacteria, and viruses) and natural compounds (extracts and derivatives). Among these, plant-beneficial microorganisms have emerged as particularly valuable agents for improving plant health without adverse environmental impacts (Goulet & Hubert, 2020). Policies like the Ministry of Agriculture's 'National Bioinputs Program' leverage Brazil's biodiversity to stimulate research, production, and use of biological products across agricultural sectors (MINISTRY OF AGRICULTURE AND LIVESTOCK, 2025; EBC AGENCY., 2025).

While Bioinput research initially focused on major crops like soy and corn, increasing attention is being directed toward fruit production due to its agricultural significance. These biological tools offer cost reduction, decreased environmental impact, and reduced dependence on synthetic inputs while enhancing plant growth, development, and environmental interactions. Biostimulants, biofertilizers, and biodefenses have shown particular success in commercial fruit production, for example, around of 64% of Brazilian farms used biofertilizers in crops fields and 61% used biodefensis for crop protectctions (EBC AGENCY., 2025).

Despite growing adoption, synthetic fungicides remain prevalent in fruit cultivation due to their immediate efficacy, despite requiring multiple applications (Mohd Zainudin, Abd Murad e Shaari, 2024). Current research explores improved application methods, logistics, and storage solutions to enhance bioinput effectiveness for fruit production (Iñiguez-Moreno *et al*., 2021).

Eaching US$1.2 billion in the 2024/25 season (a 46% increase from 2022/23), while the Latin American market is valued at US$11 billion (CROPLIVE, 2025). However, market growth faces challenges including limited producer awareness and regulatory hurdles. Until 2021, bioinputs were regulated under laws designed for agrochemicals (Decree 4,047/02), lacking specific guidelines (Castellanos, 2021). Currently, two bills (Law No. 658/2021 and Law No. 3668/2021) propose specific regulations for bioinput classification, production, and agricultural use (Agência Senado, 2023).

This review compiles comprehensive information on bioinput applications in fruit production, examining biological agents, mechanisms of action, and Brazilian market projections.

METHODOLOGY

The research involved systematic searches across academic databases (Periódico Capes, ResearchGate, Scielo, Google Scholar), thesis repositories, and government sources (Buitrago, García-Suaza, Garzón-Restrepo, 2024), using key terms including 'bioinputs', 'biostimulants', and 'biological products in fruit production' without date or language restrictions, for the last 10 years in relation to 2025 January.

The article comprises four sections: (1) The National Bioinputs Program's role in technological innovation and biodiversity utilization; (2) Commercial bioinput products (biostimulants, biopesticides, biofertilizers, postharvest coatings); (3) The Brazilian bioinputs market landscape; and (4) Sustainability impacts, emphasizing reduced non-renewable resource dependence and enhanced agricultural resilience.

NATIONAL BIOINPUTS PROGRAM

In Brazil, the Ministry of Agriculture, Livestock, and Supply launched the National Bioinputs Program through Decree No. 10,375 on May 27, 2020. This initiative is part of the Ministry’s broader bioeconomy strategy, which seeks to promote access to, development of, and the sustainable use of the country’s rich biological diversity. The program aims to foster technological innovation while delivering economic benefits and improving the quality of life for producers across all stages of agricultural production, as well as for society as a whole (Brasil, 2020).

As part of the program’s initial phase, the **‘Bioinsumos’ mobile application** was developed in collaboration with Embrapa Agricultural Informatics. Available for both iOS and Android devices, the app is designed to facilitate access to biological-origin products recommended for nutrition, pest control, and disease management. Unlike Agrofit—which classifies products by crop—the Bioinsumos app allows users to search for inputs based on the specific pest they wish to control (Vidal *et al*., 2021).

COMMERCIAL PRODUCTS BASED ON BIOINSUMPTS

Bioinputs include a wide variety of products, including inoculants, biostimulants, biofertilizers and biological pesticides, formulated with beneficial microorganisms or plant extracts to control pests and diseases. This category also includes herbal products and technologies with biological components used for various purposes, such as the treatment of plants and animals, as well as for postharvest processing (Vidal *et al*., 2021).

According to their composition, some bioproducts contain amino acids as the main active ingredient, which benefits plants by facilitating the absorption of water and nutrients (Zulfiqar *et al*., 2024). In temperate fruit plants, for example, the use of amino acids has become common for protecting buds and fruits against damage caused by frost, in addition to improving the effectiveness of specific fungicides in disease control (Ruzzi *et al*., 2024; Zulfiqar *et al*., 2024).

Bacillus spp. based-products are the most importnt exemaple, they widely used during the flowering and preharvest periods, aiming to reduce the incidence of fruit rot in the postharvest phase (Ruzzi *et al*., 2024). These products can affect phytopathogens in several ways, including through antibiosis, competition for resources and activation of the plant defense system. The transition toward replacing agricultural inputs that are harmful to public health and the environment fundamentally requires the adoption of biological control, which is defined as the use of living organisms to suppress the population of a specific pest, decreasing its abundance or decreasing its harmfulness (Embrapa, 2025).

Currently, in Brazil, plant growth-promoting bacteria are cultivated on approximately 40 million hectares, and products for biological pest control are cultivated on more than 10 million hectares. To give you an idea, the use of biological inputs generates annual savings of approximately US$ 13 billion for Brazil, thanks to the process of biological nitrogen fixation (BNF), exclusively in soybean crops. Furthermore, there are savings of approximately R$165 million resulting from the application of products for biological pest control (Soares, 2022).

Biostimulants

Plant biostimulants are products of biological origin, including microorganisms, which, when applied to plants or soil (roots), stimulate physiological processes promoting improved plant performance, increased growth and production, increased tolerance to stresses (biotic and abiotic), and increased product quality. Therefore, the definition of plant biostimulants is strongly linked to changes in the physiological functions of plants. The biostimulant is therefore considered an abiotic stress attenuator, as it assists in the physiological processes of plants, ensuring their survival in unfavorable environments (Ruzzi *et al*., 2024).

Algae extracts (AEs) are the main plant biostimulants available on the market (DU *et al*., 2015), and the brown alga *Ascophyllum nodosum* is the most commonly used species. These compounds can affect the growth and productivity of many crops, in addition to improving the quality of fruits. Another widely used algae is *Ecklonia maxima*, which has proven effective at improving plant growth and has shown positive results in terms of fruit quality (Rouphael *et al.,* 2017; Kulkarni *et al*., 2019).

Another widely used type of plant biostimulant in agriculture is protein hydrolysates (PHs), which consist of complex mixtures of oligopeptides, polypeptides, and amino acids. Their composition varies depending on the protein source and hydrolysis method (Johnson, Joel and Puthur, 2024). PHs have been shown to enhance plant nutrition and improve the quality of fruits and vegetables (Cardelari *et al*., 2024). For instance, a study on young olive trees (Leccino cultivar) demonstrated that the application of biostimulants containing protein hydrolysates significantly increased plant growth compared to the control group (Almadi et al., 2020).

Research also indicates that biostimulants can improve fruit quality. For example, Syncron®—a biostimulant used to induce budding and flowering in situations where insufficient chilling limits natural flowering—contains glutamic acid (which supports nitrogen transport) and osmoprotective and cryoprotective agents like proline and serine (Ruzzi et al., 2024).

Other studies support the benefits of biostimulants: Guimarães et al. (2015) reported that the biostimulant Root® enhanced the growth and development of papaya plants, while Ribeiro et al. (2017) found it to be a valuable tool in improving the quality of grapevines (cv. Crimson Seedless).

However, the efficacy of biostimulants depends on multiple factors, including product composition, application method, dosage, phenological stage, nutritional status, environmental conditions, and plant species (Ruzzi et al., 2024). This variability means that the same biostimulant may yield different results even within the same species, underscoring a lack of standardization in evaluating the effects and efficacy of these products (Johnson, Joel and Puthur, 2024; Ruzzi *et al*., 2024).

Biological pesticides

Biological control has emerged as an effective alternative to pesticides, offering a sustainable approach to managing pests and diseases and mitigating the damage associated with the excessive use of chemicals. To this end, it is very important that producers be aware of these advantages for their viability and adoption. The benefits of these methods include ensuring worker safety, ensuring environmental preservation, eliminating the waiting period between application and harvest, precisely targeting target organisms and ensuring that biological agents can remain in the harvest indefinitely under suitable conditions (Matten *et al*., 2024).

Furthermore, biological control methods are environmentally friendly, do not generate pollution, and are economically accessible options. However, these methods face limitations, such as the availability of effective strains, challenges in marketing products with live organisms, limited periods of activity, lack of awareness among farmers and inexperienced personnel, and high initial production costs (Johnson, Joel and Puthur, 2024).

Bioinsecticides

Bioinsecticides play a fundamental role in sustainable agriculture by protecting crops against pests while minimizing environmental impact. Unlike conventional chemical pesticides, they are derived from microorganisms or their byproducts and can be categorized into formulations based on fungi, viruses, nematodes, and bacteria (Embrapa, 2025). Key advantages include their targeted action against specific pests, reduced toxicity, applicability at low concentrations, and rapid degradation. These properties help decrease reliance on synthetic pesticides and mitigate ecological harm (Nascimento et al., 2024). The effective use of bioinsecticides has demonstrated significant success in reducing pest populations in Brazilian agriculture, as illustrated by the following examples of widely adopted bioinsecticides in the region.

a) Beauveria bassiana is a biological insecticide formulated (50 g kg^{-1}), effective against insect larvae, pupae, and adults by colonizing the host and causing death within 72 hours (Agrolink, 2025). Applications are recommended at 7, 10, or 21-day intervals at 0.5–1 kg ha^{-1}, ideally in the late afternoon or on cloudy days with temperatures between 25–35 °C and humidity above 60%. Storage under refrigeration (0–4 °C) extends shelf life up to 180 days, and at -12 to -4 °C, up to 365 days. Although not officially used in banana cultivation, studies by Moreira et al. (2017) confirmed its effectiveness in controlling *Cosmopolites sordidus* (banana weevil), particularly at higher concentrations (10–20 g/L), showing good adaptation to local climates (Brasil, 2025).

b) ***Bacillus thuringiensis*** (Bt) is a biological insecticide based, which produces enzymes and endotoxins that disrupt the insect gut, leading to death (Ragasruthi et al., 2024). Studies show its high efficacy, in a classical papers, Morandi-Filho et al. (2007) reported 91% mortality of *Argyrotaenia sphaleropa* in grape leaves after 72 hours, and Lima et al. (2009) observed promising results combining Bt and *Arazadactina indica* leaves against *Spodoptera frugiperda*. Monteiro and Souza (2010) also confirmed its effectiveness against *Bonagota salubricola* in apple orchards. Registered with Brazil's Ministry of Agriculture, DIPEL WG is Bt based-product widely used in crops like pineapple—applied from the onset of floral emergence every 15 days—and citrus, as part of Integrated Pest Management, with control measures triggered when up to 10 fruits show signs of pest damage (Adapar, 2025), in Table 1.

Table 1. Scientific and popular names and dosage of ***Bacillus thuringiensis*** based products.

Cultures	**Scientific name**	**Popular name**	**Dosage (p.c.)**
All crops with occurrence of the biological target	*Alabama argillacea*	Curuquerê	700 g ha^{-1}
	Anticarsia gemmatalis	Lagarta da soja	250 a 300 g ha^{-1}
	Argyrotaenia sphaleropa	Lagarta das fruteiras	50 a 75 g 100 L^{-1} of water
	Diaphania nitidalis	Broca dos frutos	500 a 700 g ha^{-1}
	Diatraea saccharalis	Broca do colmo	750 g ha^{-1}
	Ecdytolopha aurantiana	Bicho furão	25 a 37,5 g 100 L^{-1} of water
	Erinnyis ello	Mandarová	500 a 700 g ha^{-1}
	Grapholita molesta	Mariposa orienta	100 g 100 L^{-1} of water
	Helicoverpa armigera	Helicoverpa	500 a 700 g ha^{-1}

Manduca sexta paphus	Mandarová do fumo	500 a 700 g ha^{-1}
Plutella xylostella	Traças das crucíferas	100 a 125 g 100 L^{-1} of water
Pseudoplusia includens	Lagarta-falsa-medideira	300 a 400 g ha^{-1}
Strymon basalides	Broca do fruto	100 a 125 g ha^{-1}
Tuta absoluta	Traça do tomateiro	750 a 1000 g ha^{-1}

p.c.: commercial product

(*)Product with proven efficiency for crops: Pineapple, Cotton, Sugarcane, Citrus, Beans, Tobacco, Apple, Cassava, Melon, Cabbage, Soy, Tomato and Grape

Biofungicide

Biofungicides are highly advantageous alternatives to synthetic fungicides because of their ability to be applied at any stage of crop development, including harvest day. This flexibility eliminates the need for a withdrawal period (Ihara, 2025; Agro Bayer, 2025).

In fruit growing, two genera of biological agents stand out as biofungicides: *Bacillus* spp. and *Trichoderma* spp. These microorganisms play crucial roles in protecting plants against fungal diseases, providing a sustainable and effective approach to phytosanitary management (Valenzuela Ruiz et al., 2025; Thambugala *et al*., 2020).

a) Bacillus spp.

Species of the genus *Bacillus* have been widely studied and applied; these species are distinguished by their ability to promote plant growth and their effective potential in the biocontrol of diseases that affect several agricultural crops (Ajuna et al., 2024). This relevance is particularly notable in the context of managing diseases caused by the soil-born pathogens (Ihara, 2025; Agro Bayer, 2025).

Serenade® Max, developed by Bayer, is a product of natural origin based on the Between them, the *Bacillus subtilis* strain QST 713 is a wet table powder containing 15.67% (w/w) *Bacillus subtilis* QST 713. This product is formulated to effectively control diseases caused by fungi or bacteria in various crops, such as strawberry, banana, mango, avocado, cashew, persimmon, grape, guava and papaya plants. It stands out for its four modes of action: creation of an inhibition zone in the leaf, secretion of antagonistic lipopeptides, induction of systemic resistance in the plant through peroxidase and affecting mycelial growth, and modification of pathogen membranes (Agro bayer, 2025).

Certified by BioGro for organic production, Serenade® Max has been shown to be effective at controlling gray rot (*Botrytis cinerea*) in grapevines (Anonymous, 2011). Its main mechanism of action involves the production of lipopeptides that destroy pathogen membranes, providing a resistance management strategy and potential synergy with single-site fungicides (Ajuna et al., 2024).

According to Thomidis (2016), Serenade® Max can be a viable alternative for controlling grape rot during organic fruit production. It is recommended that a spraying program that includes Serenade® Max in conjunction with the application of fungicides in integrated fruit production systems be implemented to reduce the incidence of rot. It is worth mentioning that this product has specific registration for vine cultivation.

b) Trichoderma spp.

Soil-borne fungi of the genus *Trichoderma* spp. are promising biofungicide agents widely used to combat various pathogens affecting roots, leaves, and postharvest fruits. Their effectiveness stems from a unique combination of traits, including rapid growth and reproduction rates, target specificity, efficient nutrient assimilation, tolerance to diverse biotic and abiotic conditions, ability to modulate the rhizospheric environment, and induction of plant defense mechanisms (Zin & Badaluddin, 2020; Thambugala et al., 2020).

Studies show that *Trichoderma harzianum* isolates, applied individually or in combination, are effective in controlling both anthracnose and gray mold in strawberry plants. These fungi operate through mechanisms such as antagonism, antibiosis, and mycoparasitism, and combining different isolates can enhance their efficacy against pathogens. However, controlling gray mold requires periodic applications to maintain effectiveness (Jin & Alberti, 2025).

In banana cultivation, preventive application of *Trichoderma* spp. reduced root-knot nematode populations two months after inoculation and has become a valuable tool for managing Panama disease (Taribuka et al., 2017). For other crops, such as melon, products based on *Trichoderma* species are registered with the Ministry of Agriculture in Brazil and recommended for controlling fungal pathogens (e.g., *Rhizoctonia solani* and *Macrophomina phaseolina*) and nematodes (e.g., *Pratylenchus* spp. and *Meloidogyne incognita*) (Brazil, 2025).The product is registered with the Ministry of Agriculture, Livestock and Supply for some crops, as shown in Table 2.

Table 2 - Information on the use of a quality WG-dispersible granulated formulation based on *Trichoderma* sp. for the control of diseases caused by soil-borne phytopathogens in various crops.

Culture	**Formulation WG**		
	Application method	**Time and number of applications**	**Dose/Application**
Hydroponics		Each renewal reapply	750 g 1000 L^{-1}
Potato	Planting furrow	Planting(1)	300 g ha^{-1}
Potato	Pulverization	landfill (1)	300 g ha^{-1}
Sugarcane	Planting furrow	Planting(1)	200 a 300 g ha^{-1}
Banana	Seedling treatment (by immersion)	Planting(1)	2 g L^{-1} of water
Banana	Pulverization	Vegetative phase (every 30 days)	200 a 300 g ha^{-1}

Strawberry	Seedling treatment (by immersion)	Planting (every 30 days)	2 g L^{-1} of water
Strawberry	Spray or drip	30 days after planting (every 30 days)	200 g ha^{-1}

Biofertilizers

Depending on their composition, biofertilizers can supply all essential macro- and micronutrients required for healthy plant growth and development (Moradi et al., 2024). Adequate nutrient availability enhances plants' natural defense mechanisms against insects, mites, fungi, and other pathogens. Additionally, as living products, biofertilizers introduce microorganisms that compete with or inhibit plant pathogens, leading to their destruction or suppression (Liu *et al*., 2024).

Numerous studies across diverse crops demonstrate the benefits of biofertilizers. For instance, Mazaro et al. (2013) reported significant increases in productivity, average fruit size, and total fruit number in strawberry plants following biofertilizer application. Similarly, Lima et al. (2019) observed notable improvements in yellow passion fruit cultivation, especially with increased application frequency, underscoring the potential of biofertilizers to enhance crop performance. Globally, countries are increasingly adopting natural alternatives to chemical fertilizers and pesticides to mitigate environmental pollution and reduce production costs (Alalaf, 2019). Among these, biofertilizers stand out as a promising sustainable solution, containing living organisms that improve nutrient availability and address key challenges in modern agriculture (Moradi *et al*., 2024; Liu et al., 2024).

A notable example in Brazilian agriculture is Soil-Set™, a compound produced through fermentation that stabilizes nutrient flows and supports crop protection. Its formulation includes sulfur, copper, iron, manganese, and zinc derived from sulfates. The product enhances rhizospheric balance, stimulates soil microbiological activity, and suppresses pathogenic microorganisms. Application rates are crop-specific, with tailored dilution guidelines per hectare. Studies also indicate that Soil-Set™, when combined with FitoForce Plus, effectively suppresses *Xanthomonas campestris* pv. *passiflorae*, highlighting its potential for pathogen control in cultivation systems (Ferreira, 2019).

Postharvest coatings and new technologies

Fruit quality is influenced by both cultivation management and climatic conditions, but postharvest measures are essential to prevent microbiological deterioration and mitigate physiological and biochemical changes (Sharma *et al*., 2024). Due to their high moisture content and active metabolism, fruits are prone to dehydration, mechanical damage, environmental stress, and fungal diseases, which limit their shelf life (Ali *et al*., 2025).

Edible coatings have emerged as effective solutions, serving as physical barriers that reduce respiratory activity and ethylene production, thereby extending postharvest longevity. These coatings also exhibit antimicrobial, antioxidant, and antifungal properties (Iñiguez-Moreno et al., 2021). Composed of materials such as nanoparticles, alginate, proteins, and polysaccharides, they are applied via immersion or spraying. Their efficacy is measured by adhesion, gas permeability, reduction in water loss, inhibition of ethylene production, shelf-life extension, and maintenance of sensory qualities. They are safe, nontoxic, and economical (Sharma *et al*., 2024). Recent advancements incorporate biological compounds like antioxidants, antimicrobials, nutraceuticals, and flavoring agents to enhance functionality (Shinga, Silue, & Fawole, 2025).

Specific studies demonstrate the benefits:

- Bananas: Chitosan coatings delayed moisture loss, respiration, ethylene production, and climacteric peaks, reducing weight loss and slowing soluble solids accumulation. They maintained firmness, delayed skin color changes, and reduced anthracnose incidence (Wantat *et al*., 2021).

- Avocados: Sodium alginate (SA) coatings, especially with *Meyerozyma caribbica* (SAY), delayed ripening, reduced weight loss, maintained firmness, and improved color and internal appearance for up to 17 days (Iñiguez-Moreno *et al*., 2021).

- Guavas: Alginate-chitosan coatings with ZnO nanoparticles inhibited *Phyllosticta psidicola* growth and preserved quality for 20 days, with chitosan-rich formulations delaying pigment degradation (Arroyo *et al*., 2020).

- Mangoes: Preharvest application of thyme oil and chitosan suppressed *C. gloeosporioides* (anthracnose), maintained firmness, reduced weight loss, and improved sensory and enzymatic markers of pathogen resistance (Shah *et al*., 2021). These findings underscore the potential of edible coatings as sustainable tools for postharvest preservation across diverse fruit species.

PORTRAIT OF THE BIOINPUTS MARKET IN BRAZIL

In 2019, the Brazilian federal government launched a specific part of the Plan for Agroecology and Organic Agriculture (Planapo 2) related to bioinputs. This initiative aimed to promote organic agriculture as a sector that was not only a niche but also strengthened Brazil's position in agricultural exports. Furthermore, agribusinesses could benefit from technological and biotechnological innovations in the field of biological inputs (POLICARPO *et al*., 2023). The concept of bioinputs, previously associated with alternatives to agribusiness, began to play a fundamental role in promoting agriculture based on bioeconomic guidelines, more information's for Brazil fields using Bioinputs can be see in Corrêa et al. (2024)

Bioinputs represent an attempt to align interests that previously seemed opposed: the dominant agribusiness regime aimed at global markets and agroecological approaches aimed at small farmers in disadvantaged rural areas. The development of bioinputs aims to reconcile the interests of rural areas and Brazil as a whole, seeking to balance issues such as employment, wealth distribution, productivity and environmental protection. This approach seeks to unite advanced technologies with ecological practices to promote sustainable development (Sharma *et al*., 2024; Ali *et al*., 2025).

The increase in bioinputs represents a significant change, going beyond the conversion of large producers to organic agriculture in Brazil. These inputs are designed to serve all farmers, regardless of whether they are organic or conventional or regardless of the size of their operations, including both large and small farmers, in according to Corrêa *et al*. (2024).

The demand for biological pesticides is mainly concentrated in soybean crops (62% of the total market), corn (23%) and sugar cane (10%). The consultancy department predicts that the adoption of these inputs should continue to increase in the coming years for crops such as corn, coffee, beans and horticulture. Bioinsecticides led to 30% of the total sales, followed by bionematicides (24%) and biofungicides (13%) (CROPLIVE, 2025).

The strategic intelligence considers that the trend toward integrating biological products into producer management is solidified, driven by the growing supply of products and technological innovations in the area (POLICARPO *et al*., 2023). The multiplication of technical information in the field and the need to diversify products to contain pest resistance also contribute to the expectation of economic growth of these products in the coming harvests (Sharma *et al*., 2024; Ali *et al*., 2025).

Additionally, according to research by Spark Inteligencia Estratégica, the bioinputs market experienced significant growth in the 2024/2025 harvest, reaching more than 156 billion ha (CROPLIVE, 2025).

Promotion and credit for bioinputs

The 2024/2025 Harvest Plan is currently in the spotlight for its specific measures aimed at sustainability in agriculture, especially through the RenovAgro and Inovagro Programs. This comprehensive financing plan encompasses not only the production of bioinputs but also conservation practices, offering attractive interest rates set at 10% p.a. for bioinputs. Furthermore, the plan's focus extends to strengthening sustainable production systems, with a reduction in interest rates for the recovery of pastures and incentives for sustainable agricultural practices. Additionally, noteworthy are incentives such as the reduction in funding interest rates for producers with an analyzed Rural Environmental Registry, with the possibility of accumulating reductions, reaching an interest rate as low as 1%. It is worth mentioning that the ABC Program was renamed RenovAgro and now incorporates specific financing for sustainable and low-carbon practices in agriculture (Brasil, 2025).

Moreover, the 2024/2025 Harvest Plan provides crucial support for the recovery of degraded pastures used for agricultural production. In a complementary way, the Inovagro program seeks to stimulate the use of bioinputs and the construction of biofactories. These initiatives are intertwined in a cohesive way, converging to promote sustainable agriculture and strengthen the capacity to adapt to climate change (Brasil, 2025).

SUSTAINABILITY AND IMPACTS OF BIOINPUTS IN THE AGRICULTURAL PRODUCTION SYSTEM

The sustainability of the production system is intrinsically linked to the characteristics of the inputs used, which are fundamentally related to reducing the dependence on nonrenewable resources. In this context, the notable relationship between the genetic material used and the amount of inputs needed highlights the importance of more resistant reproductive materials capable of demanding fewer resources. Thus, biological inputs emerge as protagonists, highlighting the potential of biological assets as fundamental for sustainable production systems (Moradi *et al*., 2024).

With respect to impactful input substitution strategies, the development of biological inputs aimed at supporting plant protection and nutrition has become an undeniable trend. Based on this premise, Embrapa plays a significant role in promoting the sustainability of production systems by combining the maintenance of productivity with environmental protection (Embrapa, 2025a, b, c).

In the field of crop protection, the development of *Baculovirus*-based biopesticides is a safe and effective alternative to chemical products for caterpillar control because of the associated lower costs and reduced environmental impact (Embrapa, 2024). Among the promising results, scientific proof of the feasibility of using neem leaf extract (*Azadirachta indica*) as an insecticide to control the fall armyworm (*Spodoptera frugiperda*) in crops such as corn and various fruit trees is essential (Embrapa, 2025a).

Therefore, the incorporation of these biopesticides into agricultural practices not only provides robust protection to fruit crops but also significantly contributes to promoting sustainability and reducing the environmental impact associated with the use of conventional phytosanitary products (Sharma *et al*., 2024; Ali *et al*., 2025). This integrated approach stands out as an effective strategy for facing phytosanitary challenges in the fruit sector, promoting more sustainable and resilient practices (Ajuna *et al*., 2024).

CONCLUSION

The integration of bioinputs into orchard management offers significant advantages, both nationally and internationally. These inputs enhance the quality and safety standards of agricultural products, making them essential for meeting the growing demands of consumers and global markets. Increasing concern for sustainability and health in food production is driving the acceptance and preference for farming practices that incorporate bioinputs into cultivation systems.

The use of bioinputs provides agricultural products with a competitive edge on the global stage, especially as demand rises for healthier foods produced through environmentally responsible methods. However, it is essential to emphasize that the effectiveness of bioinputs is closely linked to their quality and to strict compliance with existing regulations. Choosing bioinputs that are officially registered with the Ministry of Agriculture, Livestock and Supply, and strictly following manufacturers' guidelines, ensures the full realization of their benefits—making bioinputs a cornerstone of sustainable agricultural practices.

In the specific context of fruit production, potential research directions include improving the effectiveness of bioinputs and exploring their interactions with different fruit crop varieties. Additionally, developing sustainable production practices is key to enhancing both crop growth and postharvest quality. These efforts not only foster innovation in the sector but also strengthen producers' competitiveness in global markets, reinforcing sustainability and economic resilience in the current agricultural landscape.

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