AGRICULTURAL POLICIES IN DEBATE

Bioinputs in Agriculture

Trends and Challenges in Brazil

CHRISTIANE ABREU DE OLIVEIRA PAIVA
DANIEL BINI

APD | DIÁLOGO AGROPOLÍTICO BRASIL · ALEMANHA
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SCN Quadra 1 Bloco C salas 1102-1104
Ed. Brasília Trade Center Brasília - DF
+55 61 9 9964-3731
contato@apd-brasil.de
www.de.apdbrasil.de
APD Brasil Alemanha
APD Brasil Alemanha

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ABOUT THIS STUDY
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AUTHORS

CHRISTIANE ABREU DE OLIVEIRA PAIVA
Christiane Abreu de Oliveira-Paiva is an agricultural engineer and researcher at Embrapa Milho e Sorgo. She specializes in Agricultural and Soil Microbiology and holds a doctoral degree in Plant-Microorganism Interaction and Master in Ecology from Universidade Federal de Minas Gerais (UFMG). Christiane has been a curator for Embrapa's Collection of Multifunctional Microorganisms since 2010. Conducts research on the development of microbial bioinputs, including BiomaPhos. This was the first product registered in Brazil capable of increasing phosphorus absorption by plants, biological control of diseases, and plant-soil-microorganism interaction. Recognized for her contribution to science, Christiane was paid tribute at Agrishow 2023 and received the BRICS Solutions Award in 2025.

DANIEL BINI
Daniel Bini is a biologist specializing in Agricultural and Environmental Microbiology. He holds a doctoral degree in Soils and Plant Nutrition from Escola Superior de Agricultura Luiz de Queiroz da Universidade de São Paulo (ESALQ/USP) and a master's degree in Microbiology from Universidade Estadual de Londrina (UEL). He is currently a postdoctoral researcher at Embrapa Milho e Sorgo, in Sete Lagoas, where he conducts research on the development of microbial inoculants, with an emphasis on phosphate-solubilizing bacteria, and sustainable strategies for soil management.

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1. Introduction

In the 1970s, Brazil was still highly dependent on imported food and technology. In less than five decades, it has become a world leader in the development of tropical agriculture based on science and innovation, an unparalleled achievement on the global stage. Such an agricultural revolution has made the country a leading producer and exporter of grains and strategic crops, such as corn, soybean, coffee, sugarcane and cotton, playing a pivotal role in the world's food security (Policarpo et al., 2025). At the same time, Brazilian agriculture has stood out as a hub of emerging technologies that combine high productivity, economic feasibility, and environmental sustainability.

Brazil is among the world's leading grain producers, alongside China, the United States, and India. There has been a significant rise in production levels. The 2024/2025 harvest is estimated at 350 million tons, setting a new historical record and exceeding the volume of 324 million tons seen in 2022/2023 (Conab, 2025). In international trade, Brazil also stands out, as in 2023 it exported around 161 million tons of grains, which accounted for approximately 24% of the global volume, which is above the average of recent years (21%) (Embrapa, 2024a). This performance results from the combination of technological development, expansion of agricultural frontiers, incentive policies and subsidized credit, growing external demand, logistical improvements, favorable climate conditions and fertile soils (Conab, 2025).

However, the modernization of Brazilian agriculture has been directed not only toward productivity gains, but also toward the incorporation of more sustainable practices. Bioinputs or bioproducts thereby have achieved a solid status as promising alternatives to reduce dependence on traditional chemical inputs (Policarpo et al., 2025). These alternatives respond to core industry challenges, such as high dependence on synthetic fertilizers, mostly imported, the intensive use of agrochemical pesticides, high production costs, and the need to mitigate greenhouse gas emissions (Policarpo et al., 2025).

From an agronomical angle, there is a wide variety of bioinputs on the market in Brazil, including plant growth-promoting microorganisms, such as *Rhizobium*, *Azospirillum*, *Bacillus*, and *Trichoderma*, which have proven to increase nutrient use efficiency, stimulate phytohormone production, induce systemic resistance against phytopathogens and increase crop tolerance to abiotic stresses such as drought and salinity (de Andrade et al., 2023; Sharma et al., 2025; Vermelho et al., 2025).

The expansion of bioinputs in Brazil, resulting from the concerted effort of researchers, producers, corporations and society, has transformed the agricultural scene. The Brazilian bioinputs market has grown rapidly, with an average annual rate of 21% over the last three years, which is four times higher than the global average. These products are used in Brazil's most widely grown crops, including soybean, corn, sugarcane, cotton, coffee, citrus, fruits, and vegetables (Croplife Brasil, 2024a; Vermelho et al., 2025).

Brazil's beneficial legal framework is an encouragement, aligning the country with the global trends in sustainable agriculture and strengthening its competitiveness. This progress responds both to the social demand for responsible practices and to the need to adapt to climate change as a strategy to lower greenhouse gas emissions and help to achieve the UN Sustainable Development Goals (SDGs) (Policarpo et al., 2025). This aims to strengthen the health and quality of crops, ensuring consistent advances in the sustainability and resilience of Brazilian agriculture.

1.1. Challenges of Brazilian Agriculture

Brazil's growing agricultural production is accompanied by many environmental, economic and geopolitical challenges. These include high dependence on imported fertilizers, intensive use of agrochemicals, reduction of greenhouse gas emissions, global population growth, and, consequently, the greater demand for grains (CropLife, 2024a; Pereira & Cardoso, 2025; Policarpo et al., 2025). These factors make Brazilian agricultural production costlier and increase the need for technological innovation, adoption of sustainable practices, and more efficient use of resources to support global food security.

Meeting global food demand and reducing the impacts of agricultural practices is a challenging task. This is especially relevant as the global population should rise to approximately 9.7 billion people by 2050 and exceed 10 billion by the end of the century (UN, 2019). In this scenario, global agriculture will be pressured to expand its production capacity to meet global food needs. This pressure falls especially on countries with great agricultural potential, such as Brazil, where production adjustments will be necessary.

Fertilizer consumption in Brazil is high. In 2023 and 2024, it imported about 45 million tons, which makes it one of the world's largest importers, as reported by the National Association for the Diffusion of Fertilizers (ANDA, 2025). In general, it is estimated that about 80% of the fertilizers used in Brazilian agriculture are imported. The country is mostly dependent on potassium (95%), nitrogen (80%), and phosphate (60%) imports (Brasil, 2023; Agrolink, 2023). This high consumption is largely explained by the conditions of tropical soils, which are naturally acidic and have low fertility, requiring regular correction and replenishment of nutrients to maintain agricultural productivity. In 2024, fertilizers accounted for about 23% of the production costs of soybean, corn, and cotton. Fertilizer imports, dominated by a few suppliers, generate high external dependence, dollar expenses, and greater vulnerability to exchange rate variations, especially given the limited domestic production (Pereira & Cardoso, 2025).

In addition to fertilizers, Brazil is among the world's leading consumers of agrochemicals (300,000 tons annually). Over the last forty years, agrochemical consumption rose 700%, while agricultural activity grew by 78% (Embrapa, 2021a). This surprising volume exceeds consumption in the United States — which ranks second in the global consumption — by nearly 60%. This intense use of agrochemicals is due to the abundance of agricultural pests and diseases exacerbated by the hot and humid tropical climate as well as to concerns about the spread and introduction of agricultural pests and productivity losses in strategic crops such as soybean, corn, citrus, and sugarcane. Added to this is the poor monitoring of pests and diseases, which makes early detection difficult and leads to inappropriate use of pesticides. Despite the importance of pesticides for agricultural purposes, they adversely impact the environment and human health, especially among workers exposed during handling, application and disposalThe Brazilian climate is also challenging, as each region has a different reality. Brazil is a tropical country subject to higher levels of crop diseases and pests than countries with a temperate climate (Angelotti et al., 2024). When climate emergencies come into play, this becomes more complex due to more frequent and intense heat waves and periods of drought, impacting vulnerable populations more severely (Angelotti et al., 2024). Agriculture plays a significant role in the generation of greenhouse gases. According to the Intergovernmental Panel on Climate Change (IPCC), agriculture, forestry, and other land uses are the second largest contributors to global greenhouse gas emissions, accounting for around 22% of emissions in 2019 (IPCC, 2023).

Brazilian agriculture also faces technical management challenges, with producers and industry players still depending on traditional practices and intensive use of chemical inputs, and low levels of adoption of digital technologies and integrated land management. Access to information must be democratized to deliver social services with different levels of impact on the various production systems and property sizes (Embrapa, 2023b). There are also problems related to soil and natural resources, such as degradation, nutritional imbalance, and water shortage (Embrapa, 2021b).

Progress in agriculture therefore depends on the pursuit of sustainable alternatives that balance social, environmental, and economic concerns. It is essential to increase plant resilience, reduce production losses, and promote technologies that improve soil health, reduce greenhouse gas emissions and the use of synthetic inputs to make agricultural systems more sustainable and ensure greater food and economic security.

1.2. Background of Bioinputs in Brazil

Since their introduction in Brazil about 70 years ago, bioinputs have offered innovative solutions to long-standing agricultural issues. Over the past years, these products have proven to be essential tools for productive and sustainable agriculture, promoting plant growth, nutrient availability, and plant health. Integrated into different production systems, from crop production and cattle ranching to post-harvest and processing, these products include microorganisms (viruses, bacteria, and fungi), macroorganisms (beneficial insects, predators, and parasitoids), ecosystem services such as pollination, semiochemicals (pheromones), biochemicals, probiotics, animal feed supplements, bioproducts for disease control in livestock and pastureland, and additives and inputs that interact with the soil microbiota, such as rock powder and remineralizers (Vidal et al., 2021).

Historically, in the first decades of the 20th century, multiple unsuccessful attempts to import and approve biocontrol agents were made in Brazil (Parra, 2014; Fontes and Valadares-Inglis, 2019). A study conducted by Parra (2014) details the historical advancement of biological control in Brazil and outlines one of the first successful cases of the use of biopesticides in Brazil in 1967, using *Neodusmetia sangwani* — a ladybug species — in the biological control of cochineal (*Antonina graminis*). It also points out that the scalation in the import of natural enemy species, such as parasitoids, predators and pathogens, occurred after the establishment of the quarantine system in 1991 by

Empresa Brasileira de Pesquisa Agropecuária (Embrapa) in Jaguariúna, in the state of São Paulo. To this end, agents were imported for the purpose of controlling exotic and, occasionally, native pests. The use of native natural enemies increased over the years.

Currently, many biological pest control agents are known to be used in various crops, such as the parasitoids *Cotesia flavipes* and *Trichogramma galloi*, the entomopathogens *Bacillus thuringiensis* and *Beauveria bassiana*, the semiochemical taken from the pheromone of the codling moth *Cydia pomonella*, and others (Parra et al., 2014; Fontes and Valadares-Inglis, 2019). Some examples include the *B. thuringiensis* formulations used to control insect caterpillars, such as *Spodoptera frugiperda* and *Helicoverpa armigera*, as well as *Beauveria bassiana*, *Metarhizium anisopliae*, *Baculovirus anticarsia* and *Trichoderma harzianum* products, used to manage different agricultural pests, diseases and even nematodes (Fontes and Valadares-Inglis, 2019). *Deladenus siricidicola* is used to manage woodwasp (*Sirex noctilio*) in Pinus stands (Alves; Lopes, 2008; Fontes and Valadares-Inglis, 2019). In 2025, a new bioinsecticide was launched in Brazil from a strain of *Baculovirus spodoptera multiple nucleopolyhedrovirus (SfMNPV).* Field tests have attested to its effectiveness in controlling fall armyworm *Spodoptera frugiperda*. Similarly, a biofungicide formulated from the bacterial strain *Paenibacillus ottowii* was approved to manage soil fungi, including *Fusarium spp*, *Macrophomina phaseolina,* and *Colletotrichum graminicola*, which cause root and stem rot in corn, soybean and other crops throughout Brazil, with an average efficiency of 80% (Diniz et al., 2025; Embrapa, 2025a). Brazil is considered a leader in the production and application of biological control agents in agriculture. Over **70 million hectares in Brazil applied** these products in 2022, especially in soybean, corn, sugarcane, and coffee crops (Bettiol and Medeiros 2023).

The first studies on microorganisms used as inoculants date back to 1920. Nevertheless, starting in the 1960s, these inputs gained prominence with studies demonstrating the positive effect of microorganisms on plant nutrition, especially nitrogen-fixing bacteria in soybean crops (Hungria and Nogueira, 2022; Vermelho et al., 2025). Back then, when skepticism prevailed regarding the potential of biological nitrogen fixation (BNF) to compete with mineral fertilizers, a pioneering program was launched by Brazil's National Soybean Commission (Comissão Nacional da Soja) to overcome the limitations of BNF in tropical legumes and demonstrate that it was possible to establish highly efficient symbioses with rhizobia, thereby eliminating the need for nitrogen fertilizers in soybean crops (Hungria and Nogueira, 2022; Vermelho et al., 2025). Brazil progressed on this topic in 1980, as it established a legal framework that provided guidelines for the selection of microorganisms and the development and registration of inoculant products, setting up a Network of Laboratories for the Recommendation, Standardization and Dissemination of Microbial Inoculant Technology of Agricultural Interest (RELARE) (Hungria and Nogueira 2022). These events promoted the large-scale adoption of BNF and laid the foundations for the expansion of other bioinputs, aligning Brazilian agriculture with more sustainable and competitive practices on the global stage. The large-scale use of rhizobia is well-established in Brazil, especially *Bradyrhizobium diazoefficiens*, *B. elkanii,* and *B. japonicum* in soybean crops, and *Rhizobium tropici* in bean crops, which has led to a significant drop in production costs and firmly established the competitiveness of Brazilian soybean on the global market. BNF combines environmental sustainability and economic gains, standing out among bioinputs in Brazil. In 2022, BNF in soybean crops generated about R$72 billion, 89% more than in 2021 (Embrapa, 2025b).

In terms of plant nutrition, further studies have been carried out on non-leguminous plants associated with growth-promoting bacteria, and important species have been characterized and become great success stories in Brazilian agriculture, such as *Azospirillum brasilense*, *Nitrospirillum amazonense*, *B. megaterium*, *B. subtilis*, *Pseudomonas sp.,* and others (de Andrade et al., 2023; Vermelho et al., 2025). The *A. brasilense* AbV5 and Ab-V6 strains were launched as commercial inoculants for corn and wheat in 2009 (Hungria and Nogueira, 2022). Subsequently, they were used in other crops, including brachiaria, bean, and soybean. With an associative potential, these strains can improve the production capabilities of crops by promoting plant growth through hormonal mechanisms. The average productivity increase of corn is about 26%. That of wheat is 31% (Hungria. 2011). Additionally, single or combined inoculations of *A. brasilense* AbV5 and Ab-V6 with rhizobia in legumes enhance BNF and promote plant growth, potentially leading to productivity gains of 15 and 8% in soybean and bean crops, respectively (Chibeba et al., 2015; Galindo et al., 2022). The first commercial product for soybean co-inoculation appeared in 2013, delivering significant results. Compared to inoculation with *Bradyrhizobium spp.* alone, an average increase of 11% in root mass, 5.4% in the number of nodules, 10.6% in nodule mass, 3.6% in grain yield, and 3.2% in grain N content were observed (Barbosa et al., 2021).

In 2019, a new inoculant was developed by Embrapa and partners for biological phosphate solubilization (BPS). Formulated with the strains *B. subtilis* B2084 and *B. megaterium* B119, it became the first Brazilian phosphate inoculant authorized for corn crops (2019) and, later, for soybean crops (2021) (Oliveira-Paiva et al., 2024). Capable of solubilizing and mineralizing phosphate and promoting plant growth, these strains have demonstrated significant results in Brazilian agriculture, helping to reduce dependence on imported fertilizers, in line with the sustainability and decarbonization goals of Brazilian agriculture. In 2023, an inoculant containing the bacteria *B. aryabhattai* was developed by Embrapa to protect corn, soybean, wheat and other crops against the effects of drought and heat by hydrating the roots and stimulating growth.

Brazil's bioinputs background has been followed by a historic alliance between research, especially by Embrapa, and the inoculants industry, which not only promoted the extension of knowledge on beneficial microorganisms, but also developed more efficient and high-quality formulations capable of ensuring greater viability, persistence, and agronomic efficiency.

2. Regulation of Bioinputs in Brazil

2.1. Biological Products according to the Brazilian Legislation

The concept of bioinputs may vary from country to country. In Brazil, it is characterized by the Ministry of Agriculture and Livestock (MAPA) as biobased products, processes or technologies meant for crop production, forestry, aquaculture, and cattle ranching systems, including inoculants, biofertilizers, biopesticides, biological control agents, and bioactives. The Food and Agriculture Organization (FAO) presents a similar concept, as it defines bioinputs as products of biological origin, including microorganisms, macro-organisms and natural substances capable of improving agricultural productivity sustainably.

In Brazil, the National Bioinputs Program (Brazil, 2020) didactically separates bioinputs into four large groups: phytosanitary products or biological pesticides, biofertilizers, inoculants and biostimulants (Figure 1).

Biological pesticides are aimed at the biological control of pests and diseases, supporting the maintenance of plant health. They include biofungicides, bioinsecticides, bionematicides, and other products (Law No. 7802/1989 (Pesticide Law) (Brazil, 1989). In general, they can be formulated from natural pest antagonists, which are called biological agents, and include mites, insects, nematodes, bacteria, fungi, viruses or protozoa, and control substances such as semiochemicals (pheromones and allelochemicals) or even biochemical products, such as hormones, enzymes, and growth regulators.

Biofertilizers, which equate to inoculants in some countries, have a different and more comprehensive definition in Brazil, where they are framed in a category of active organic components and/or substances, of microbial, vegetable or animal origin, which aim to improve the productivity and quality of plants, especially in terms of nutritional support (Brazil, 2020). On the other hand, inoculants are products exclusively formulated by live microorganisms (bacteria and fungi) that promote plant growth and nutrition. Finally, biostimulants are substances such as plant extracts, algae, humic acids, amino acids, and others, which can improve some physiological aspects of the plants.

Figure 1 – Categories of bioinputs according to the conceptual basis of the National Bioinputs Program of the Ministry of Agriculture and Livestock of Brazil

Category	Composition	Function
Biofertilizers	Active organic substances of microbial, plant or animal origin	Improve plant productivity and quality with an emphasis on nutritional support
Inoculants	Products formulated exclusively with beneficial microorganisms	Emphasis on plant nutrition and plant growth promotion
Biopesticides	Biological agents (bacteria, fungi, viruses, mites), semiochemicals (pheromones, allelochemicals), others.	Biological control of pests and diseases (biofungicides, bioinsecticides, bionematicides)
Biostimulants	Plant extracts, algae, humic acids, aminoacids	Improvements in physiological aspects of the plant (growth, stress tolerance, vigor)

Source: Bioinputs Law No. 15070/2024).

2.2. Legal Background of Bioinputs in Brazil

Over the past years, the use of bioinputs has risen significantly in Brazil. However, until 2024, its regulation was generic, included in the Pesticides Law (nº 7802/1989), created for agricultural pesticides, fertilizers or biological control products. However, this approach did not reflect the technical specificities and the benefits of bioinputs, which generated legal uncertainty and distress in agriculture. Moreover, important concepts about biofertilizers and inoculants were outlined in another law — the Fertilizer Law (Law No. 6894/1980) — which differed little from chemical fertilizers, resulting in a generic definition that did not cover the technical and functional particularities of bioinputs.

Advancement toward more appropriate regulation was encouraged by the Brazilian government in 2020, with the launch of the **National Bioinputs Program** (Decree No. 10375/2020). In the wake of this initiative, alongside the filing of two bills of law (Bill 658/2021 and Bill 3668/2021), the **Legal Framework of Bioinputs** was established in Brazil, thereby pushing the industry forward. The objectives of the program were to expand the supply of bioinputs, reduce dependence on synthetic inputs, spur innovation, promote the bioeconomy, and encourage the production of healthier foods, resulting in greater productivity and improved quality in agriculture (Brazil, 2020).

2.3. Legal Framework of Bioinputs

In 2024, Law No. 15070/2024 (Brazil, 2024) was passed. It specifically regulates bioinputs. Known as the Bioinputs Law, it sets out guidelines for all agricultural stages, including production, import, export, registration, marketing, use, inspection, research, experimentation, packaging, labeling, advertising, transport, storage, waste disposal, and incentives for the production for agricultural, cattle ranching, aquaculture, and forestry applications. This is a historic landmark, which places Brazil among the world's leading players in the production and use of bioinputs.

The **Bioinputs Law** has introduced specific regulations on bioinputs, and this has solved several problems from the previous regulatory model, fostered innovation, strengthened inspection mechanisms and promoted industry-level sustainability (Brazil, 2024). It seeks to promote sectoral innovation by offering legal certainty for investments and the development of new technologies. It simplifies and streamlines the registration of bioinputs, especially those intended for organic and low-risk agriculture (Vermelho et al., 2025). It also exempts from registration those bioinputs produced for self-use on rural properties. In terms of concepts, many of them have been updated, such as the terms “biofertilizers,” “inoculants,” and “biostimulants,” which were treated generically in the former law. In fact, the Bioinputs Law materializes Brazil's commitments to the UN, as it aligns work on bioinputs and promotes the achievement of the Sustainable Development Goals (SDGs 2, 3, 6, 7, 12, 13, 14, and 15).

2.4. How is a microbial pesticide registered in Brazil?

In Brazil, microbial pesticides are registered via a detailed process conducted by three federal agencies: the Ministry of Agriculture and Livestock (MAPA), the Brazilian Health Surveillance Agency (ANVISA), and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). To this end, in 2023, it was established that the procedures for the registration of microbial products used in agriculture as biopesticides will be carried out by MAPA, IBAMA and ANVISA (Vidal et al., 2021). Generally, it starts with an application for registration and the submission of a detailed technical dossier outlining the results of studies on the effects of the product on human health and the environment, followed by field tests to assess its efficiency and impact. In this case, ANVISA handles toxicological and food safety matters, MAPA analyzes the product's agronomic efficiency data, and IBAMA classifies the potential for environmental hazards. Assessment is simultaneous, and the applicant only receives the registration certificate, along with the label and leaflet for the product to be marketed, after all agencies have granted approval.

2.5. How is an inoculant registered in Brazil?

For inoculants, Normative Instruction (IN) No. 53/2013 (Brazil, 2013) regulates the registration and sets out additional guidelines. MAPA is the only agency with powers to grant validation. In general, IN No. 53/2013 sets out criteria for registering and marketing inoculants or other inputs (fertilizers, soil amendments, biofertilizers, remineralizers, plant substrate, and secondary nutrients), specifies the minimum requirements for assessing agronomic feasibility and efficiency, and requires the preparation of a technical-scientific report ahead of the registration.

IN No. 53/2013 sets forth that experimental tests can be conducted under field conditions or in a controlled environment, such as a greenhouse. Field experiments must be conducted in regions representative of the crop cultivation within the national territory, covering two soil types and two harvests, or in four different locations with diverse edaphoclimatic conditions in one single harvest. On the other hand, greenhouse experiments must be conducted with at least two distinct crops and a minimum of four replications.

Registration with MAPA is mandatory for fertilizers, inoculants, soil amendments, biofertilizers and plant substrates, both for the purposes of producing, importing, and selling these inputs, and for individuals or corporations conducting such activities. To this end, in addition to the application for registration, laboratory analyses characterizing the product and a research report must be presented, and both must be provided by accredited research institutions (Embrapa, Universities, Research Centers, and others).

2.6. Technical Overview of the Development of Bioinputs in Brazil

Biosafety and control are required in the development of bioinputs in Brazil. Because of this, it is recommended that microorganisms of interest come from properly registered germplasm banks and official collections accredited by SISGEN/IBAMA. In general, a microbial germplasm bank serves as a "living library," where strains are collected, preserved, characterized, and provided for research and innovation. Under these conditions, microorganisms remain accessible and preserved for long periods without losing their genetic and functional characteristics.

To set up a germplasm bank, some important technical steps must be followed, such as looking for promising microorganisms and functional and genetic characterizations. In short, it begins with the bioprospecting and collecting of samples from different environments (soil, rhizosphere, roots, leaves, water, and others). Then, the microorganisms of interest are isolated in appropriate culture media. Subsequently, functional characterization is often conducted to evaluate mechanisms of interest, including biological nitrogen fixation, phosphate solubilization, production of phytohormones, antibiotics and enzymes, and taxonomic characterization. Information on origin, phenotypic characteristics, and potential uses is collected and entered in the germplasm banks.

Microorganisms of interest and potential use as bioinputs must be tested both in a greenhouse and in the field to prove their agronomic efficiency. Field tests follow MAPA standards (Brazil, 2013) and are conducted in different regions and for distinct harvests to evaluate productivity, nutrient use, stress tolerance, as well as pathogen control. The subsequent steps involve formulation tests to ensure the viability and stability of the microorganism over its shelf life, by defining the media (liquid, powder, granule, gel, capsule), addition of protectants or nutrients, and storage conditions (Bashan et al., 2014). Once the formulation is defined, the microorganisms are cultivated in controlled bioreactors (aeration, temperature, pH, and nutrients), scaling from laboratories to plants, with quality tests to ensure concentration, purity, viability, and absence of contaminants. Furthermore, it must meet the MAPA, Anvisa and IBAMA regulatory requirements, including registrations, safety certificates, and proof of effectiveness. It is a complex process that takes 8 to 10 years before the product is put on the market.

However, on-farm[1] production of inoculants is exempt from registration. It is authorized and regulated for self-use only and cannot be sold (Brazil, 2024). For this purpose, the producer is required to follow the good practices defined by the federal agricultural defense authority. Worthy of note, only strains from accredited germplasm banks or from products specifically registered for this purpose may be used. It is not allowed to use off-the-shelf products as a source of inoculum.

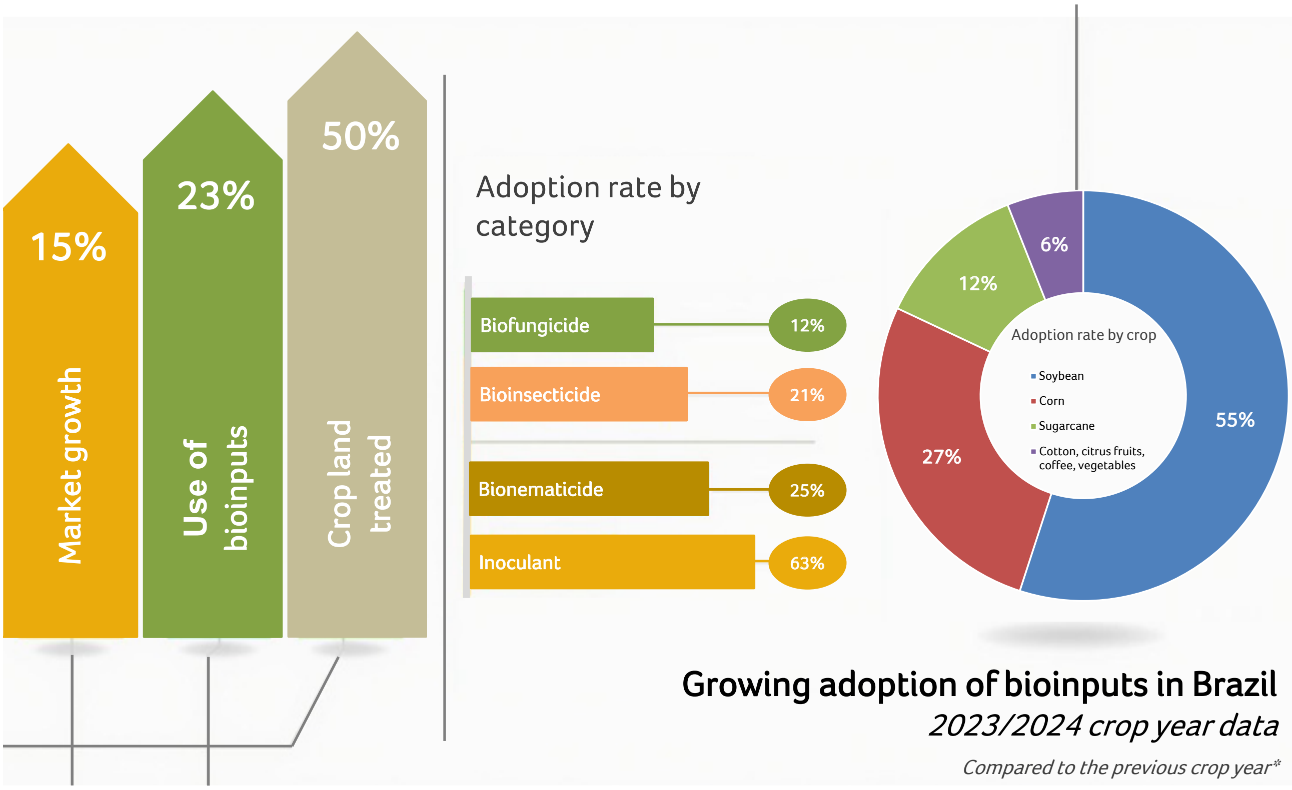
1 For on-farm bioinput production, see chapter 5.

3. Trends in the Brazilian Bioinputs Market

The Brazilian bioinputs market has grown significantly over the past few years. In 2023, the global market was estimated at around US$13 to 15 billion, covering biological control, inoculants, and biostimulants (Croplife Brasil, 2024b). By 2032, it is projected to grow at an annual rate of up to 14%, peaking at about US$45 billion, driven primarily by the increased adoption of bioinputs in the United States, Europe, and Brazil, which is among the world leaders in terms of use.

On the domestic scene, the National Bioinputs Program and its Strategic Council have placed Brazil in a strategic position to reduce dependence on imported inputs while sustainably unlocking the potential of its biodiversity. This strategy is in line with the growing demand from producers and agribusinesses for more sustainable production systems. In this scenario, the Brazilian bioinputs market has expanded at a fast pace. A study commissioned by CropLife Brasil (2024b) presents some important indicators of this growth. From 2021 to 2023, it grew at an average annual rate of 21%, which is four times above the global average. **In the 2023/2024 crop year,** adoption rate of bioinputs increased, and **the industry advanced around 15% compared to the previous crop year**, generating about R$5 billion (Figure 2).

Figure 2 – Data on the growing use of bioinputs in Brazil in the 2023/2024 crop year



Source: Adapted from CropLife Brasil, 2024.

In fact, bioinput registrations in Brazil have historically grown the most over the last 23 years (2000–2022), outperforming other chemical inputs. To date, Brazil has **786 registered pest control products and 747 inoculants.** Regarding inoculants, 44 crops are covered. Of these registrations, 458 are exclusively meant for soybean, which shows the relevance of this crop in the utilization of biological technologies according to the "*Bioinsumos*" app developed by Embrapa and MAPA (Embrapa, 2025c). This industry trend is driven by companies and startups, which have increased their footprint in Brazil. For example, according to the National Association of Inoculant Producers and Importers (ANPII, 2020), roughly 97% of the inoculants used in Brazil in 2021 were produced domestically by 36 registered companies, a figure that rose to 63 in 2025 (Policarpo et al., 2025).

This development reflects the strategic change of course of manufacturers of farming inputs, which have been designing solutions aligned with agribusiness and consumers' demands for food security and sustainability. With a more enabling regulatory environment, investments in new technologies and production capacity increase, offering farmers a greater diversity of bioproducts capable of replacing or complementing chemical pesticides and fertilizers.

4. Challenges to the Production and Advancement of Bioinputs in Brazil

Brazil is a world reference in terms of bioinputs. Nonetheless, significant logistical and bureaucratic bottlenecks still complicate the development of new products. These hurdles range from cumbersome registration processes and poor infrastructure to the lack of adequate conditions for on-farm production.

Registering bioinputs is key to ensuring the traceability, safety, and effectiveness of these products. Nevertheless, bureaucracy combined with slowness and high paperwork costs are a significant obstacle to innovative solutions reaching the market, especially those developed by new entrepreneurs, small businesses, and startups (Sambuichi et al., 2024). Alternatively, the Bioinputs Law does not require self-use products to be registered, and establishes special treatment for products originating from smallholders, indigenous peoples, and traditional communities, representing an important step forward in reducing bureaucratic hurdles for smaller groups. Even so, it is still necessary to pass more precise regulations on the technical and operational criteria applicable to each type of product and context of use so as to cover both large and smaller-scale production chains, including organic and agroecological systems (Policarpo et al., 2025).

Regional issues are a strategic factor for the expansion of bioinput production in Brazil. This is because most companies are concentrated in the South and Southeast, which limits their presence and growth in other regions of Brazil with great potential given their still untapped biodiversity and specific agricultural demands (Policarpo et al., 2025). As Brazil has distinct climatic and production conditions, it is crucial to promote research and encourage the setup of small and medium-sized companies and startups in underserved regions. These initiatives must be combined with infrastructure improvements and access to credit lines.

However, the production of bioinputs is an intricate activity that requires well-equipped labs, advanced fermentation systems, strict quality control protocols and additional support in terms of technologies, qualified labor, and innovation ecosystems.

Many Brazilian regions, especially the most remote and least developed ones, do not have this minimum infrastructure, whether due to logistical, operational or qualification limitations (Sambuichi et al., 2024). In this scenario, the combination of public policies with private investments is a strategic and robust avenue to overcome such challenges and promote the balanced regional development of this industry.

5. Challenges of On-Farm Production

On-farm products are a viable alternative to respond to the challenges related to the universalization of the use of bioinputs in Brazil. However, the production of bioinputs faces some tough challenges related to good production practices, safety, and efficiency. The quality of on-farm products is a point of attention, as the lack of standardized protocols may lead to undesirable variations and low-effectiveness products (Lana et al., 2019; Lana et al., 2022; Bocatti, 2022; Policarpo et al., 2025). It is crucial to ensure proper production conditions, such as aseptic facilities, temperature, pH, and oxygen control to guarantee greater stability and safety, thereby reducing the risk of contamination by pathogenic microorganisms and losses in agricultural productivity.

An important comparison must be established between on-farm bioinputs and off-the-shelf bioinputs. In Brazil, off-the-shelf bioinputs are derived from microorganisms of biological risk level 1 and follow strict quality control standards to avoid contamination. For example, the inoculants cannot present contaminants even when subjected to a dilution of 1 part of the product to 100,000 parts of solvent (dilution of 1×10^{-5}) (Brazil, 2010). Contaminated batches of these products cannot be put on the market. Embrapa studies by Bocatti (2022) revealed that on-farm inoculants based on *Bradyrhizobium* and *Azospirillum* collected from different regions of Brazil presented 100% contamination by microorganisms, 44% of which contained potential human pathogens (*Enterobacter, Klebsiella, Staphylococcus, Acinetobacter*) and one third were resistant to antimicrobials. Similar results were found in on-farm bioinsecticides based on *B. thuringiensis* (Lana et al., 2019). Similarly, abnormalities in the concentration of the active ingredient (microorganism or metabolite) are detrimental to the product efficiency due to either under or overdosage. For example, high doses of *A. brasilense*, plant growth promoting rhizobacteria (PGPR) highly capable of producing phytohormones, can generate the opposite effect to that expected, limiting plant development and causing losses (Fukami et al., 2016). While off-the-shelf products must follow strict registration processes, in on-farm production, quality control is not mandatory, consequently, production processes may vary greatly.

There are no official estimates of on-farm bioinput practices in Brazil, although bioinput producers have pointed out that 8% of bioinputs used in Brazil are not registered for commercial applications. In fact, producers buy off-the-shelf products and use them as an initial inoculum (live microorganisms to be propagated or subcultured). The inoculums are kept in inappropriate “tanks”, often in the open air. Few agricultural properties adopt appropriate technical protocols, and the need for specialized consulting and equipment makes the process costly and often unfeasible for most producers. In fact, although the Bioinputs Law allows on-farm production, a clear, well-established definition of good practices for this type of production is unavailable. This, added to limited access to information and few qualified professionals, shows the need for educational programs and courses and rural extension initiatives to all stakeholders (Embrapa, 2023a; Policarpo et al., 2025).

This creates structural inequality between large scale farmers and smallholders: while the former have financial resources and infrastructure to hire specialized support and skilled professionals, smallholders find it hard to access technical knowledge and implement safe and efficient practices (Policarpo et al., 2025). Public policies on capacity-building, technical support, and democratization of access to information are then the key elements to promote greater equity and sustainability in the bioinputs industry.

By working directly in the development and application of bioproducts in Brazilian agriculture, Embrapa has warned about the need for regulation of this activity. In adittion, it has encouraged and advised production by cooperatives or farmers’ associations to ensure quality and proper production conditions with technical support (Embrapa, 2023a). The lack of proper regulation may result in low-quality farming inputs, undermine the credibility that bioproducts have gained over the years, and pose risks to people’s health and the environment.

6. Main Trends and Prospects for the Brazilian Bioinputs Portfolio

Bioinputs are not mere substitutes or additions to traditional agrochemical inputs, but rather fundamental elements for a more balanced and efficient production system. Bioinputs are tools that can boost productivity sustainably, help to protect natural resources, and mitigate climate change. Therefore, there is a growing demand for microorganisms or consortia of multifunctional microorganisms to expand the benefits of bioinputs to many crops. This will unlock seamless solutions, as single-strain inoculation strategies are outperformed by microbial consortia, where multiple strains are combined for better effectiveness and resilience (Bargaz et al., 2014; Mitter et al., 2021; Gómez-Godínez et al., 2021).

Bioprospecting for microorganisms with the potential to promote plant growth and biological control has escalated, driven by increased market interest in sustainable solutions. Genomics-based approaches speed up the identification and production of new off-the-shelf bioinputs, especially those sold by startups developing innovative and disruptive technologies (Zvinavashe et al., 2021; Singh et al., 2025).

Recent developments are directly related to increased research and development capabilities to obtain a new generation of microorganisms based on molecular biology and genetic engineering tools, and metabolites of interest. New formulations that ensure longer shelf life, environmental resilience, chemical compatibility, and tolerance to various stresses in the field are also the focus of current and future research.

Molecular biology tools, such as CRISPR-Cas, enable targeted editing of microorganisms, optimizing microbial functions such as nutrient solubilization and the synthesis of bioactive compounds (Lee and Lee, 2021). At the same time, genetic plant improvement has focused on developing cultivars that are more responsive to interactions with microorganisms, using rhizosphere engineering, genomics, transgenics, and gene editing strategies (Zvinavashe et al., 2021; Singh et al., 2025). A promising line of research involves microbiome-based biofertilizers, although challenges related to stability and performance in different soils, climates, and agricultural systems persist. Successful implementation depends on real-life validation. Advances in synthetic biology have the potential to transform agriculture by simultaneously promoting productivity and sustainability (Singh et al., 2025).

Similarly, the development of fertilizers enriched with beneficial microorganisms should also increase and add value to the end product. Microbial encapsulation techniques directly into seeds are expected to reduce manual inoculation procedures onat the rural properties. Additionally, integrated nutrient management practices are an important trend in Brazilian agriculture. It seeks to balance nutrient sources, conservation practices and bioinputs to increase production efficiency and sustainability. Bioinputs, such as biofertilizers, will be crucial to improve plant nutrition techniques and agricultural sustainability, thereby reducing costs and increasing productivity. Successful examples are already in practice, where rhizobia and *Azospirillum* inoculation are either fully or partially replacing nitrogen fertilization in soybean and other crops. In addition, these initiatives aim to enhance the utilization of poorly mobile fertilizers in the soil, such as phosphates, through the application of *Bacillus* and *Pseudomonas*, and even stimulate soil microbiota and its processes (e.g., decomposition, mineralization) through green manure and maintenance of crop residues. Combined, all of these practices also help to improve soil quality and make crops more resistant to future climate stresses.

7. Brazilian Research Success Stories and Market Potential

7.1. Embrapa's Bioinputs Breakthroughs

Embrapa plays a leading role in the research and development of bioinputs. It strengthens the industry and unlocks important partnerships to leverage biological solutions in agriculture. Of all biological innovations promoted by Embrapa, inoculants and biopesticides are the best known. Embrapa has a range of microbial germplasm banks dedicated exclusively to the preservation and characterization of microorganisms, biopesticides and plant growth promoters. This collection includes about 10,000 lineages of bacteria, fungi and viruses that control plant pests and diseases, and more than 14,000 lineages of plant growth-promoting microorganisms (Embrapa, 2020). As it recognizes the importance of this topic, Embrapa provides a portfolio of specific biological solutions for many Brazilian crops. Many products on the market today are formulated with organisms researched and developed by Embrapa and its partners. These organisms include *B. bassiana*, *B. thurigiensis*, *Thichoderma spp.*, and others, some of which are shown in Table 1.

Similarly, the biofertilizers developed by Embrapa and partners are examples of agricultural success and innovation, aligning increased productivity, reduced fertilizer application, and improved plant growth promotion. Table 2 presents some biological solutions of inoculants and biostimulants.

Table 1 – Examples of biopesticides produced from Embrapa's biological solutions.

Innovation	Agent/Technology	Target	Main Targets
Biofungicide	*Bacillus velezensis (IM14) and Paenibacillus ottowii (LIS04)*	Controls soil fungi with up to 80% efficiency; application on seeds	Corn, soybean, grains
Biofungicide	*Trichoderma sp.*	White mold (*Sclerotinia sclerotinun*)	Soybean, cotton, other crops
Bioinsecticide	Baculovirus	*Spodoptera frugiperda, Helicoverpa armigera* and *Chrysodeixis includens*	Soybean, corn, cotton, others

Innovation	Agent/Technology	Target	Main Targets
Bioinsecticide	*Cordyceps javanica (BRM27666)*	Whitefly control (*Bemisia tabaci*)	Multiple crops
Bioinsecticide	*Metarhizium anisopliae*	Froghoppers (*Hemiptera: Cercopidae*)	Pasturelands
Bioinsecticide	*Trichogramma spp.*	Fall armyworm (*Spodoptera frugiperda*)	Corn and other crops
Bioinsecticide	*Bacillus. thuringiensis*	Velvetbean caterpillar (*Anticarsia gemmatalis*), soybean looper moth (*Chrysodeixis includens*), and fall armyworm (*Spodoptera frugiperda*).	Soybean, corn, other crops

Source: Embrapa: https://www.embrapa.br/portfolio/insumos-biologicos

Table 2 – Some examples of inoculants and biostimulants produced from Embrapa's biological solutions.

Innovation	Agent/Technology	Benefit	Main Targets
Inoculant: PGPR	*Azospirillum brasilense* Ab-V5 and Ab-V6	Stimulates rooting, nitrogen fixation, and others.	Corn, wheat, soybean, other crops
Inoculant: BNF	*Bradyrhizobium spp., Rhizobium spp.*	Biological nitrogen fixation.	Soybean, beans, other legumes
Inoculant: PGPR	*Nitrospirillum viridazoti* BR11145	Increases biomass, stimulates rooting, nitrogen fixation, others.	Sugarcane
Inoculant: P solubilizer	*Bacillus megaterium* B119 and *B. subtilis* B2084	P use efficiency, soil P availability, root development	Corn, soybean, sugarcane, others.
Inoculant: PGPR	*Bacillus aryabhattai* CMAA 1363	Mitigates the effects of water stress on plants; promotes growth.	Soybean, corn, wheat, others.
Inoculant: PGPR	*Bacillus subtilis* BRM 1A11	Mitigates the effects of water stress on plants; promotes growth	Soybean, others.
Biostimulant: hormonal function	Carbon nanoparticles	Stimulates rooting and photosynthesis; increases productivity	Tomato and strawberry
Biostimulant	Plant extract	Increases grain productivity and quality; root and soil microbiota development	Corn and soybean

Source: https://www.embrapa.br/portfolio/insumos-biologicos

Embrapa works on expanding the use of bioinputs in pest control, growth promotion, nutrient supply, antibiotic replacement, and agroindustrial applications in conventional and ecological systems. This streamlines research and development of bioinputs, propelling the pursuit of new solutions and helping to share important information with producers and other stakeholders, thereby democratizing information on this topic.

7.2. Case 1: The first Brazilian phosphate solubilizer (BiomaPHOS)

In a scenario of high production costs due to rising fertilizer prices, the launch of **BiomaPHOS** in 2019 raised high expectations. It was the first inoculant specifically designed for biological phosphate solubilization produced in Brazil by a public-private partnership between Embrapa and the company Bioma (Oliveira-Paiva et al., 2009; Oliveira-Paiva et al., 2024).

In the research and development phase, which began in 2002, Embrapa collected and characterized around 1,200 isolates of phosphate-solubilizing microorganisms. Those isolates were subjected to multiple lab, greenhouse, and field tests to identify the strains that could best solubilize phosphate in the soil. The findings from this preliminary phase were published in 2009 in the journal "Soil Biology and Biochemistry" (Oliveira et al., 2009). The selection of *Bacillus* strains started the intensive phase of development of the inoculant under field conditions in 2011, followed by the establishment of a partnership with Bioma in 2016. In 2019, BiomaPHOS was commercially launched. In this period, various field experiments were conducted using different formulations, application methods, and concentrations of the biological product, in different regions of Brazil and for different crops (corn, soybean, and cotton).

The formulation of BiomaPhos contains *B. megaterium* CNPMS B119 strains isolated from the rhizosphere of corn plants, and the *B. subtilis CNPMS* B2084 strain, characterized as a corn endophyte (residing inside corn plant tissues without apparently harming their host). Especially capable of increasing the mobilization and absorption of phosphorus (P) by the plants, they are also considered multifunctional, capable of producing organic acids, phytohormones, phosphatase enzymes, biofilms, and siderophores (Sousa et al., 2020; Oliveira-Paiva et al., 2024). Basically, these mechanisms efficiently ensure biological solubilization of phosphate, P mineralization, and an increase in root surface area, leading to high productivity levels in corn crops (Sousa et al., 2020; Velloso et al., 2021; Oliveira-Paiva et al., 2024). Additionally, the ability to build endospores leads to high resistance to environmental variations, a highly interesting characteristic also from an industrial point of view (Oliveira-Paiva et al., 2024). Another relevant point is the absence of antagonistic effects between the BiomaPHOS strains and the off-the-shelf inoculants formulated with *Azospirillum* and *Bradyrhizobium*, making it possible to combine them when necessary (Oliveira-Paiva et al., 2024).

Initially launched for corn inoculation, BiomaPHOS utilization rose **from a land use of 228,000 hectares in the 2018/2019 crop year to nearly 4 million in the 2022/2023 crop year** (Embrapa, 2024b), plus an increase of 11% to 24% in average productivity, and corn grain P content ranging from 12% to 20% (Oliveira-Paiva et al., 2024). Continuous use of the inoculant is expected to lead to a gradual reduction in the application of phosphate fertilizers, depending on the nutritional status of crops throughout the harvest seasons. This approach helps to boost production system sustainability and to decrease environmental costs and impacts. A recent survey on the contribution of BiomaPHOS to soybean crops has found that the adoption of this technology could generate productivity gains of about **R$28.5 billion per harvest, with savings of up to R$15.7 billion in reduced fertilizer costs and reductions** in greenhouse gas emissions, thereby contributing to the decarbonization of Brazilian agriculture by up to R$1 billion (Caligaris et al., 2025).

This public-private partnership model expanded the scalability of national and international distribution of strains. For this purpose, there are specific products for sugarcane and soybean crops. These are recommended for seed treatment or application via a directed jet in the seeding furrow. In this case, BiomaPHOS and its clones (recommended for other crops under different names for marketing reasons) have not only yielded financial returns on the investment but have also raised the visibility of Embrapa in Brazil and in other countries.

In this context, the international sale of the Brazilian product is another special feature in the marketing strategy of Embrapa and its partners. In recent years, BiomaPhos has gone beyond the domestic market and went global. It is internationally known as SolubPhos. In 2022, the United States authorized the technology to be used in 14 states. In 2024, the product was registered in Germany, Canada, Argentina, Paraguay, Bolivia, and Costa Rica, and will serve the markets of these countries from 2026 forward.

7.3. Case 2: A Biofungicide for Soil Diseases

An innovation in the market of bioinputs was launched in 2025, and it is called Eficaz Control. Developed by Embrapa in association with Simbiose, it was officially registered with MAPA. This biofungicide has an innovative effect as it is the first product on the market containing a strain of the microorganism *Paenibacillus ottowii*. This technology represents a biological breakthrough in the control of *Fusarium verticillioides*, a fungus with wide geographic distribution that is commonly associated with seed deterioration and damage to corn crops (Diniz et al., 2025; Embrapa, 2025a).

This technology is the result of nine years of research, which began in 2016, involving a detailed process of isolating and selecting 190 microorganisms from corn silk and sorghum seeds. These isolates were tested for their ability to inhibit the growth and development of phytopathogenic fungi, especially *F. verticillioides*, and to promote plant growth (Diniz et al., 2025). In this process, two bacterial strains stood out: *P. ottowii* BRM053425 (LIS04) and *B. velezensis* BRM046334 (IM14), which are part of the formulation of the biofungicide Eficaz Control. The strain *P. ottowii* BRM053425 (LIS04) was isolated from sorghum seeds (*Sorghum bicolor* L.) collected in the Cerrado biome. This strain is capable of producing secondary metabolites, such as fusaricidins, recognized for their potent antifungal activity (Diniz et al., 2025). The strain *B. velezensis* BRM046334 (IM14) is a corn endophyte (*Zea mays* L.), isolated from corn silk from the Cerrado region. It produces the lipopeptides fengycin, iturin and surfactin, and the hydrolytic enzymes cellulase, pectinase, protease, and chitinase, which are bioactive compounds associated with antifungal activity (Diniz et al., 2025).

The compatibility between the two strains allowed their combined formulation, resulting in synergism between the mechanisms of action and greater effectiveness in controlling diseases, such as corn fusariosis. As a result, treatment with Eficaz Control promoted an incidence of *F. verticillioides* below the 9% limit with no differences compared to the chemical products Certeza N and Maxim Advanced, which are used in the phytosanitary management of fusariosis(Diniz et al., 2025; Embrapa, 2025a). Additionally, Eficaz Control represents an advance in the management of pathogen resistance. The combined use of microorganisms with different mechanisms of action reduces selective pressure on *Fusarium*, delaying the emergence of resistance and ensuring more effective and stable control throughout the harvests. Application via seed treatment makes the product an easy-to-implement solution, with positive impacts from the early stages of crop development.

8. Conclusion

Bioinputs are a strategic tool for enhancing sustainability in Brazilian agriculture. The potential of this technology offers new prospects for overcoming constant challenges in agriculture, such as dependence on synthetic fertilizers and pesticides, high production costs, and the environmental impact of agricultural activity. At the same time, the advantage of **using bioinputs is related to the appreciation of Brazilian biodiversity, a resource that is still little explored**, but which demonstrates important advantages in the agricultural and environmental scenario witnessed over the past years. This is brought to light by the pursuit of more sustainable practices capable of reducing environmental impacts and promoting food security.

The formulation of appropriate laws for the entire chain of development, production, registration, and use of bioinputs signals Brazil's position on the issue, while making it a global reference in this industry. Reduced bureaucracy and greater legal certainty brought about by the Bioinputs Law foster research, development, and production of these inputs. With incentives directed at research institutions, startups, the industry and retail, new products are expected to hit the market in the coming years, meeting the industry's demand for efficient, low-cost, environmentally and economically feasible alternatives.

Future prospects are not only related to new products, more efficient formulations, and to overcoming the challenges of Brazilian agriculture, but also to democratizing the use of bioinputs across Brazil and at a global level. Brazilian bioinputs are exported to many countries, including Paraguay, the United States and Germany. Furthermore, investments in education, courses, and safe on-farm production methods must be encouraged and disseminated to the whole agricultural chain. In all of these scenarios, Embrapa and other Brazilian agricultural research institutions play a crucial technical and scientific role in making Brazilian agriculture more sustainable by employing safe and effective bioproducts.

9. References

Associação Nacional Para Difusão De Adubos (ANDA). Relatório sobre o Mercado de Fertilizantes – Janeiro a Dezembro/2024. Comentários Mercado de Fertilizantes, São Paulo, 06 março 2025. Retrieved October 3, 2025, from www.anda.org.br/wp-content/uploads/2025/03/Comentarios.pdf.

Agrolink (2023). Mais de 70% dos fertilizantes são importados no Brasil. www.agrolink.com.br/noticias/mais-de-70--dos-fertilizantes-sao-importados-no-brasil_483200.html

Andrade, L. A., Santos, C. H. B., Frezarin, E. T., Sales, L. R., & Rigobelo, E. C. (2023). Plant growth-promoting rhizobacteria for sustainable agricultural production. Microorganisms, 11(4), 1088. https://doi.org/10.3390/microorganisms11041088

Angelotti, F., Hamada, E., & Bettiol, W. (2024). A comprehensive review of climate change and plant diseases in Brazil. Plants, 13(17), 2447. https://doi.org/10.3390/plants13172447

Barbosa, J. Z., Hungria, M., Sena, J. V. S., Poggere, G., Reis, A. R., & Corrêa, R. S. (2021). Meta-analysis reveals benefits of co-inoculation of soybean with Azospirillum brasilense and Bradyrhizobium spp. in Brazil. Applied Soil Ecology, 163, 103913. https://doi.org/10.1016/j.apsoil.2021.103913

Bashan, Y., de-Bashan, L. E., Prabhu, S. R., & Hernandez, J. P. (2014). Advances in plant growth-promoting bacterial inoculant technology: Formulations and practical perspectives (1998–2013). Plant and Soil, 378, 1–33. https://doi.org/10.1007/s11104-013-1956-x

Bettiol, W., & Medeiros, F. H. V. de. (2023). Como o Brasil se tornou o maior produtor e consumidor de produtos de biocontrole. Embrapa Notícias. Brasília, DF: Embrapa. Retrieved September 24, 2025, from www.embrapa.br/busca-de-noticias/-/noticia/79156418/artigo-como-o-brasil-se-tornou-o-maior-produtor-e-consumidor-de-produtos-de-biocontrole

Bocatti, C. R., Ferreira, E., Ribeiro, R. A., Chueire, L. M. O., Delamuta, J. R. M., Kobayashi, R. K. T., Hungria, M., & Nogueira, M. A. (2022). Microbiological quality analysis of inoculants based on Bradyrhizobium spp. and Azospirillum brasilense produced "on farm" reveals high contamination with non-target microorganisms. Brazilian Journal of Microbiology, 53, 267–280. https://doi.org/10.1007/s42770-021-00649-2

Brasil. (1989). Lei nº 7.802, de 11 de julho de 1989. Dispõe sobre a pesquisa, produção, comercialização e utilização de agrotóxicos e afins. Diário Oficial da União, Seção 1. Brasília, DF, 12 jul. 1989. Retrieved September 22, 2025, from www.planalto.gov.br/ccivil_03/leis/l7802.htm

Brasil. (2020). Decreto nº 10.375, de 26 de maio de 2020. Institui o Programa Nacional de Bioinsumos e dá outras providências. Diário Oficial da União. Brasília, DF. Retrieved September 14, 2025, from www.planalto.gov.br/ccivil_03/_ato2019-2022/2020/decreto/d10375.htm

Brasil. (2024). Lei nº 15.070, de 23 de dezembro de 2024. Dispõe sobre a produção, comercialização e uso de bioinsumos para fins agrícolas, pecuários, aquícolas e florestais. Diário Oficial da União. Brasília, DF. Retrieved September 22, 2025, from www2.camara.leg.br/legin/fed/lei/2024/lei-15070-23-dezembro-2024-796798-publicacaooriginal-173902-pl.html

Brasil. Ministério da Agricultura, Pecuária e Abastecimento. (2010). Instrução Normativa SDA nº 30, de 12 de novembro de 2010: Estabelece os métodos oficiais para análise de inoculantes, sua contagem, identificação e análise de pureza. Diário Oficial da União, Brasília, DF, 17 Nov 2010. Retrieved September 24, 2025, from www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/fertilizantes/legislacao/in-30-2010-dou-17-11-10-metodo-inoculantes.pdf

Brasil. Ministério da Agricultura, Pecuária e Abastecimento. (2013). Instrução Normativa nº 53, de 23 de outubro de 2013: Aprova os métodos analíticos oficiais para fertilizantes minerais, orgânicos, organominerais e corretivos destinados à agricultura. Diário Oficial da União, 150(207), 20. Retrieved September 25, 2025, from www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/31385951/do1-2013-10-24-instrucao-normativa-n-53-de-23-de-outubro-de-2013-31385934

Brasil. Ministério da Indústria, Comércio Exterior e Serviços. Secretaria de Desenvolvimento Industrial, Inovação, Comércio e Serviços. (2023). Plano nacional de fertilizantes 2050: uma estratégia para os fertilizantes no Brasil (197 p.). Brasília, DF: SDIC/MGI. ISBN 978-65-981379-4-6. Retrieved September 24, 2025, from www.gov.br/mdic/pt-br/assuntos/sdic/confert/pnf/pnf-v-08-06-12-23.pdf

Caligaris, B. S. A., Vieira Filho, J. E. R., & Paiva, C. A. O. (2025). Bioinsumos e solubilização biológica de fosfato: ganhos de produtividade e redução de custos (Texto para Discussão, n. 3151, 45 p.). Rio de Janeiro: Ipea. https://dx.doi.org/10.38116/td3151-port

Carregosa, L., & Barbosa, M. (2022, março 30). Fertilizantes representam até 30% dos custos agrícolas. Poder360. Retrieved September 24, 2025, from www.poder360.com.br/economia/fertilizantes-representam-ate-30-dos-custos-agricolas/

Chibeba, A. M., Guimarães, M. F., Brito, O. R., Nogueira, M., Araujo, R. S., & Hungria, M. (2015). Co-inoculation of soybean with Bradyrhizobium and Azospirillum promotes early nodulation. American Journal of Plant Sciences, 6, 1641–1649. https://doi.org/10.4236/ajps.2015.610164

Companhia Nacional de Abastecimento (Conab). (2025). Acompanhamento da safra brasileira de grãos: safra 2024/25 (v. 12, n. 12, décimo segundo levantamento, setembro 2025). Brasília, DF: Conab.

Croplife Brasil. (2024a). Bioinsumos: soluções sustentáveis para o agronegócio. Retrieved June 28, 2025, from https://croplifebrasil.org/bioinsumos/

Croplife Brasil. (2024b). Mercado de bioinsumos cresceu 15% na safra 2023/2024. Retrieved August 21, 2024, from https://croplifebrasil.org/noticias/mercado-de-bioinsumos-cresceu-15-na-safra-2023-2024/

Diniz, G. F. D., Cruz-Magalhães, V., de Sousa, S. M., Cota, L. V., de Paula Lana, U. G., Figueiredo, J. E. F., Ferreira, L. V. S., dos Santos, V. L., & Oliveira-Paiva, C. A. (2025). Draft genome of Paenibacillus ottowii LIS04 and Bacillus velezensis IM14: Dual biocontrol bacterial strains with broad-spectrum antifungal activity. Microbiology Resource Announcements, 14(6), e00184-25. https://doi.org/10.1128/mra.00184-25

Embrapa. (2020). Pesquisa com bioinsumos mobiliza mais de 600 especialistas da Embrapa. Brasília, DF: Embrapa. Retrieved September 25, 2025, from www.embrapa.br/en/busca-de-noticias/-/noticia/52713763/pesquisa-com-bioinsumos-mobiliza-mais-de-600-especialistas-da-embrapa

Embrapa. (2021a). Agrotóxicos no Brasil. Brasília, DF: Embrapa. Retrieved September 14, 2025, from www.embrapa.br/agencia-de-informacao-tecnologica/tematicas/agricultura-e-meio-ambiente/qualidade/dinamica/agrotoxicos-no-brasil

Embrapa. (2021b). Megatendências da Ciência do Solo 2030. Brasília, DF: Embrapa. Retrieved September 24, 2025, from www.alice.cnptia.embrapa.br/alice/bitstream/doc/1143326/1/Megatendencias-da-Ciencia-do-Solo-2030.pdf

Embrapa. (2021c). *Novo bioinseticida usa microrganismo com alta eficiência no controle da lagarta-do-cartucho.* Brasília, DF: Embrapa. Retrieved September 25, 2025, from www.embrapa.br/en/busca-de-noticias/-/noticia/65539256/novo-bioinseticida-usa-microrganismo-com-alta-eficiencia-no-controle-da-lagarta-do-cartucho

Embrapa. (2023a). *Bioinsumos: tendência de crescimento no Brasil.* Retrieved September 22, 2025, from www.embrapa.br/busca-de-noticias/-/noticia/85620702/bioinsumos-tendencia-de-crescimento-no-brasil

Embrapa. (2023a). *O futuro da agricultura brasileira: 10 visões.* Brasília, DF: Embrapa, Superintendência Estratégica. 114 p. Retrieved September 12, 2025, from www.embrapa.br/en/busca-de-publicacoes/-/publicacao/1153216/o-futuro-da-agricultura-brasileira-10-visoes

Embrapa. (2024a). *Agropensa.* Brasília, DF: Embrapa. Retrieved September 24, 2025, from www.embrapa.br/en/agropensa/agro-em-dados/agricultura/graos

Embrapa. (2024b). *Tecnologia Embrapa para absorção de fósforo rende R$ 4 bilhões ao Brasil em cinco anos.* Brasília, DF: Embrapa. Retrieved September 22, 2025, from www.embrapa.br/busca-de-noticias/-/noticia/95533715/tecnologia-embrapa-para-absorcao-de-fosforo-rende-r-4-bilhoes-ao-brasil-em-cinco-anos

Embrapa. (2025b). *Novo biofungicida controla fungos de solo com até 80% de eficiência.* Brasília, DF: Embrapa. Retrieved September 19, 2025, from www.embrapa.br/busca-de-noticias/-/noticia/102045647/novo-biofungicida-controla-fungos-de-solo-com-ate-80-de-eficiencia

Embrapa. (2025b). *Ciência amplia escopo da fixação biológica de nitrogênio no Brasil.* Brasília, DF: Embrapa. Retrieved September 19, 2025, from www.embrapa.br/busca-de-noticias/-/noticia/98368676/ciencia-amplia-escopo-da-fixacao-biologica-de-nitrogenio-no-brasil

Embrapa. (2025c). *Bioinsumos Brasil: aplicativo para consulta de produtos biológicos agrícolas.* Retrieved September 22, 2025, from www.embrapa.br/bioinsumos-aplicativo

Fontes, E. M. G., & Valadares-Inglis, M. C. (Eds.). (2020). *Controle biológico de pragas da agricultura.* Brasília, DF: Embrapa. 510 p. ISBN 978-65-86056-01-3

Fukami, J., Nogueira, M. A., Araujo, R. S., & Hungria, M. (2016). Accessing inoculation methods of maize and wheat with *Azospirillum brasilense.* AMB Express, 6(1), 1–13. https://doi.org/10.1186/s13568-015-0171-y

Galindo, F. S., Pagliari, P. H., da Silva, E. C., Silva, V. M., Fernandes, G. C., Rodrigues, W. L., Céu, E. G. O., de Lima, B. H., Jalal, A., Muraoka, T., Buzetti, S., Lavres, J., & Teixeira Filho, M. C. M. (2022). Co-inoculation with *Azospirillum brasilense* and *Bradyrhizobium* sp. enhances nitrogen uptake and yield in field-grown cowpea and did not change N-fertilizer recovery. *Plants (Basel), 11*(14), 1847. https://doi.org/10.3390/plants11141847

Gómez-Godínez, L. J., Martínez-Romero, E., Banuelos, J., & Arteaga-Garibay, R. I. (2021). Tools and challenges to exploit microbial communities in agriculture. *Current Research in Microbial Sciences, 2,* 100062. https://doi.org/10.1016/j.crmicr.2021.100062

Hungria, M. (2011). *Inoculação com Azospirillum brasilense: inovação em rendimento a baixo custo.* Londrina, PR: Embrapa Soja. 36 p. Retrieved September 19, 2025, from https://ainfo.cnptia.embrapa.br/digital/bitstream/item/29676/1/Inoculacao-com-azospirillum.pdf

Hungria, M., & Nogueira, M. A. (2022). Fixação biológica do nitrogênio. In Meyer, M. C., Bueno, A. F., Mazaro, S. M., & Silva, J. C. (Eds.), *Bioinsumos na cultura da soja* (pp. 141–162). Brasília, DF: Embrapa. Retrieved from www.alice.cnptia.embrapa.br/alice/bitstream/doc/1147044/1/cap-8-Bioinsumos-na-cultura-da-soja.pdf

IPCC**.** *Summary for Policymakers*. In: IPCC. *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Core Writing Team: H. Lee; J. Romero (eds.). Geneva: IPCC, 2023. p. 1–34. DOI: 10.59327/IPCC/AR6-9789291691647.001.

Lana, U. G. P., et al. (2022). *Avaliação da qualidade de inoculantes à base de Bacillus para promoção de crescimento de plantas produzidos em sistema on farm.* Sete Lagoas: Embrapa Milho e Sorgo.

Lana, U. G. P., et al. (2019). *Avaliação da qualidade de biopesticidas à base de Bacillus thuringiensis produzidos em sistema "on farm".* Sete Lagoas: Embrapa Milho e Sorgo.

Lee, H. J., & Lee, S. J. (2021). Advances in accurate microbial genome-editing CRISPR technologies. *Journal of Microbiology and Biotechnology, 31*(7), 903–911. https://doi.org/10.4014/jmb.2106.06056

MAPA – Ministério da Agricultura e Pecuária. (2020). *Conceitos.* Brasília, DF: MAPA. Retrieved September 22, 2025, from www.gov.br/agricultura/pt-br/assuntos/inovacao/bioinsumos/o-programa/conceitos

Mitter, E. K., Tosi, M., Obregón, D., Dunfield, K. E., & Germida, J. J. (2021). Rethinking crop nutrition in times of modern microbiology: innovative biofertilizer technologies. *Frontiers in Sustainable Food Systems, 5,* 606815. https://doi.org/10.3389/fsufs.2021.606815

Oliveira, C. A., Alves, V. M. C., Marriel, I. E., Gomes, E. A., Scotti, M. R., Carneiro, N. P., Guimarães, C. T., Schaffert, R. E., & Sá, N. M. H. (2009). Phosphate solubilizing microorganisms isolated from rhizosphere of maize cultivated in an oxisol of the Brazilian Cerrado Biome. *Soil Biology and Biochemistry, 41*(9), 1782–1787. https://doi.org/10.1016/j.soilbio.2008.01.012

Oliveira-Paiva, C. A., Bini, D., de Sousa, S. M., Ribeiro, V. P., dos Santos, F. C., de Paula Lana, U. G., et al. (2024). Inoculation with *Bacillus megaterium* CNPMS B119 and *Bacillus subtilis* CNPMS B2084 improve P-acquisition and maize yield in Brazil. *Frontiers in Microbiology, 15,* 1426166. https://doi.org/10.3389/fmicb.2024.1426166

Parra, J. R. P. (2014). Controle biológico de pragas: histórico, situação atual e perspectivas. *Economic Analysis of Law Review, 12*(3), 557–574.

Pereira, L. A. C., & Cardoso, V. M. (2025). How dependent is Brazilian agriculture on fertilizer imports? *Agro in Data – Insper.* Retrieved September 24, 2025, from https://agro.insper.edu.br/en/agro-in-data/artigos/qual-e-a-dependencia-do-agro-brasileiro-das-importacoes-de-fertilizantes

Policarpo, M. A., Silva, A. C. B., Macedo, L. O. B., Gomes, F. M. S., Oliveira, L. G., Pereira, F. S., et al. (2025). *Desafios e oportunidades para o avanço da produção de bioinsumos no Brasil* (Texto para Discussão, n. 3133). Brasília, DF: Ipea. https://doi.org/10.38116/td3133-port

Sambuichi, R. H. R., et al. (2024). *Acompanhamento, sistematização e análise dos resultados iniciais de execução do Programa Nacional de Bioinsumos.* Brasília, DF: Ipea.

Sharma, N., Mahawar, L., Mishra, A., & Albrechtsen, B. R. (2025). Microbial contributions to plant growth and stress tolerance: mechanisms for sustainable plant production. *Plant Stress, 17,* 100966. https://doi.org/10.1016/j.stress.2025.100966

Singh, M., Jha, S., Pathak, D., et al. (2025). Advancing biofertilizers: the evolution from single-strain formulations to synthetic microbial communities (SynCom) for sustainable agriculture. *Discovery Plants, 2,* 226. https://doi.org/10.1007/s44372-025-00318-w

Sousa, S. M., Oliveira, C. A., Andrade, D. L., Carvalho, C. G., Ribeiro, V. P., Pastina, M. M., et al. (2021). Tropical *Bacillus* strains inoculation enhances maize root surface area, dry weight, nutrient uptake and grain yield. *Journal of Plant Growth Regulation, 40,* 867–877. https://doi.org/10.1007/s00344-020-10146-9

United Nations (ONU), Department of Economic and Social Affairs, Population Division. (2019). *World Population Prospects 2019: Highlights* (ST/ESA/SER.A/423).

Velloso, C. C., Oliveira, C. A., Gomes, E. A., Lana, U. G. P., Carvalho, C. G., Guimarães, L. J. M., et al. (2020). Genome-guided insights of tropical *Bacillus* strains efficient in maize growth promotion. *FEMS Microbiology Ecology, 96,* fiaa157. https://doi.org/10.1093/femsec/fiaa157

Vermelho, A. B., Macrae, A., Neves, A., Domingos, L., De Souza, J. E., Borsari, A. C. P., De Oliveira, S. S., Von der Weid, I., Veillard, P., & Zilli, J. E. (2025). Microbial bioinputs in Brazilian agriculture. *Journal of Integrative Agriculture.* https://doi.org/10.1016/j.jia.2025.09.013

Vidal, M. C., Amaral, D. F. S., Nogueira, J. D., Mazzaro, M. A. T., & Lira, V. M. C. (2021). Bioinsumos: a construção de um Programa Nacional pela Sustentabilidade do Agro Brasileiro. *Economic Analysis of Law Review, 12*(3), 557–574.

Zvinavashe, A. T., Mardad, I., Mhada, M., Kouisni, L., & Marelli, B. (2021). Engineering the plant microenvironment to facilitate plant-growth-promoting microbe association. *Journal of Agricultural and Food Chemistry, 69*(45), 13270–13285. https://doi.org/10.1021/acs.jafc.1c00138

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