

REVIEW

Bioinputs in Brazilian agriculture: Contributions to the reduction of agrochemical use

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Abstract: Modern agriculture faces the challenge of increasing the production of food, fiber, and biofuels while minimizing environmental impacts and preserving soil quality. In this context, bioinputs have emerged as a promising alternative for reducing dependence on agrochemicals in Brazilian agriculture. This study aimed to analyze the advancement of bioinputs in Brazil and their contribution to reducing the use of synthetic chemical inputs. Specifically, the study sought to identify the main types of bioinputs used in agriculture, describe their characteristics and applications, evaluate their advantages and limitations, and examine their development and the challenges associated with their large-scale adoption. The research was conducted through a qualitative and descriptive literature review, based on scientific articles, dissertations, theses, and institutional documents published between 2010 and 2026. The results revealed significant growth in the Brazilian bioinputs sector, with an estimated market value of approximately BRL 5 billion during the 2023/2024 crop season, representing a 15% increase compared to the previous season and an average annual growth rate of nearly 21% in recent years. Furthermore, the potential area treated with bioinputs exceeded 155 million hectares during the 2024/2025 crop season, highlighting their increasing incorporation into agricultural production systems. The reviewed literature indicates that inoculants, biological control agents, biofertilizers, and biostimulants contribute to the partial replacement of chemical fertilizers and pesticides, improving soil fertility, supporting integrated pest management, and enhancing agricultural sustainability. It is concluded that bioinputs represent a strategic technology for sustainable Brazilian agriculture, with substantial potential to reduce dependence on agrochemicals and mitigate environmental impacts, provided that their adoption is supported by continuous investments in research, innovation, technical assistance, and public policies that encourage their use.

Keywords: Bioinputs; Sustainable agriculture; Agrochemicals; Sustainability; Agricultural production.

1. Introduction

Modern agriculture faces the challenge of meeting the growing global demand for food, fiber, and biofuels while simultaneously reducing environmental impacts

associated with the intensive use of mineral fertilizers and synthetic chemical pesticides (Hemathilake; Gunathilake, 2022; Suchithkumar et al., 2024). In this context, bioinputs have emerged as a strategic alternative for promoting more sustainable, efficient,

and resilient agricultural systems. These products consist of microorganisms, plant extracts, natural substances, or biologically active metabolites capable of stimulating plant growth, improving nutrient availability, and assisting in the control of pests and diseases, thereby reducing dependence on conventional chemical inputs (Shahwar et al., 2023; Faria; Wander, 2024).

Bioinputs can be classified into biofertilizers, microbial inoculants, biopesticides, biostimulants, and biosolubilizers (Barbosa et al., 2025). These products act through mechanisms such as biological nitrogen fixation, phosphorus solubilization, phytohormone production, induction of systemic resistance, and biological control of phytopathogens. Such characteristics contribute to increased agricultural productivity while minimizing the negative impacts of excessive agrochemical use (Shahwar et al., 2023; Valente et al., 2025).

Over recent decades, growing concerns regarding environmental degradation, water contamination, biodiversity loss, and the effects of chemical residues on human health have driven the development of agricultural technologies based on biological processes. In this scenario, bioinputs have gained prominence within sustainable and regenerative agriculture programs, being considered essential tools for the transition toward production systems with lower environmental impacts (Miranda, 2024; Rosales-Castillo et al., 2025; Shahwar et al., 2023).

The expansion of this sector has occurred rapidly in several countries. Brazil, recognized as one of the world's leading references in the adoption of bioinputs, has experienced an average annual market growth exceeding 20% in recent years, significantly above the global average. It is estimated that more than 60% of Brazilian farmers currently use some type of biological product in their production systems, especially in soybean, corn, and sugarcane crops (Reuters, 2024; Medina et al., 2025).

In addition to their agronomic benefits, bioinputs hold strategic importance for achieving the Sustainable Development Goals (SDGs) established by the United Nations Agenda 2030. Their main contributions include reducing environmental pollution, conserving natural resources, strengthening food security, and promoting agricultural systems that are more resilient to climate change. Consequently, their use aligns with global demands for sustainable production and the mitigation of environmental impacts caused by conventional agriculture (Faria; Wander, 2024; Förster, 2025; Miranda, 2024).

Scientific advances related to bioinputs have also

been driven by developments in microbiological and biotechnological technologies. Recent studies have demonstrated that microbial inoculants can enhance nutrient uptake, improve plant tolerance to biotic and abiotic stresses, and increase crop productivity without compromising soil environmental quality. These findings reinforce the potential of bioinputs as complementary or alternative tools to synthetic fertilizers and pesticides (Medina et al., 2025; Rocha et al., 2024; Shahwar et al., 2023).

Given this scenario, it is important to understand how the increasing use of bioinputs has contributed to reducing agrochemical dependence in Brazilian agriculture. Although their environmental and productive benefits are widely recognized, challenges remain regarding regulation, standardization, storage, technical assistance, and large-scale adoption by farmers (Faria; Wander, 2024; Medina; Cunha, 2025).

The scientific relevance of this study is associated with the need to expand knowledge regarding the impacts of bioinputs on agricultural sustainability, providing support for researchers, extension agents, policymakers, and rural producers. Furthermore, this study contributes to understanding technological trends that are transforming the agricultural sector and promoting more sustainable and competitive production systems (Reuters, 2024; Medina et al., 2025).

Based on this context, the following research question is proposed: How has the advancement of bioinputs contributed to reducing the use of agrochemicals in Brazilian agriculture? The hypothesis is that the increasing adoption of bioinputs is directly associated with reduced dependence on synthetic fertilizers and pesticides, thereby favoring more sustainable production systems. However, economic, regulatory, technological, and cultural factors may influence the pace and effectiveness of this substitution process (Medina; Cunha, 2025; Ulrich, 2023).

Therefore, the general objective of this study is to analyze the advancement of bioinputs and their role in reducing agrochemical use in Brazilian agriculture. The specific objectives are to identify the main types of bioinputs used in agriculture, describe their characteristics and applications, evaluate their advantages and limitations compared with conventional agrochemicals, examine the evolution of their use over time, and analyze their contributions to the sustainability of national agricultural production.

2. Methodology

This study is characterized as qualitative research with

descriptive and exploratory objectives, conducted through a literature review. This type of research enables the collection, analysis, and synthesis of previously published scientific knowledge on a given topic, contributing to the understanding of the current state of knowledge and the identification of trends, advances, and research gaps (Gil, 2019).

The literature search was carried out between March and April 2026 using the databases Scopus, Web of Science, SciELO, and Google Scholar, selected due to their broad coverage of national and international publications related to Agricultural Sciences, Biotechnology, Sustainable Agriculture, and related fields.

Searches were performed using descriptors in Portuguese, English, and Spanish, either individually or combined through the Boolean operators AND and OR. The main search terms included: “bioinsumos”, “biofertilizantes”, “bioestimulantes”, “biopesticidas”, “control biológico”, “agricultura sustentável”, “agroquímicos”, “bioinputs”, “biofertilizadores”, “biostimulantes”, “biopesticidas”, “biological control”, “sustainable agriculture”, “agrochemicals”, “bioinsumos agrícolas”, “biofertilizantes”, “biopesticidas”, “control biológico”, and “agricultura sostenible”.

Eligible sources included scientific articles, books, book chapters, dissertations, theses, institutional documents, and legislation published between 2020 and 2026 in Portuguese, English, and Spanish. These languages were selected due to their broad representation in the scientific literature concerning bioinputs, sustainable agriculture, and biological technologies applied to agricultural systems. Additionally, official documents from governmental agencies, research institutions, and agribusiness organizations were consulted, provided they contained information relevant and consistent with the objectives of this study.

The inclusion criteria comprised studies directly addressing agricultural bioinputs, including topics related to biofertilizers, biostimulants, inoculants, biological control agents, regulations, market development, and agricultural sustainability. Exclusion criteria included duplicate publications, studies without full-text access, documents not directly related to the proposed topic, and publications whose methodological quality or scientific relevance did not contribute to the objectives of the review.

After the selection stage, the studies underwent exploratory, selective, and analytical reading. Subsequently, information regarding bioinput types, mechanisms of action, agricultural applications, advantages, limitations, regulatory aspects, market development, and contributions to reducing agrochemical

use was extracted. The collected data were organized and discussed descriptively, enabling the development of a critical analysis of the advancement of bioinputs and their role in promoting more sustainable agricultural systems.

3. Bioinputs

3.1 Fundamentals of bioinputs: Definition, classification, applications, and production

Biological inputs are products and technologies that utilize biological agents, such as fungi, bacteria, plants, insects, and animals, for agricultural, aquaculture, and livestock production, and are also considered an alternative to conventional agrochemicals (Buss et al., 2025; Vermelho et al., 2024). The growing demand for healthy food and more sustainable agricultural practices has created new opportunities for the development and adoption of biological inputs. Despite relying on biological agents, their production involves certain risks, making it essential that professionals responsible for handling these agents possess adequate training and knowledge regarding their characteristics and specific requirements. Such expertise is necessary to prevent misuse and contamination by pathogenic organisms, which may pose risks to both the environment and agricultural production systems (Khatri et al., 2024; Vidal, 2023).

Among the various types of biological inputs available, special attention should be given to biological products used for pest and disease management in agriculture. These products can be classified as macrobiological agents, including mites, insects, and nematodes; microbiological agents, such as viruses, bacteria, and fungi; semiochemicals, including pheromones; and biochemical products, such as hormones and phytochemical compounds derived from plants (Beyari, 2025). These substances are considered biologically active ingredients and play a fundamental role in the formulation of numerous products used in agricultural production, storage, and processing systems (Monteiro, 2024).

Pest and disease control represents one of the major challenges in agricultural production and often requires substantial investments in crop protection products, many of which are chemically based (Bouri et al., 2023). Within the context of biological inputs, microorganisms are among the most widely used agents for pest and disease management. In particular, bacteria belonging to the genus *Bacillus* are extensively utilized due to their effectiveness and versatility (Li; Wang, 2024). These Gram-positive, aerobic bacteria can be found in a variety of environments, including soils, stored grains, and dead insects, making them valuable tools for sustainable crop protection strategies (Silva, 2024; Tomar et al., 2024).

Unlike conventional pesticides, which rely on chemical active ingredients that may present risks to producers, consumers, production systems, and the environment, biological inputs are based on beneficial microorganisms, bacteria, fungi, and insects. These agents can function as biofertilizers, biological control agents against pests and diseases, plant growth promoters, and enhancers of mineral nutrition in plants and animals. In many cases, biological inputs can even be produced directly on farms. Farms engaged in the production of biological inputs require specialized facilities known as biofactories, which enable the proper handling and multiplication of biological agents. Such facilities depend on appropriate equipment, selected raw materials, and culture media to ensure the propagation, conservation,

and maintenance of the beneficial properties of these organisms (Benaissa, 2024; Mira, 2025).

To facilitate the organization and understanding of the information presented on biological inputs, (Table 1) is proposed to summarize the main types, characteristics, applications, and challenges associated with their use. This resource allows for a clearer visualization of the diversity of biological inputs and their importance within the context of sustainable agriculture. Furthermore, it highlights critical aspects that still require attention, including the need for technical training, quality control, and regulatory improvements to support their broader adoption.

Table 1. Classification, characteristics, applications, and challenges of biological inputs in agriculture.

Type of biological input	Examples	Main characteristics	Applications	Challenges
Macrobiological agents	Mites, insects, and nematodes	Living organisms used for biological control	Pest control	Large-scale production
Microbiological agents	Bacteria, fungi, and viruses	Beneficial microorganisms for soil and plant health	Pest and disease control	Standardization and proper cultivation
Semiochemicals	Pheromones	Substances involved in communication between organisms	Pest monitoring and control	Efficiency in large agricultural areas
Biochemical products	Hormones and plant extracts	Natural compounds with physiological effects on plants	Plant growth promotion	Stability and formulation
On-farm production	On-farm biofactories	Local production of biological inputs	Cost reduction and increased farm autonomy	Biosafety and quality control

Source: Authors, 2026.

3.2 Bioinputs: Concepts, functions, and importance in sustainable agriculture

Table 2 summarizes the main types of biological inputs used in agriculture, highlighting their characteristics, applications, and associated challenges. It is observed that, despite their great potential to reduce the use of agrochemicals and promote more sustainable practices, important limitations still exist, particularly regarding standardization, large-scale production, and the need for technical knowledge among producers.

In this context, the term “on-farm” refers to the production of biological inputs directly on rural properties, a practice that has been expanding due to the high cost of commercial agricultural pesticides and the search for more sustainable alternatives (Goulet, 2023). Although this model provides greater autonomy and cost reduction, it also requires strict biosafety measures, since there are risks associated with contamination and improper handling of microorganisms (Caldas et al., 2024).

Table 2. Main milestones related to the development and regulation of bioinputs in Brazil.

Year	Regulatory or institutional milestone	Main contributions
Until 2010	Expansion of research in biological control and biofertilizers	Consolidation of the first initiatives focused on the use of microorganisms and biological agents in Brazilian agriculture.
2010–2020	Growth of the bioinputs market and Strengthening of on-farm production	Expansion of scientific research and increased interest from producers in alternatives to conventional agrochemicals.
2020	Launch of the National Bioinputs Program	Establishment of guidelines to encourage the production, innovation, and use of bioinputs in Brazilian agriculture.
2021–2023	Increased discussions on specific regulatory frameworks	Intensification of debates on the need for differentiated regulations for bioinputs and biological production systems.
2024	Advances in Biosafety research and on-farm production	Greater attention to technical qualification, quality control, and safety in bioinput production (Caldas et al., 2024).
2025–2026	Expansion of biological technologies and regulatory improvements	Strengthening of research on bioinoculants, biofertilizers, biopesticides, and biostimulants, aiming to expand their adoption in sustainable agriculture (Mininel, 2026).

Source: Authors, 2026.

3.3 On-farm production and technical and regulatory challenges

On-farm production involves important challenges, especially regarding the standardization of microbial incubation time and the suitability of culture media. In addition, the replacement of raw material suppliers can directly affect microbial multiplication efficiency (Faria et al., 2023; Queiroz, 2025; Goulet, 2023).

Another relevant obstacle is the lack of technical training among rural producers, many of whom are still accustomed to conventional agrochemical use. This highlights the need for technological dissemination and rural extension actions to support the adoption of bioinput-based practices (Bortoloti, 2024).

Additionally, the current regulatory framework still treats different technologies in a uniform manner, which limits the specific advancement of biological inputs. Therefore, it is necessary to establish more appropriate legislation that considers their biological and operational characteristics.

3.4 Mechanisms of action and applications of biological

inputs in crops

Biological inputs act through biological and natural mechanisms, differing from conventional agrochemicals, as they use living organisms or natural substances to promote pest and disease control and stimulate plant growth (Monteiro, 2024; Priya et al., 2023).

In soybean cultivation, inoculants based on *Bradyrhizobium* stand out due to their role in biological nitrogen fixation, reducing the need for nitrogen fertilizers. In addition, microorganisms such as *Bacillus* spp. and fungi such as *Trichoderma* spp. are widely used in the management of diseases and nematodes (Silva, 2024; Monteiro, 2024).

In maize and cotton crops, entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* are used for biological insect pest control, while plant growth-promoting bacteria contribute to root development and nutrient uptake (Liu et al., 2022; Santos, 2024).

In sugarcane cultivation, biological inputs play an important role in improving soil fertility and pest control, promoting greater biological balance and reducing dependence on agrochemicals (Cunha, 2023).

3.5 Comparison between biological inputs and conventional agrochemicals

Biological inputs offer important advantages, such as lower toxicity, reduced environmental impact, and greater sustainability. However, unlike agrochemicals, their action tends to be more specific and highly dependent on environmental and management conditions (Brunelle et al., 2024).

While agrochemicals provide rapid and standardized responses, biological inputs require greater technical knowledge and strict control of factors such as formulation, incubation, and quality of biological agents (Queiroz, 2025).

3.6 Classification of biological inputs

The classification of biological inputs can be based on their biological nature, divided into five main categories: microorganisms, macroorganisms, natural substances, semiochemicals, and mixed systems (Mininel, 2026).

Microorganisms include bacteria, fungi, entomopathogenic viruses, and yeasts used in biofertilizers and biological control. Macroorganisms involve predatory insects, parasitoids, and mites used in pest control (Dmytruk et al., 2025).

Natural substances include plant extracts, humic acids, and organic compounds with physiological effects. Semiochemicals act as communication mediators between organisms, such as pheromones. Mixed biological inputs include products such as bokashi and fermented compounds produced on-farm, presenting specific regulatory challenges (Bavaresco, 2024).

3.7 Biological inputs as biofertilizers, biopesticides, and biostimulants

Biological inputs can function as biofertilizers, promoting plant growth and improving soil microbiota. *Pseudomonas* spp. strains have demonstrated the ability to produce indole acetic acid, solubilize phosphates, and increase drought tolerance (Araújo, 2023).

In addition, zinc-solubilizing bacteria have shown positive effects on soybean growth and productivity (Cordeiro, 2023). Microorganisms such as *Bacillus*, *Azospirillum*, and *Rhizobium*, as well as fungi such as *Trichoderma*, are also widely used as bioinoculants (Shahwar et al., 2023; Souza et al., 2024).

Biopesticides include bioherbicides, biofungicides, and bioinsecticides. Recent technologies such as nanoencapsulation and essential oil-based formulations have improved their efficiency and stability (Polcarpo et

al., 2023).

In the biostimulant field, compounds derived from organic waste, chitin, chitosan, and microalgae such as *Chlorella* spp. and *Arthrospira platensis* stand out, promoting plant growth and tolerance to environmental stresses (Feitosa et al., 2024; Viana, 2025).

3.8 Biological inputs and agricultural sustainability

The use of biological inputs is directly related to the Sustainable Development Goals (SDGs), contributing to reduced environmental impact, improved soil health, and decreased dependence on synthetic agrochemicals (García-Poza et al., 2022).

4. Evolution of Bioinputs: Concepts, Functions, and Importance in Sustainable Agriculture

The organization of the main milestones demonstrates that the development of bioinputs in Brazil occurred gradually, following the advancement of scientific research and the growing demand for more sustainable production systems. It is observed that, in addition to technological evolution, there has been a strengthening of discussions on regulation and biosafety, particularly regarding on-farm production and the need for specific standards for these inputs. Presenting this information in a tabular format facilitates the reader's understanding of the historical evolution of the topic and the institutional transformations that have driven the expansion of bioinputs in the Brazilian agricultural sector (Barbosa et al., 2025; Vaz et al., 2025).

4.1 Evolution of the bioinputs sector

The evolution of bioinput-related legislation in Brazil began with laws and decrees regulating the production and commercialization of fertilizers and pesticides. Law No. 6,894 of December 16, 1980 established guidelines for the inspection and control of the production and trade of fertilizers, soil amendments, inoculants, stimulants, and biofertilizers. Bioinputs intended for crop fertilization were included under this general legislation, without a specific distinction between chemical and biological products (Fazenda Pública, 1980).

Regarding bioinputs used for phytosanitary purposes, they were incorporated into Law No. 7,802 of July 11, 1989, known as the Pesticide Law, which defined these products as agents of physical, chemical, or biological processes used in agricultural production, storage, and processing, as well as in forest protection and other ecosystems, aiming to alter flora or fauna composition to protect crops from harmful organisms (Brasil, 2015).

Thus, based on this definition, phytosanitary bioinputs

used in pest and disease control were classified as pesticides, being treated equivalently to chemical inputs. Over time, however, new regulations were developed to provide bioinputs with their own legal identity, mainly due to their close association with organic farming and agroecological systems. Therefore, the legal framework for bioinputs has evolved closely linked to organic agriculture regulation (Sousa, 2024).

4.1.1 Productivity

The regulation of organic production in Brazil began in the 1990s, aiming to ensure product quality for consumers and meet international market demands. One of the key drivers of this process was the establishment of Technical Regulation No. 2,092 of June 24, 1991, by the European Economic Community, then the main importing market for these products (Martins, 2014).

Subsequently, in order to promote and strengthen organic production, the Brazilian government established rules and procedures for production, classification, processing, packaging, distribution, labeling, and certification of plant and animal organic products, as defined by Normative Instruction No. 7/1999 of the Ministry of Agriculture. Decree No. 4,074 of January 4, 2002, which regulated the Pesticide Law, also began prioritizing the evaluation of products with lower toxicity and reduced environmental hazard (Brasil, 2016).

In 2003, a significant milestone was achieved with the enactment of Law No. 10,831, known as the Organic Law. One of its main advances is Article 9, which establishes that inputs authorized for organic agriculture must follow a simplified and faster registration process. This law adopted a broad concept of organic production, including agroecology, biodynamics, permaculture, and sustainable extractivism (Brasil, 2003).

In 2004, the Ministry of Agriculture launched the Organic Agriculture Development Program (Pró-Orgânico) through Ordinance No. 158. The program aimed to improve technical and organizational capacity, strengthen regulatory frameworks, and encourage production and commercialization, playing a key role in structuring discussions on inputs and reducing production costs in organic systems (Brasil, 2004).

Between 2005 and 2006, four joint normative instructions were published to regulate the registration of biological products, classifying them into biochemical, semiochemical, biological control agents, and microbiological control agents. Biochemical products are naturally derived substances or synthetic analogues with non-toxic modes of action.

4.1.2 Market

Semiochemicals refer to substances responsible for communication between organisms, acting within or between species. Biological control agents include macroorganisms such as insects, mites, and nematodes that act as predators, parasites, or competitors (Maurya et al., 2022). Microbiological control agents consist of naturally occurring microorganisms, excluding genetically modified organisms (Brasil, 2006).

Subsequently, regulatory changes were introduced to improve toxicological and ecotoxicological assessment criteria, particularly for biochemical and microbiological products, ensuring greater technical rigor and safety in the registration process. Decree No. 6,913 of July 23, 2009, represented a key milestone by establishing clearer distinctions between biological and chemical products (Brasil, 2016).

This decree introduced the concept of phytosanitary products authorized for organic agriculture and provided detailed guidelines for their registration. One of its main innovations was the creation of “reference specifications,” allowing product registration based on data and studies conducted by public or private research institutions under the coordination of the Ministry of Agriculture, reducing development costs for applicants (Prieto, 2021).

4.2 Agriculture and the relationship between bioinputs and agrochemicals

Agricultural production systems worldwide have undergone major transformations. In this context, agricultural productivity has been enhanced by technological advances and the use of bioinputs, leading to increased yields alongside environmental conservation, rational water use, and reduced dependence on agrochemicals (Lima et al., 2025).

The use of organic inputs has grown in Brazil and globally due to regulatory, market, and management factors. The global organic agricultural market, including biopesticides, inoculants, biostimulants, and biofertilizers, was estimated at USD 9.9 billion in 2020, with biocontrol products accounting for approximately USD 5.2 billion (Sambuichi, 2024).

In agriculture, bioinputs represent a key pillar enabling high productivity levels. Brazil has become the world's largest soybean producer and a global reference in the bioinput market. This leadership is associated with industry investment, continuous product innovation, discovery of new microorganisms, formulation combinations, metabolite synthesis, and plant extract use (Fontenelle et al., 2025).

The bioinput sector is characterized by strong innovation capacity, supported by highly qualified

technical teams and collaboration with public research institutions, improving strategies, compatibility, and application conditions (Cipriani et al., 2025).

Bioinputs are increasingly recognized as promising technologies that reconcile productivity and sustainability, meeting growing consumer and market demands for reduced chemical input use (Corrêa et al., 2025; Soares, 2023). They are becoming widely integrated into crop management systems, offering economically viable and environmentally sustainable alternatives (Portela et al., 2025).

4.3 Agricultural productivity and market expansion

Agricultural productivity increasingly relies on scientific and technical evidence supporting sustainable technologies for pest control and soil fertilization. Bioinput use in Brazil has expanded over the last decade, driven by scientific progress, innovation policies, and increased adoption of integrated pest management (Sousa et al., 2025).

Recent data indicate that the Brazilian bioinput market moved approximately BRL 5 billion in the 2023/2024 season, growing 15% compared to the previous year and averaging 21% annual growth over the last three years—around four times the global average. The treated area reached 155.4 million hectares in the 2024/2025 season, highlighting rapid consolidation of these technologies (Croplife Brasil, 2024).

Despite this progress, adoption rates remain moderate, with approximately 20% of Brazilian farmers using bioinputs. However, awareness and adoption have increased significantly, especially in soybean production (Zanetti et al., 2025).

Production, formulation, and commercialization are largely driven by the private sector in partnership with public institutions, accelerating innovation (Pinheiro et al., 2025). Brazil's biodiversity also offers significant potential for new bioinput development, although molecular and physiological studies are still needed for broader application (Cruz, 2025).

Contrary to earlier assumptions that bioinputs are limited to small-scale farming, recent evidence shows effective application in large-scale agricultural systems (Delvaux, 2025).

Finally, Cunha (2023), Santos (2023) and Silva et al. (2025) emphasize that large-scale adoption depends on stable formulations, industrial production capacity, mechanization, and technical support. Environmental conditions also play a critical role in application success.

4.4 Regulation and final considerations

Brazilian regulation is based mainly on Law No. 7,802/89 and Law No. 6,894/80; however, differences remain regarding biofertilizers and biostimulants compared to international definitions (Brasil, 2016). The lack of a clear definition for biostimulants creates regulatory inconsistencies (Bavaresco, 2024).

Industries must comply with federal, state, and municipal regulations to ensure quality and safety. Bioinputs contribute significantly to national savings, especially through biological nitrogen fixation in soybean production (Basso et al., 2025).

Overall, farmers are increasingly adopting biological solutions due to productivity gains, cost reduction, and soil quality improvement. Government initiatives and knowledge dissemination programs continue to support this transition (Vidal, 2023).

5. Conclusion

Based on the findings, it was possible to understand that the advancement of bioinputs has played a fundamental role in transforming Brazilian agriculture, particularly in reducing dependence on agrochemicals. It is evident that the transition toward more sustainable production systems is not merely a contemporary trend, but a strategic necessity to ensure agricultural productivity, the conservation of natural resources, and environmental and food safety.

The guiding research question of this study was addressed by demonstrating that bioinputs significantly contribute to reducing the use of agrochemicals by acting in biological pest and disease control, improving soil fertility, and promoting plant development. In many cases, these inputs already play a complementary or substitutive role to conventional chemical products, without compromising crop productivity.

Regarding the proposed objectives, it was possible to identify the main types of bioinputs used in agriculture, understand their characteristics and modes of application, and analyze their advantages and limitations. It was observed that, although they present significant benefits—such as lower environmental impact, greater safety in handling, and potential cost reduction—important challenges still remain, particularly regarding the need for technical training, process standardization, and appropriate application conditions across different production contexts.

Additionally, the use of bioinputs has shown continuous growth over the years, driven by scientific advances, technological innovation, and increasing demand for sustainable agricultural practices. However, large-scale adoption still faces barriers related to knowledge dissemination, technical assistance, and

regulatory frameworks. Despite these constraints, Brazil presents highly favorable conditions for the development of this sector, especially due to its biodiversity, productive capacity, and relevance in the global agricultural scenario.

Thus, it is concluded that bioinputs represent a viable, strategic, and expanding alternative for strengthening a more sustainable, efficient, and balanced agriculture. Rather than merely replacing chemical inputs, these products represent a paradigm shift in the way food is produced, valuing biological processes and the balance of agricultural ecosystems.

Finally, the results of this study contribute to broadening the understanding of the topic and reinforce the importance of continued investment in research, technological development, professional training, and public policies aimed at consolidating the use of bioinputs, benefiting both the productive sector and society as a whole.

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Author's Contributions

Alex Silva do Carmo: conceptualization, investigation, data curation, writing – original draft. *Carlos Frederico de Souza Castro*: investigation, data curation, formal analysis. *Francisco Rafael Santos da Conceição*: investigation, methodology, validation. *Hellen Regina Fernandes Batista Ventura*: supervision, project administration, writing – review & editing.

Ethics

This study did not involve research with insects, animals, or humans.