*Review Article*

Use and Management of Bioinputs: Reflections from the Perspective of Sustainable Agriculture

.

ABSTRACT

|  |
| --- |
| The use of bioinputs in agriculture emerges as a promising strategy to promote more sustainable agricultural systems, aligned with the principles of agroecology and low environmental impact farming. They reduce dependence on chemical inputs, such as synthetic fertilizers and pesticides, minimizing environmental impacts and health risks. Biofertilizers and microbial inoculants improve soil health by promoting water and nutrient retention and the decomposition of organic matter, which supports long-term fertility. Biopesticides, such as Bacillus thuringiensis and Beauveria bassiana, provide a safer and more effective alternative to conventional pesticides. Additionally, bioinputs contribute to plant growth by increasing water and nutrient absorption and plant resistance to environmental stresses, such as drought and salinity. Their adoption can also reduce production costs, especially for small farmers, and improve the quality and productivity of crops, granting access to niche markets, such as organic products. Furthermore, bioinputs have a positive impact on social inclusion and rural development, offering income opportunities for small communities and strengthening producers' autonomy. However, challenges such as a lack of technical knowledge, inadequate infrastructure, and a lack of regulation hinder large-scale adoption. Research and development of new bioinputs, along with integration with other agroecological practices, have the potential to drive agriculture toward a more sustainable and resilient future, aligned with current global challenges. |

*Keywords: Sustainable agriculture, Biological inoculants, Climate challenges, Agricultural management*

1. INTRODUCTION

Contemporary agriculture faces unprecedented challenges, such as the need to increase food production to meet the demands of a growing global population while simultaneously reducing the environmental impacts of conventional farming practices (FAO, 2021). In this context, sustainable agriculture emerges as an essential paradigm, aiming to balance productivity, conservation of natural resources, and social equity. Within this framework, bioinputs have gained prominence as promising tools for fostering more resilient agricultural systems that are less dependent on chemical inputs (Altieri & Nicholls, 2017).

Bioinputs, defined as biologically derived products used in agricultural management, include biofertilizers, biopesticides, microbial inoculants, and other biological agents that promote plant growth, control pests and diseases, and improve soil health (Brazil, 2020; Miranda et al., 2024). These inputs represent a viable alternative to synthetic fertilizers and pesticides, whose negative impacts on the environment and human health have been widely documented (Pimentel & Burgess, 2014). Additionally, bioinputs align with the principles of agroecology, which advocates for the integration of ecological processes into agricultural systems (Gliessman, 2018).

The adoption of bioinputs has been encouraged by public policies in various countries, including Brazil, where the National Bioinputs Program was launched in 2020 to promote their production and use (Brazil, 2020; de Miranda Santos et al., 2023). However, despite progress, significant challenges remain regarding the efficacy, regulation, and large-scale adoption of these products. Recent studies highlight the need for increased investment in research and development, as well as technical training for farmers (Santos et al., 2021).

From an environmental perspective, bioinputs help reduce soil and water contamination, mitigate greenhouse gas emissions, and preserve biodiversity (Kumar et al., 2022; Rocha et al., 2024). For example, the use of nitrogen-fixing microorganisms can decrease reliance on nitrogen fertilizers, whose production and application are associated with high energy costs and environmental harm (Malusá & Vassilev, 2014). Furthermore, bioinputs can aid in the recovery of degraded soils, enhancing fertility and water retention capacity (Lehmann et al., 2011).

From a socioeconomic standpoint, bioinputs can generate significant benefits, particularly for small and medium-sized farmers, by lowering production costs and increasing crop profitability (Díaz-Rodríguez et al., 2025). However, their adoption is still limited by factors such as lack of technical knowledge, limited availability of registered products, and skepticism about their effectiveness (Bortoloti & Sampaio, 2024; Russo & Berlyn, 2021). Therefore, it is crucial to promote knowledge dissemination and strengthen the bioinputs supply chain.

This review paper aims to analyze the use and management of bioinputs in agriculture from the perspective of sustainable farming. It will discuss the benefits, challenges, and opportunities associated with these inputs, based on recent scientific evidence. The analysis seeks to contribute to the debate on transitioning toward more sustainable agricultural systems, emphasizing the role of bioinputs as strategic tools for rural development and environmental conservation.

2. literature review

**2.1 Sustainable Agriculture: Principles and Challenges)**-

Sustainable agriculture is a broad concept that seeks to integrate agricultural practices that are economically viable, socially just, and environmentally sound (FAO, 2021). According to Altieri and Nicholls (2017), sustainability in agriculture involves adopting production systems that minimize the use of non-renewable resources and promote ecosystem resilience. This paradigm emerges as a response to the negative impacts of conventional agriculture, which include soil degradation, water resource contamination, and biodiversity loss (Gliessman, 2018).

One of the fundamental principles of sustainable agriculture is the conservation of natural resources, such as soil, water, and biodiversity (Pretty, 2018). Maintaining soil health, for example, is essential to ensuring long-term agricultural productivity. Practices such as crop rotation, no-till farming, and cover crops are widely recommended to improve soil structure and fertility (Lehmann et al., 2011).

Another important principle is reducing dependence on external inputs, such as synthetic fertilizers and pesticides. Sustainable agriculture promotes the use of organic and biological inputs, which enhance nutrient cycling and natural pest and disease control (Altieri & Nicholls, 2017). This approach not only lowers production costs but also minimizes the environmental impacts associated with chemical use (Pimentel & Burgess, 2014).

Diversification of agricultural systems is another pillar of sustainable agriculture. Monoculture, a characteristic of conventional agriculture, is associated with various issues, such as increased pest and disease incidence and reduced ecosystem resilience (Gliessman, 2018). Diversification, on the other hand, promotes ecological and economic stability while contributing to food security (Pretty, 2018).

Sustainable agriculture also emphasizes the importance of social equity and the inclusion of small farmers. According to the FAO (2021), adopting sustainable practices can improve the quality of life in rural communities by ensuring access to nutritious food and generating income opportunities. However, transitioning to more sustainable agricultural systems requires appropriate public policies and investments in research and rural extension (Bortoloti & Sampaio, 2024).

Despite its benefits, adopting sustainable agriculture faces several challenges. One of the main obstacles is the lack of knowledge and technical training among farmers, especially in low-income regions (Santos et al., 2021). Additionally, transitioning to sustainable practices often involves high initial costs and economic risks, which may discourage producers (Kumar et al., 2019).

Another challenge is the need to adapt to climate change, which poses a significant threat to global agriculture. Sustainable agriculture must incorporate mitigation and adaptation strategies, such as drought-resistant crops and agroforestry systems (Malusá & Vassilev, 2014). These practices not only reduce the vulnerability of agricultural systems but also contribute to mitigating greenhouse gas emissions (Lehmann et al., 2011).

Regulation and government support are also critical factors in promoting sustainable agriculture. In many countries, the lack of appropriate public policies and financial incentives hinders the adoption of sustainable practices (Brasil, 2020). Furthermore, the absence of clear standards for certifying sustainable products can limit access to niche markets (Bortoloti & Sampaio, 2024).

Sustainable agriculture also faces challenges related to production scale. While sustainable practices are more easily implemented on small farms, their large-scale adoption requires structural changes in production and distribution systems (Pretty, 2018). Integrating innovative technologies, such as precision agriculture and bioinputs, can facilitate this transition (Díaz-Rodríguez et al., 2025).

It can thus be observed that sustainable agriculture represents a holistic approach to addressing contemporary food production challenges. Its fundamental principles include conserving natural resources, reducing dependence on external inputs, diversifying agricultural systems, and promoting social equity. However, the adoption of these practices faces significant challenges, ranging from a lack of technical training to the need for appropriate public policies (FAO, 2021).

**2.2. Bioinputs: Definition and Types**

Bioinputs are biological products used in agricultural management to promote plant growth, control pests and diseases, and improve soil health (Brasil, 2020). These inputs include microorganisms, plant extracts, enzymes, and other biological agents that act synergistically with natural ecosystem processes (Kumar et al., 2019). The definition of bioinputs encompasses a wide variety of products, which can be classified into different categories based on their function and composition. The main types of bioinputs include biofertilizers, biopesticides, microbial inoculants, and plant growth promoters (Díaz-Rodríguez et al., 2025).

Biofertilizers are products containing microorganisms capable of fixing nitrogen, solubilizing phosphates, or promoting plant growth through the production of plant hormones (Malusá & Vassilev, 2014). These inputs are particularly important for reducing dependence on synthetic fertilizers, which have negative impacts on the environment and human health (Pimentel & Burgess, 2014).

Biopesticides, in turn, are formulated with microorganisms, plant extracts, or natural substances that help control pests and diseases (Altieri; Nicholls, 2017). These products serve as an alternative to chemical pesticides, which are associated with issues such as pest resistance, soil and water contamination, and risks to farmers' health (Gliessman, 2018).

Microbial inoculants are products containing beneficial microorganisms, such as nitrogen-fixing bacteria and mycorrhizal fungi, that establish symbiotic relationships with plants (Lehmann et al., 2011). These microorganisms enhance nutrient absorption and improve plant resistance to environmental stresses, contributing to the sustainability of agricultural systems (Díaz-Rodríguez et al., 2025).

Plant growth promoters are bioinputs that contain substances such as plant hormones, amino acids, and vitamins, which stimulate plant development (Kumar et al., 2019). These products are used to increase crop productivity and quality while reducing the need for chemical inputs (Thapa & Prasad, 2011). Beyond these types, other bioinputs contribute to soil health improvement, such as biochar and organic compounds enriched with microorganisms (Lehmann et al., 2011). These products aid in the recovery of degraded soils, increasing their fertility and water retention capacity (Gliessman, 2018).

The use of bioinputs in agriculture offers numerous benefits, both environmentally and economically. From an environmental perspective, bioinputs help reduce soil and water contamination, mitigate greenhouse gas emissions, and preserve biodiversity (KUMAR et al., 2019). Additionally, they promote soil health, enhancing its ability to sustain agricultural production in the long term (Lehmann et al., 2011).

From an economic standpoint, bioinputs can lower production costs, especially for small and medium-sized farmers, by decreasing dependence on expensive chemical inputs (Díaz-Rodríguez et al., 2025). Moreover, adopting bioinputs can increase crop profitability by improving productivity and quality (Malusá & Vassilev, 2014). However, the adoption of bioinputs faces significant challenges, including a lack of technical knowledge, a shortage of registered products, and skepticism about their effectiveness (Bortoloti & Sampaio, 2024). Additionally, the production and commercialization of bioinputs require investments in research and development, as well as the establishment of public policies to encourage their use (Brasil, 2020).

The regulation of bioinputs is another crucial challenge. In many countries, the lack of clear standards for production and quality control hinders their large-scale adoption (Santos et al., 2021). Furthermore, the absence of certification mechanisms can limit access to niche markets that value sustainable agricultural practices (Bortoloti & Sampaio, 2024).

Despite these challenges, bioinputs represent a promising tool for transitioning to more sustainable agricultural systems. Integrating these inputs with other agroecological practices, such as crop rotation and integrated pest management, can enhance their benefits and contribute to the resilience of agricultural systems (Altieri & Nicholls, 2017).

Research and development of new bioinputs are areas of great potential, particularly in the context of climate change and the growing demand for sustainable food production (Kumar et al., 2019). Biotechnology, for example, has been used to develop more efficient microorganisms adapted to different environmental conditions (Díaz-Rodríguez et al., 2025). Additionally, farmer education and training are essential for promoting the adoption of bioinputs. Rural extension programs that provide technical and practical information on the use and management of these inputs can help overcome barriers to their adoption (Bortoloti & Sampaio, 2024).

It is evident that bioinputs are biological products that offer a sustainable alternative to chemical inputs in agriculture. They include biofertilizers, biopesticides, microbial inoculants, and plant growth promoters, among others. The use of these inputs brings environmental and economic benefits but faces challenges related to technical knowledge, regulation, and large-scale production (Brasil, 2020).

The integration of bioinputs with other agroecological practices and investment in research and development are fundamental strategies for overcoming these challenges and promoting the adoption of these inputs in sustainable agriculture (Altieri; Nicholls, 2017). Sustainable agriculture and bioinputs are thus interconnected concepts that offer a promising approach to addressing contemporary food production challenges. Adopting these practices can contribute to natural resource conservation, reducing environmental impacts, and promoting social equity in rural areas (FAO, 2021).

However, transitioning to more sustainable agricultural systems requires overcoming significant challenges, including the lack of technical training, the need for adequate public policies, and adaptation to climate change (Pretty, 2018). Research and innovation play a crucial role in this process, particularly in developing new bioinputs and technologies that facilitate the adoption of sustainable practices (Díaz-Rodríguez et al., 2025).

Sustainable agriculture and bioinputs represent a holistic and integrated approach to promoting more resilient agricultural systems with reduced dependence on chemical inputs. Adopting these practices can contribute to food security, natural resource conservation, and social equity, but it requires joint efforts from governments, researchers, farmers, and civil society (FAO, 2021).

2.3. **History of the Use of Bioinputs in Agriculture**

The use of bioinputs in agriculture dates to ancestral practices, in which farmers used organic compounds and microorganisms to improve soil fertility and plant growth. However, it was only in the 20th century, with advances in microbiology and biotechnology, that bioinputs began to be systematically studied and applied (Díaz-Rodríguez et al., 2025). The discovery of nitrogen-fixing microorganisms, such as bacteria of the Rhizobium genus, marked an important milestone in the development of biofertilizers, which started to be widely used in crops such as soybeans and beans (Malusá & Vassilev, 2014).

In the 1970s, with growing concerns about the environmental impacts of the Green Revolution - which promoted the intensive use of chemical fertilizers and pesticides -bioinputs gained prominence as a sustainable alternative (Altieri & Nicholls, 2017). During this period, research on plant growth-promoting microorganisms, such as bacteria of the *Azospirillum* genus and mycorrhizal fungi, expanded knowledge about the potential of these inputs to increase agricultural productivity in an ecologically responsible manner (Kumar et al., 2019).

In Brazil, the use of bioinputs began to gain traction in the 1980s, driven by the need to reduce production costs and increase the competitiveness of national agriculture. Embrapa (Brazilian Agricultural Research Corporation) played a fundamental role in the development and dissemination of bioinput-based technologies, especially in soybean cultivation, where the use of *Bradyrhizobium*-based inoculants became a common practice (Brasil, 2020). This adoption contributed to Brazil's positioning as one of the world's largest soybean producers, with a significant reduction in nitrogen fertilizer use (Santos et al., 2021).

From the 2000s onwards, the concept of bioinputs expanded to include not only biofertilizers but also biopesticides, plant growth promoters, and other biologically derived products. Advances in biotechnology enabled the development of more efficient and stable formulations, broadening the range of applications for these inputs (Díaz-Rodríguez et al., 2025). Furthermore, the growing demand for organic and sustainable food boosted the bioinput market, which came to be seen as an essential tool for organic and agroecological farming (Bortoloti & Sampaio, 2024).

In the past decade, the use of bioinputs has been encouraged by public policies in several countries, including Brazil. In 2020, the Brazilian government launched the National Bioinputs Program to promote the production and use of these inputs, fostering sustainability and competitiveness in national agriculture (Brasil, 2020). The program aims to integrate research, development, and innovation efforts while strengthening the bioinputs production chain from manufacturing to commercialization (Santos et al., 2021).

At the same time, the scientific community has been investing in research to better understand the mechanisms of action of bioinputs and develop new technologies. Recent studies have explored the potential of endophytic microorganisms, which colonize plant interiors, to promote plant growth and enhance resistance to environmental stressors (Malusá & Vassilev, 2014). Additionally, the use of molecular biology and genomics techniques has enabled the identification of genes and metabolic pathways involved in plant-microorganism interactions, opening new perspectives for developing more efficient bioinputs (Kumar et al., 2019).

Despite these advances, the use of bioinputs still faces challenges, such as a lack of standardization and regulation, a shortage of registered products, and skepticism among farmers regarding their effectiveness (Bortoloti & Sampaio, 2024). Moreover, the production and commercialization of bioinputs require investments in infrastructure and technical training, which can limit large-scale adoption, especially among small farmers (Santos et al., 2021).

The history of bioinput use in agriculture reflects a trajectory of innovation and adaptation, driven by the need to balance productivity and sustainability. From ancestral practices to recent advances in biotechnology, bioinputs have evolved into an essential tool for modern agriculture, contributing to reduced environmental impacts and the promotion of more resilient agricultural systems (Díaz-Rodríguez et al., 2025). However, overcoming current challenges requires joint efforts from governments, researchers, farmers, and industries to expand access to and adopt these inputs in various agricultural contexts (Brasil, 2020).

**2.4. Benefits of Bioinputs in Agriculture**

Bioinputs have emerged as an essential tool for promoting sustainability in agriculture, offering a range of environmental, economic, and social benefits. One of the main benefits is the reduction in the use of chemical inputs, such as synthetic fertilizers and pesticides, which are associated with negative impacts on the environment and human health (Altieri & Nicholls, 2017). By replacing or complementing these inputs, bioinputs help decrease soil and water contamination, as well as reduce greenhouse gas emissions (Kumar et al., 2019).

The use of biofertilizers, for example, enables biological nitrogen fixation and phosphate solubilization, processes that increase the availability of nutrients for plants without the need for chemical fertilizers (Malusá & Vassilev, 2014). This not only reduces production costs but also minimizes the risks of eutrophication in water bodies, a common issue associated with excessive use of nitrogen fertilizers (Lehmann et al., 2011).

Another significant benefit of bioinputs is the improvement of soil health. Microorganisms present in biofertilizers and inoculants promote soil structuring, increasing its porosity and water retention capacity (Díaz-Rodríguez et al., 2025). Additionally, these microorganisms contribute to nutrient cycling and organic matter decomposition, essential processes for maintaining soil fertility in the long term (Gliessman, 2018).

Bioinputs also play a crucial role in biological pest and disease control. Biopesticides based on microorganisms, such as Bacillus thuringiensis and Beauveria bassiana, provide an effective and safe alternative to chemical pesticides, reducing pest resistance incidence and minimizing risks to the health of farmers and consumers (Bortoloti & Sampaio, 2024). Furthermore, these products are biodegradable and do not leave toxic residues in the environment (Santos et al., 2021).

Promoting plant growth is another important benefit of bioinputs. Growth-promoting microorganisms, such as bacteria of the *Azospirillum* genus and mycorrhizal fungi, produce plant hormones that stimulate root and shoot development (Malusá & Vassilev, 2014). This results in higher nutrient and water absorption, increasing crop productivity and resistance to environmental stresses such as drought and salinity (Kumar et al., 2019).

The diversification of agricultural systems is another indirect benefit of using bioinputs. By reducing dependence on chemical inputs, bioinputs facilitate the adoption of agroecological practices, such as crop rotation and plant intercropping, which promote ecological and economic stability in agricultural systems (Altieri & Nicholls, 2017). This diversification also helps preserve biodiversity, a crucial factor for the resilience of agricultural ecosystems (Gliessman, 2018).

From an economic perspective, bioinputs can significantly reduce production costs, especially for small and medium-sized farmers. Replacing expensive chemical fertilizers with biofertilizers and reducing pesticide use results in direct savings for producers (Díaz-Rodríguez et al., 2025). Moreover, increased productivity and quality of crops can lead to higher profitability and access to differentiated markets, such as organic products (Bortoloti; Sampaio, 2024). The adoption of bioinputs also contributes to food and nutritional security. By improving crop productivity and quality, these inputs ensure greater availability of nutritious food, particularly in low-income regions (FAO, 2021). Additionally, the reduced use of pesticides decreases the risks of food contamination, benefiting consumers' health (Pimentel & Burgess, 2014).

Another important benefit is the contribution of bioinputs to climate change mitigation. Biological nitrogen fixation and soil health promotion reduce nitrous oxide emissions, potent greenhouse gas (Lehmann et al., 2011). Moreover, the enhanced water retention capacity of soil improves crop resilience to extreme weather events such as droughts and floods (Malusá & Vassilev, 2014).

Bioinputs also have a positive impact on social inclusion and rural development. The production and commercialization of bioinputs can generate income opportunities for small farmers and rural communities, especially when integrated into public policies that promote them (Brasil, 2020). Furthermore, the adoption of sustainable practices strengthens farmers' autonomy, reducing their dependence on external inputs (Santos et al., 2021).

The use of biological inputs also fosters technological innovation in agriculture. Recent research has explored the potential of endophytic microorganisms and molecular biology techniques to develop more efficient bioinputs adapted to different environmental conditions (Kumar et al., 2019). These advancements have the potential to revolutionize agriculture, making it more sustainable and resilient (Díaz-Rodríguez et al., 2025).

Additionally, bioinputs contribute to reducing the agricultural ecological footprint. By replacing chemical inputs with biologically derived products, these inputs decrease the consumption of non-renewable resources, such as petroleum and natural gas, used in the production of fertilizers and pesticides (Gliessman, 2018). This aligns agriculture with the principles of a circular economy, promoting efficient resource use and waste reduction (Lehmann et al., 2011).

The adoption of bioinputs also strengthens the resilience of agricultural systems. Growth-promoting microorganisms and biopesticides increase plants' ability to withstand biotic and abiotic stresses, such as pests, diseases, and climate variations (Malusá & Vassilev, 2014). This is particularly important in the context of climate change, where adaptability is crucial for agricultural sustainability (FAO, 2021).

This strategy contributes to building a positive image of agriculture in society. The adoption of sustainable and environmentally responsible practices improves consumers' perceptions of agricultural products, increasing their market value (Bortoloti & Sampaio, 2024). This is especially relevant in a scenario of growing demand for healthy, responsibly produced food (Santos et al., 2021).

Thus, bioinputs offer a range of benefits, from reducing environmental impacts to promoting social equity and technological innovation. Their adoption represents a fundamental strategy for transitioning to more sustainable, resilient, and inclusive agricultural systems, aligned with the global challenges of the 21st century (Altieri & Nicholls, 2017).

3. DISCUSSION

The use of bioinputs in agriculture has proven to be a promising strategy to promote the sustainability of agricultural systems, aligning with the principles of agroecology and low-impact agriculture (Altieri & Nicholls, 2017). Integrating these inputs with practices such as crop rotation, no-till farming, and integrated pest management can enhance their benefits, contributing to the resilience and productivity of agroecosystems (Gliessman, 2018).

One of the main benefits of bioinputs is the reduction of dependence on chemical inputs, such as synthetic fertilizers and pesticides, which are associated with negative impacts on the environment and human health (Kumar et al., 2019). Studies show that the use of biofertilizers and microbial inoculants can significantly decrease the use of nitrogen fertilizers, reducing production costs and the risk of contamination of soils and water bodies (Malusá & Vassilev, 2014).

Moreover, bioinputs play a crucial role in improving soil health. Microorganisms present in biofertilizers and inoculants promote soil structuring, increasing its water and nutrient retention capacity (Lehmann et al., 2011). These microorganisms also contribute to nutrient cycling and organic matter decomposition, processes essential for maintaining soil fertility in the long term (Díaz-Rodríguez et al., 2025).

Biological pest and disease control is another significant benefit of bioinputs. Microbial-based biopesticides, such as Bacillus thuringiensis and Beauveria bassiana, offer an effective and safe alternative to chemical pesticides, reducing pest resistance and minimizing health risks for farmers and consumers (Bortoloti & Sampaio, 2024). Additionally, these products are biodegradable and do not leave toxic residues in the environment (Santos et al., 2021).

Promotion of plant growth is another important benefit of bioinputs. Growth-promoting microorganisms, such as *Azospirillum* bacteria and mycorrhizal fungi, produce plant hormones that stimulate the development of roots and above-ground plant parts (Malusá & Vassilev, 2014). This results in greater absorption of nutrients and water, increasing crop productivity and resistance to environmental stresses, such as drought and salinity (Kumar et al., 2019).

The diversification of agricultural systems is another indirect benefit of using bioinputs. By reducing dependence on chemical inputs, bioinputs facilitate the adoption of agroecological practices, such as crop rotation and plant consortia, which promote the ecological and economic stability of agricultural systems (Altieri & Nicholls, 2017). This diversification also contributes to the preservation of biodiversity, a crucial factor for the resilience of agricultural ecosystems (Gliessman, 2018).

From an economic perspective, bioinputs can significantly reduce production costs, especially for small and medium-sized farmers. Replacing expensive chemical fertilizers with biofertilizers and reducing the use of pesticides result in direct savings for producers (Díaz-Rodríguez et al., 2025). Furthermore, increased productivity and quality of crops can lead to greater profitability and access to differentiated markets, such as the organic products market (Bortoloti & Sampaio, 2024).

The adoption of bioinputs also contributes to food and nutritional security. By improving the productivity and quality of crops, these inputs ensure greater availability of nutritious food, especially in low-income regions (FAO, 2021). Additionally, reducing pesticide use decreases food contamination risks, benefiting consumer health (Pimentel & Burgess, 2014).

Another important benefit is the contribution of bioinputs to climate change mitigation. Biological nitrogen fixation and promotion of soil health reduce nitrous oxide emissions, a potent greenhouse gas (Lehmann et al., 2011). Furthermore, the greater water retention capacity of the soil improves crop resilience to extreme weather events, such as droughts and floods (Malusá & Vassilev, 2014).

Bioinputs also have a positive impact on social inclusion and rural development. The production and marketing of bioinputs can generate income opportunities for small farmers and rural communities, especially when integrated into public policies promoting them (BRASIL, 2020). Moreover, the adoption of sustainable practices strengthens farmers' autonomy, reducing their dependence on external inputs (Santos et al., 2021).

The use of bioinputs also promotes technological innovation in agriculture. Recent research has explored the potential of endophytic microorganisms and molecular biology techniques to develop more efficient bioinputs adapted to different environmental conditions (Kumar et al., 2019). These advances have the potential to revolutionize agriculture, making it more sustainable and resilient (Díaz-Rodríguez et al., 2025).

Additionally, bioinputs contribute to reducing the ecological footprint of agriculture. By replacing chemical inputs with biological products, these inputs decrease the consumption of non-renewable resources, such as oil and natural gas, used in the production of fertilizers and pesticides (Gliessman, 2018). This aligns agriculture with the principles of the circular economy, promoting efficient resource use and waste reduction (Lehmann et al., 2011).

The adoption of bioinputs also strengthens the resilience of agricultural systems. Growth-promoting microorganisms and biopesticides increase plants' ability to resist biotic and abiotic stresses, such as pests, diseases, and climatic variations (Malusá & Vassilev, 2014). This is particularly important in the context of climate change, where the ability to adapt is crucial for the sustainability of agriculture (FAO, 2021).

It is important to understand that bioinputs contribute to building a positive image of agriculture in society. Adopting sustainable and ecologically correct practices improves consumers' perception of agricultural products, increasing their market value (Bortoloti & Sampaio, 2024). This is especially relevant in a context of growing demand for healthy and responsibly produced food (Santos et al., 2021).

However, the adoption of bioinputs faces significant challenges, including the lack of technical knowledge, the scarcity of registered products, and farmers' distrust regarding their effectiveness (Bortoloti & Sampaio, 2024). Furthermore, the production and commercialization of bioinputs require investments in infrastructure and technical training, which may limit their widespread adoption, especially by small farmers (Santos et al., 2021).

The regulation of bioinputs is another important challenge. In many countries, the lack of clear standards for the production and quality control of these products hinders their widespread adoption (Santos et al., 2021). Moreover, the absence of certification mechanisms can limit access to differentiated markets that value sustainable agricultural practices (Bortoloti & Sampaio, 2024).

Despite these challenges, bioinputs represent a promising tool for transitioning to more sustainable agricultural systems. Integrating these inputs with other agroecological practices, such as crop rotation and integrated pest management, can enhance their benefits and contribute to the resilience of agricultural systems (Altieri & Nicholls, 2017).

Research and development of new bioinputs are areas with great potential, especially in the context of climate change and the growing demand for sustainable food (Kumar et al., 2019). Biotechnology, for example, has been used to develop more efficient microorganisms adapted to different environmental conditions (Díaz-Rodríguez et al., 2025).

In this way, bioinputs offer a range of benefits, from reducing environmental impacts to promoting social equity and technological innovation. Their adoption represents a fundamental strategy for transitioning to more sustainable, resilient, and inclusive agricultural systems, aligned with the global challenges of the 21st century (Altieri & Nicholls, 2017).

4. Conclusion

The use and management of bioinputs in agriculture represent a fundamental strategy for transitioning to more sustainable agricultural systems, aligned with the global challenges of the 21st century. As demonstrated throughout this article, bioinputs offer a range of environmental, economic, and social benefits, from reducing the use of chemical inputs to promoting soil health and biodiversity. These inputs have the potential to transform agriculture, making it more resilient and less dependent on non-renewable resources.

However, the adoption of bioinputs faces significant challenges, including a lack of technical knowledge, a shortage of registered products, and farmers' skepticism about their effectiveness (Bortoloti & Sampaio, 2024). Additionally, the production and commercialization of bioinputs require investments in infrastructure and technical training, which may limit their large-scale adoption, especially among small-scale farmers. Overcoming these challenges requires joint efforts from governments, researchers, farmers, and industries to expand access and adoption of these inputs in different agricultural contexts (Brasil, 2020).

Research and development of new bioinputs are areas of great potential, especially in the context of climate change and the growing demand for sustainable food (Díaz-Rodríguez et al., 2025). Biotechnology, for example, has been used to develop more efficient microorganisms adapted to different environmental conditions, opening new perspectives for the future of agriculture (Malusá & Vassilev, 2014). Furthermore, integrating bioinputs with other agroecological practices, such as crop rotation and integrated pest management, can enhance their benefits and contribute to the resilience of agricultural systems (Altieri & Nicholls, 2017).

Farmer education and training are essential to promote the adoption of bioinputs. Rural extension programs that provide technical and practical information on the use and management of these inputs can help overcome adoption barriers (Bortoloti; Sampaio, 2024). Additionally, the creation of public policies that encourage the use of bioinputs and the proper regulation of these products are fundamental measures to ensure their quality and efficacy (Brasil, 2020).

In conclusion, bioinputs represent a promising tool for building more sustainable, resilient, and inclusive agricultural systems. Their adoption can contribute to food security, natural resource conservation, and social equity, aligning with global sustainable development goals (FAO, 2021). However, realizing this potential requires continuous efforts in research, innovation, and training, as well as the commitment of all stakeholders in the agricultural production chain (Díaz-Rodríguez et al., 2025).

References

Altieri, M. A., & Nicholls, C. I. (2017). Agroecology: A brief account of its origins and currents of thought in Latin America. *Agroecology and Sustainable Food Systems, 41*(3–4), 231–237. <https://doi.org/10.1080/21683565.2017.1287147>

Bortoloti, G., & Sampaio, R. M. (2024). Desafios e estratégias no desenvolvimento dos bioinsumos para controle biológico no Brasil. *Tecnologia e Sociedade, 20*(60), 291–307.

Brasil. Ministério da Agricultura, Pecuária e Abastecimento. (2020). *Programa Nacional de Bioinsumos*. <https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/bioinsumos>

Díaz-Rodríguez, A. M., Parra-Cota, F. I., Cira-Chávez, L. A., García-Ortega, L. F., Estrada-Alvarado, M. I., Santoyo, G., & de los Santos-Villalobos, S. (2025). Microbial inoculants in sustainable agriculture: Advancements, challenges, and future directions. *Plants, 14*(2), 191. <https://doi.org/10.3390/plants14020191>

FAO. (2021). *The state of food and agriculture 2021: Making agrifood systems more resilient to shocks and stresses*. FAO. <https://doi.org/10.4060/cb4476en>

Gliessman, S. R. (2018). *Agroecology: The ecology of sustainable food systems* (3rd ed.). CRC Press. <https://www.routledge.com/Agroecology-The-Ecology-of-Sustainable-Food-Systems/Gliessman/p/book/9781439895610>

Kumar, S., Diksha, S. S. S., & Kumar, R. (2019). Biofertilizers: An eco-friendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences, 3*, 100094.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C., & Crowley, D. (2011). Biochar effects on soil biota – A review. *Soil Biology and Biochemistry, 43*(9), 1812–1836. <https://doi.org/10.1016/j.soilbio.2011.04.022>

Malusá, E., & Vassilev, N. (2014). A contribution to set a legal framework for biofertilisers. *Applied Microbiology and Biotechnology, 98*(15), 6599–6607. <https://doi.org/10.1007/s00253-014-5828-y>

Pimentel, D., & Burgess, M. (2009). Environmental and economic costs of the application of pesticides primarily in the United States. In D. Pimentel & R. Peshin (Eds.), *Integrated pest management* (pp. 47–71). Springer. <https://doi.org/10.1007/978-94-007-7796-5_2>

Pretty, J. (2018). Agricultural sustainability: Concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences, 373*(1754), 20160273. <https://doi.org/10.1098/rstb.2016.0273>

Sammauria, R., Kumawat, S., Kumawat, P., Singh, J., & Jatwa, T. K. (2020). Microbial inoculants: Potential tool for sustainability of agricultural production systems. *Archives of Microbiology, 202*(4), 677–693. <https://doi.org/10.1007/s00203-019-01795-w>

Santos, M. S., Nogueira, M. A., & Hungria, M. (2021). Outstanding impact of *Azospirillum brasilense* strains Ab-V5 and Ab-V6 on the Brazilian agriculture: Lessons that farmers are receptive to adopt new microbial inoculants. *Revista Brasileira de Ciência do Solo, 45*, e0200128. <https://doi.org/10.36783/18069657rbcs20200128>

Satish Kumar, S., Diksha, S. S. S., & Kumar, R. (2022). Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences, 3*, 100094.

Thapa, S., & Prasad, R. (2011). Role of plant growth-promoting rhizobacteria (PGPR) in sustainable agriculture: Prospects and challenges. *Journal of Agricultural Science and Technology, 3*(1), 1–15.

Miranda, A. M., Hernandez-Tenorio, F., Villalta, F., Vargas, G. J., & Sáez, A. A. (2024). Advances in the Development of Biofertilizers and Biostimulants from Microalgae. *Biology*, *13*(3), 199.

da Silva Medina, G., Rotondo, R., & Rodríguez, G. R. (2024). Innovations in agricultural bio-inputs: commercial products developed in Argentina and Brazil. *Sustainability*, *16*(7), 2763. (da Silva Medina et al., 2024)

de Miranda Santos, L., de Moura, J. B., Lopes Filho, L. C., Teixeira, M. F., & de Castro Peixoto, J. (2023). Bioinputs: a sustainable alternative to traditional pesticide cultivation. *Observatório De La Economía Latinoamericana*, *21*(12), 24777-24816.

Rocha, T. M., Marcelino, P. R. F., Da Costa, R. A. M., Rubio-Ribeaux, D., Barbosa, F. G., & da Silva, S. S. (2024). Agricultural bioinputs obtained by solid-state fermentation: From production in biorefineries to sustainable agriculture. *Sustainability*, *16*(3), 1076.

Russo, R. O., & Berlyn, G. P. (2021). Agricultural and forestry extension in biostimulants and bioinputs in Costa Rica: a short review. *Brazilian Journal of Animal and Environmental Research*, *4*(4), 5290-5296.