v. 5, n. 6, 2025

Journal of Agricultural Sciences Research

Acceptance date: 09/10/2025

CORPORATE EVOLUTION OF AGRICULTURAL BIO-INPUTS: GLOBAL AND BRAZILIAN MARKETS

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Abstract: The global market for agricultural bio-inputs has grown significantly over the last decade and is expected to reach US$ 44 billion by 2032, driven by growing demand for sustainable practices, intensifying regulatory pressures, and technological advances. This review analyzes the corporate evolution of the sector, with an emphasis on microbiological bio-inputs for pest and disease control. Europe and North America consolidate their leadership through robust regulatory frameworks and strong associations with organic agriculture, while Latin America, especially Brazil, and Asia-Pacific stand out for their dynamism in adopting large-scale crops. The study addresses market segmentation, regional trends, and business dynamics, ranging from pioneering companies that emerged with a focus on alternative solutions to conventional inputs and grew organically until the 2000s. This was a phase of intense transformation in the sector, marked by mergers, acquisitions, joint ventures, partnerships with research institutions, and the entry of leading multinationals in agrochemicals. Technological advances are discussed in four generations, ranging from single-strain products to multifunctional formulations, encapsulated carriers, digital integration, synthetic biology, and nanotechnology. The data collected reinforce that the consolidation of agricultural bio-inputs depends not only on scientific innovation but also on corporate strategies capable of accelerating market access, diversifying portfolios, and integrating biologicals into sustainable and regenerative agriculture.

Keywords: Agricultural bio-inputs; Biocontrol; Biofertilizers; Corporate evolution; Sustainable agriculture

INTRODUCTION

Agricultural inputs are traditionally classified into two broad categories: pesticides and fertilizers. Pesticides include products or agents of a physical, chemical, or biological nature used in agriculture, pastures, forests, ecosystems, and even urban and industrial environments, with the purpose of altering flora or fauna to protect them from harmful organisms. This category also includes substances used as defoliants, desiccants, and growth regulators. Fertilizers, on the other hand, comprise mineral or organic substances, natural or synthetic, capable of providing one or more essential nutrients to plants (BRAZIL, 1989; BRAZIL, 2004).

Thus, when bio-inputs first appeared, they were classified into two categories: bio-inputs associated with pest control and plant regulators; and biofertilizers and inoculants associated with nutrition (MEYER et al., 2022; MARRONE, 2019; EBIC, 2016). However, because they are living organisms or their metabolites, bio-inputs often have not just a single function, but multiple actions , so a microorganism registered as a biofertilizer can also have an effect on disease control (FIGIEL et al., 2025).

This multifunctionality has been recognized in recent years, as defined and described by the European Biostimulants Industry Council (EBIC), as the ability of the same component to perform and fulfill different functions, so that it can be regulated in different categories. In this context, multifunctionality is linked to the component, defined as the organic or synthetic substance that may be involved in more than one function, as described in Figure 1 . Therefore, there may be different formulations and products with the same component that perform different functions, such as biostimulant, biocontrol, and biofertilizer (FIEL et al., 2025; DOS-REIS et al., 2024).

In addition, components may be associated with multiple effects depending on the formulation and end use of the product, and

the presence of a single component alone cannot necessarily predict the effects of the product (FADIJI, et al., 2024; EBIC, 2016).

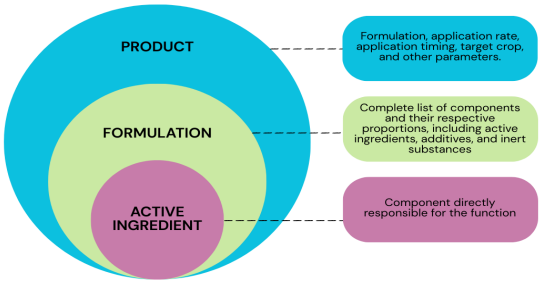

Figure 1. Composition of agricultural pesticides and fertilizers. Source: EBIC (2016), with modifications.

In this context, this review brings together recent data and trends in the agricultural bio-inputs market, with an emphasis on those positioned for the control of insect pests and diseases. The main *players* in the sector are presented , as well as corporate developments, including the main mergers and acquisitions, strategic partnerships, and the positioning of these major *players*. Finally, the impact of these relationships and prospects for the sector are discussed.

GLOBAL AND BRAZILIAN MARKET FOR AGRICULTURAL BIO-INPUTS

The bioinputs market, considering all categories, was estimated at US$ 14 billion in 2023 and is expected to reach US$ 44 billion by 2032 (MARKET AND MARKETS, 2025 ; CROP LIFE, 2024). In this context, Brazil represents about 6.5% of the global market and has stood out for its average annual growth rate (CAGR) of 21% between 2021 and 2024, four times higher than the world average, which is estimated at 5% per year (REUTERS, 2024; CROPLIFE BRASIL, 2025).

Thus, considering this subdivision in relation to market positioning as bio-inputs for pest and disease control , a TAM-SAM-SOM analysis was performed, with the total addressable market (TAM), the accessible addressable market (SAM), and the accessible market that can be obtained (SOM). TAM SAM SOM includes three key market size metrics that can help companies of all sizes, from startups to medium-sized companies and established companies, understand their market potential, set realistic goals, and make informed strategic decisions, as illustrated in Figure 2.

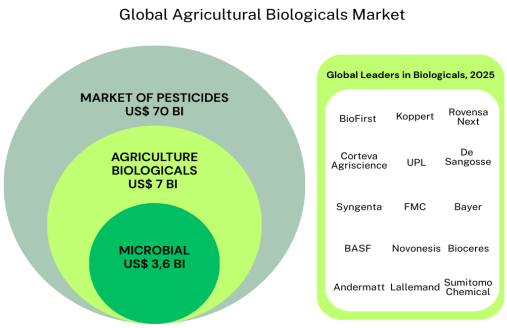

Figure 2. Global Agricultural Biological Market (TAM-SAM-SOM of biocontrol and global Leaders). Source of information: Crop Life, 2025; Global Market Insights, 2025, MARKET AND MARKETS, 2025, Reuters, 2024.

In this analysis, TAM (*Total Addressable Market)* was considered to be the total global market for pesticides, estimated at US$ 70 billion in 2024, including both chemical and biological pesticides, covering herbicides, insecticides, fungicides, and acaricides in all regions and agricultural crops (MARKET AND MARKETS, 2025).

The SAM (*Serviceable Available Market*), on the other hand, corresponds to the biological pesticides segment within the global pesticide market, estimated at US$ 6 billion in 2024, with a forecast of reaching US$ 7 billion by 2025 and expected to reach US$ 26.4 billion in 2034, with a compound annual growth rate (CAGR) of 15.9% (GLOBAL

MARKET INSIGHTS, 2025). It includes microbial, macrobiological, biochemical, and semiochemical biopesticides, used as sustainable alternatives to conventional chemicals.

The SOM (Serviceable Obtainable Market), in this case, refers to the microbiological sub-segment of biological pesticides, whose active ingredients are fungi, bacteria, and other microorganisms, which was estimated at US$ 3.6 billion in 2024 (MARKET AND MARKETS, 2025; CROP LIFE, 2025).

The distribution of the market worldwide can be seen at Figure 3 , which shows that the most significant regions in relation to the bioinputs market are Europe and North America, which account for about 60% of the sector's turnover, each with about 30%. This growth is driven by the effectiveness of the products and their low environmental impact, which makes them popular among farmers who adopt Integrated Pest Management (IPM) and, above all, organic systems, coupled with a robust regulatory framework (S&P GLOBAL COMMODITY INSIGHTS, 2025; FORTUNE BUSINESS INSIGHTS, 2025).

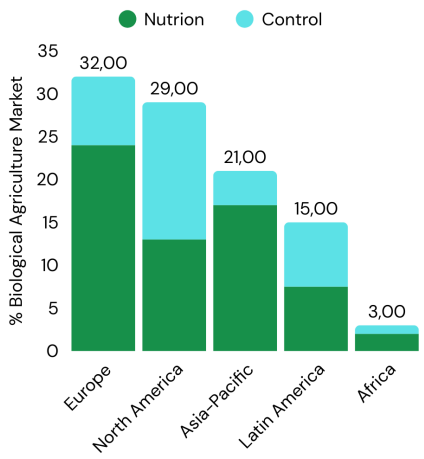

Figure 3. Market share of bio-inputs by region (% of market value). Source: S&P Global Commodity Insights, 2025; Fortune Business Insights, 2025.

European initiatives, such as the *Green Deal*, carried out by the European Union (EU), aim to make Europe the first climate-neutral continent by 2050, decoupling economic growth from the use of natural resources. And the *Farm to Fork Strategy* , associated with the purchase of food from local producers, so that it reaches the consumer's table in a shorter time and, thus, has its nutritional properties preserved, there is less use of chemical additives, and it ensures a reduction in costs and environmental impact throughout the chain. They have set ambitious targets for reducing the use of conventional fertilizers, forecasting a 20% drop by 2030 (European Commission, 2025). This measure is justified by the significant greenhouse gas emissions associated with the production of nitrogen fertilizers using the Haber-Bosch process (IEA, 2021; MESSELINK, 2021). This context also helps explain the segmentation of the biologicals market in the region in 2024, when 74% was represented by inoculants, fertilizers, and biostimulants, highlighting the predominance of this class in relation to biologicals intended for control (MODOR INTELLIGENCE, 2025a).

Most bio-inputs are used in row crops such as wheat, corn, barley, and oats, but there is also growing adoption among fruit and vegetable growers (MODOR INTELLIGENCE, 2025a). In general, these bio nd inputs are strongly associated with European organic agriculture, whose cultivated area increased from 4.9 million hectares in 2017 to 6.9 million in 2022. This advance further drives the demand for bio-inputs, as this production system prohibits the use of synthetic pesticides and fertilizers (EUROSTAT, 2024).

Germany alone generated US$ 6.3 billion in organic products in 2021, which drove the adoption of R&D (Research and Development) focused on more effective and specific biological solutions. In addition, the region is considered more restrictive in terms

of the use of conventional pesticides, a factor that also favors the expansion of biological products (S&P GLOBAL, 2025). Among the other countries that stand out in the European bio-inputs market are France, with its strong connection to organic farming, and Spain and Italy, marked by crop diversification, including fruits, vegetables, and olives. In the latter two countries, greenhouse cultivation also stands out, an environment in which the commercial use of biologicals began (MODOR INTELLIGENCE, 2025b).

North America stands out for its favorable regulatory framework for the sector and accounts for a significant share of the biologicals market, with approximately 54% of revenue distributed to biocontrol of insect pests and diseases and 46% to inoculants and biofertilizers. In the United States, the *Environmental Protection Agency* (EPA) regulates biopesticides under three main pieces of legislation: *the Federal Insecticide, Fungicide, and Rodenticide Act* (FIFRA), *the Federal Food, Drug, and Cosmetic Act* (FFDCA), and *the Food Quality Protection Act* (FQPA). In addition, a EPA maintains specific registration pathways considered a priority and conducts the *Conventional Reduced Risk* program, which encourages alternatives classified as lower risk compared to conventional pesticides. Currently, the country has about 430 registered active ingredients in biopesticides, including microorganisms, plant and algae extracts, macrobiologicals, metabolites, and components derived from living organisms (EPA, 2024).

With regard to agricultural crops, row crops such as corn, soybeans, wheat, and rice account for the largest share of bioinput use, especially in terms of inoculants and biostimulants applied via seed treatment. Control bio-inputs are most widely adopted by fruit and vegetable producers, whose demand is strongly linked to organic production, a significant market that reached US$ 69.7 billion in retail sales in the US in 2023. As the United States Department of Agriculture (USDA) regulations for organic systems prohibit synthetic fertilizers and pesticides, the demand for bio-inputs tends to be naturally increased (USDA, 2023; MODOR INTELLIGENCE, 2025b).

The Asia-Pacific market accounts for about 21% of the total bioinputs market, with nutrition-related products accounting for about 80%. China leads the bloc, with 51% of the market in this region, followed by Australia, India, and Japan (MODOR INTELLIGENCE, 2025c). Among the main active s microbiological s related to plant nutrition bio-inputs are the following microbial genera: *Azospirillum, Azotobacter, Rhizobium*, and rhizo phosphorus solubilizing bacteria; in addition to mycorrhizal fungi; among biostimulants, formulations containing amino acids, humic and fulvic acids, protein hydrolysates, and seaweed extracts stand out (KUMAR et al., 2022; SAHA et al, 2023). Another relevant point is that, although multinational companies have a significant share of the market, regional companies also stand out, such as India's *Coromandel International* Ltd., *Gujarat State Fertilizers & Chemicals* Ltd. (GSFC), and *Indian Farmers Fertiliser Cooperative* (IFFCO) (MODOR INTELLIGENCE, 2025c).

The Latin American bioinputs market accounts for around 15% of the global market, with a balance between nutrition and pest and disease control in the region, particularly in Brazil and Argentina. Brazil differs from other markets in its use of bioinputs in intensive and mechanized agricultural systems. This contrasts with countries such as the United States, where biological products generate around US$4.8 billion and are widely used in protected crops and organic systems (FORTUNE BUSINESS INSIGHTS, 2025; MORDOR INTELLIGENCE, 2025b). In

Brazil, the market is concentrated in large crops grown on large tracts of open land. In the Brazilian scenario, 94% of the bioinputs market is applied to soybean, corn, and sugarcane crops, with a focus on large-scale productivity (CROPLIFE BRASIL, 2025).

Among the types of active ingredients used in bio-inputs, microbiological ones predominate, representing 66% of registered products in Brazil and 89% in the United States (CROPLIFE BRASIL, 2025; MORDOR INTELLIGENCE, 2025). In 2025, there were 546 registered microbiological control products in Brazil, of which about 31% are based on bacteria of the genus *Bacillus* and 58% on entomopathogenic and antagonistic fungi, notably the genera *Beauveria* (18.9%), *Metarhizium* (17.9%), *Trichoderma* (16.5%), *Pochonia* (1.5%), *Purpureocillium* (1.3%), and *Cordyceps* (0.7%) (AGROFIT, 2025).

The production of microbial spores, the main active ingredient in agricultural bio-inputs, enzymes, can occur through submerged fermentation (SF) or solid-state fermentation (SSF). SF is widely used for bacteria due to its high scalability and automation in commercial bioreactors. Filamentous fungi, on the other hand, are more efficiently cultivated by SSF, which simulates their natural environment by providing a solid matrix, absence of free water, and stress conditions that induce the production of more viable and durable resistance spores (PANDEY, 2003; SINGHANIA et al., 2009).

In Brazil, rice is the most common substrate in FES for spore production, as it is a readily assimilable, low-cost source of carbon with good porosity and aeration. However, despite its strategic importance, the process of producing spores is still predominantly manual, carried out in autoclavable plastic bags, which limits quality control, biosafety, and scalability (MITCHELL et al., 2006; TAMANG et al., 2022).

There is little updated official data on the volume of rice used for the production of bio-inputs in Brazil, but companies such as Toyobo do Brasil report a capacity to inoculate 30 tons of rice per day for the production of fungal spores (AgroPages, 2025). Considering a medium-sized biofactory with the capacity to process 2 tons of rice per day, it is estimated that the substrate represents between 15% and 35% of total costs, while labor can reach up to 25% (CARDOSO et al., 2020; ELTEM et al., 2017).

Given this scenario, the current global bio-inputs market is experiencing rapid growth, regulatory pressures, and technological advances, factors that are reflected in its segmentation by region, assets, and applications. While Europe and North America consolidate their leadership through robust regulatory frameworks and strong association with organic agriculture, regions such as Asia-Pacific and Latin America, especially Brazil, stand out for their dynamism in adopting and expanding their use in major crops. Brazil, although still representing a relatively small share of the global market, has been standing out for its above-average growth and technological innovation, with the potential to become one of the world's leading centers for the production and application of bio-inputs . This scenario reinforces not only the economic relevance of the sector, but also its strategic role in the transition to more sustainable and resilient agricultural systems that are aligned with global goals for decarbonization and soil regeneration.

MAIN *PLAYERS IN THE AGRICULTURAL BIO-INPUTS MARKET*

The main players in the agricultural bio-inputs market have been subdivided into three categories: companies that were created as specialists in biologicals; large multinational

companies that dominate the market for chemical pesticides and fertilizers; and companies consolidated in non-agricultural sectors, illustrated in Figure 4.

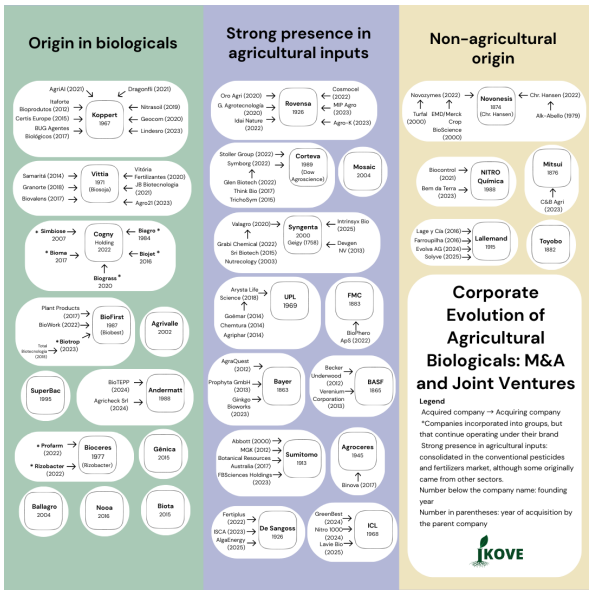

Figure 4. Corporate Evolution of Agricultural Biologicals: M&A and Joint Venture (Mergers and Acquisitions). Source: own work.

Among the pioneers, the Dutch company Koppert, founded in 1967 by producer Jan Koppert, stands out. In search of alternatives to synthetic pesticides for pest control in cucumber crops, he launched the company's first technology based on the use of the predatory mite *Phytoseiulus persimilis* to control phytophagous mites, such as *Tetranychus urticae,* marking the birth of *Koppert Biological Systems* (Koppert, 2025).

The Brazilian company Vittia, on the other hand, originated in 1971 as Biosoja, with the launch of an inoculant for soybeans containing nitrogen-fixing bacteria. s now active in the market for inoculants, biofertilizers, and bio-control inputs (VITTIA, 2025). Similarly, Argentina's Rizobacter, founded in 1977, also focuses on inoculants (RIZOBACTER, 2025).

Another pioneering company is *Andermatt Biocontrol* AG, originally from Switzerland, which began its history in 1988 with biological products based on entomopathogenic viruses (baculoviruses) as active ingredients for the control of agricultural insect pests. Its first product was Madex, with the active ingredient *Cydia pomonell granulovirus* (CpGV) for controlling the apple moth, known as codling moth (*Cydia pomonella)* (ANDERMATT GROUP, 2025).

In the Brazilian context, another prominent institution is Embrapa (Brazilian Agricultural Research Corporation), which played a key role in the development and implementation of biological nitrogen fixation (BNF) technology in the country. A pioneer in the commercialization of this technology, developed largely by Brazilian researchers since the 1960s, Embrapa benefited from notable contributions by Dr. Johanna Döbereiner, recognized worldwide for her discovery of nitrogen-fixing bacteria in grasses; and Dr. Mariangela Hungria, an international reference in agricultural microbiology and inoculants (VELLOSO AND D'ANDREA, 1982; DÖBEREINER, 1992; HUNGRIA ET AL., 2013).

Embrapa made an essential contribution to the adoption of bio-inputs in the country by demonstrating the great economic potential of the technology. It is estimated that, with each soybean harvest, approximately 40 million tons of atmospheric nitrogen are biologically fixed in Brazil alone (Hungria & Mendes, 2015), equivalent to an annual saving of approximately US$ 15 billion, considering the cost of a ton of conventional nitrogen fertilizer (urea or ammonium nitrate) at around US$ 1,000 (Hungria et al., 2020; Embrapa Soja, 2021). This economic impact has encouraged R&D into bio-inputs in the country, reflecting their prominent role in technological advances and Brazil's participation in this market.

Since 2000, there has been significant

growth in the number of bioinput companies in Brazil, notably SuperBac, created in 1995 with the aim of developing microorganism-based solutions for the treatment of industrial waste and effluents; Agrivalle, founded in 2002, operating in the area of special fertilizers , which are inputs formulated for specific applications or with differentiated technologies (e.g., controlled release, foliar application, fertigation, biostimulants); and Ballagro, founded in 2004, with an initial focus on microorganism-based biofungicides and bioinsecticides, such as *Trichoderma* and *Bacillus* (TRACXN, 2024; SUPERBAC, 2025; BALLAGRO, 2025; AGRIVALLE, 2025).

The sector reached its peak in 2010, a decade marked by the creation of companies that, in less than ten years, have come to represent a significant share of the market. Among them, the Brazilian company Biotrop stands out, founded in 2018 with initial investment from *Aqua Capital,* a *private equity* fund specializing in agribusiness and food, which in 2023 had 85% acquired by the Belgian group BioFirst with a valuation of €532 million, which is now one of the leaders in the global bio-inputs market (REUTERS, 2023). Other Brazilian companies that gained relevance during this period were Gênica, NOOA, and Biota, all with portfolios focused on microbiological agricultural pest and disease control (GÊNICA, 2025; NOOA, 2025, BIOTA, 2025).

A noteworthy point is the significant number of *startups* in the sector, a scenario that indicates the continued growth of companies in the area. In 2024, there were 1,972 *agtech startups* operating in Brazil, of which about 50 worked directly with agricultural bio-inputs (RADAR AGTECH BRASIL, 2024).

In addition to scientific and technological advances, other factors also favored the expansion of companies in the sector on the national scene, including regulatory advances and government incentives such as the ABC Plan (Low Carbon Agriculture), launched in 2010, and the National Bioinputs Program (PNB), from 2011. These paved the way for policies to encourage the use of sustainable inputs, as well as prioritizing and simplifying the registration of biofertilizers and inoculants (MAPA, 2011; BRAZIL, 2010).

A key element was the change in market demand, marked by growing consumer and global supply chain requirements for sustainably produced food with less use of agrochemicals. The advance of organic and certified agriculture, associated with international pressures, especially from the European Union, for agricultural practices with low environmental impact, has driven the adoption of bio-inputs as safe alternatives compatible with sustainable production models (ALTIERI, 2018; SOUZA et al., 2020).

Another important factor was the recurring crisis of imported chemical fertilizers and pesticides, which raised the cost of agricultural production and exposed the vulnerability of heavy external dependence. The scenario was aggravated by currency instabilities and recent geopolitical conflicts that affected the global phosphorus and potassium supply chain, stimulating interest in national and sustainable alternatives (ALMEIDA; SILVA; MENDES, 2022; OLIVEIRA; MARTINS, 2023).

These factors have also prompted established companies in other sectors to invest in agricultural bio-inputs. This is the case of Novonesis, created in 2024 from the merger of the Danish companies Novozymes (founded in 1920) and Chr. Hansen (founded in 1874), which dominated the market for enzymes for pharmaceuticals and food and, despite already being in the biosolutions area, did not have a strong presence in agribusiness until the 2000s (NOVOZYMES, 2020; CHR. HANSEN, 2021). Similarly, the Japanese

companies Toyobo (founded in 1882) and Mitsui (founded in 1876), which began their trajectory in the textile market and have an extremely diversified portfolio, operating in the chemical, pharmaceutical, biotechnology, and high-performance materials, have also moved into sustainable agriculture (TOYOBO, 2023; MITSUI, 2023).

In this context, large multinationals that dominate the conventional agricultural inputs market (pesticides and fertilizers) began to invest in the sector, mainly through acquisitions, mergers, and other types of partnerships with companies operating in bio-inputs from the 2010s onwards. The scenario is similar to what was observed in the agricultural seed sector in the 1990s and 2000s, when the sector, previously fragmented into small family businesses, became dominated by a few large agrochemical multinationals (HOWARD, 2008).

Below are examples of acquisitions, mergers, and other strategic partnerships formed between corporations related to agricultural bio-inputs.

CORPORATE EVOLUTION: M&A

As described above, since the emergence of pioneering companies in biological solutions for agriculture to the present day, the sector has been characterized by intense interactions between companies, which resort to different types of strategic arrangements to expand markets, access technologies, or strengthen their competitiveness. Among the main modalities, acquisitions, mergers, joint ventures, strategic alliances, licensing, consortia, and spin-offs stand out, whose descriptions can be found in Table 1.

These different strategic arrangements allow companies to expand their technological and commercial boundaries and are fundamental to understanding the dynamics of the global bio-inputs market, marked by constant M&A (mergers and acquisitions), partnerships, and collaborative innovation. The following describes the corporate evolution of agricultural bio-inputs, illustrated in Figure 3, as well as a discussion of their impact and the outlook for the sector.

Koppert, which originated in the macrobiological market, has significantly expanded its portfolio over time. Initially, the expansion took place with other macrobiological agents and pollinators, but from the 2010s onwards, the company underwent a phase of significant growth based on strategic acquisitions. Among these, the acquisition of Certis Europe (Europe), a specialist in microbiologicals, and Nitrasoy (Argentina), focused on inoculants for legumes, stand out. In Brazil, it consolidated its market presence by acquiring BUG Agentes Biológicos, a benchmark in biological control with macrobiologicals, and Promip, strengthening its operations in integrated pest management technologies. It also made important moves in North America and Asia, incorporating companies specializing in microbiological and biofertilizer solutions, which allowed it to expand its global research, development, and distribution network (Koppert, 2025).

Vittia, which began its journey in inoculants, intensified its operations in bio-inputs, mainly from the 2010s onwards. In 2014, after receiving investment from the BRZ fund, the company acquired Samaritá, expanding its presence in new markets in Latin America, such as Chile, Peru, Uruguay, Ecuador, and Mexico. In 2017, it incorporated Biovalens, entering the biocontrol market. In 2021, it expanded its operations in macrobiologicals through the acquisition of JB Biotecnologia, while Vitória Agro introduced innovative solutions in organomineral fertilizers based on the circular economy. In 2023, continuing its trajectory of technological

Type	Definition	New company?	Shareholding control	Duration	Example: agricultural/bio-inputs
Acquisition	One company buys another, assuming shareholding and strategic control. This can be total (elimination of the acquired brand) or partial (maintained as a subsidiary with its own identity).	No	Buyer assumes	Permanent	Vittia → Biovalens
Merger	Union of two or more companies to form a new legal entity, either by incorporation (when one absorbs the other) or by pure merger (when both cease to exist to create a new company)	Yes	Shared	Permanent	Novozymes + Chr. Hansen = Novonesis
Joint Venture JV	Creation of a new company shared by two or more companies to operate in a specific project or market, with proportional division of risks, investments, and results.	Yes	Shared	May be temporary	Syngenta + Novozymes
Alliance	They differ from JVs in that they do not involve the creation of a new company, but rather cooperation agreements in areas such as technological co-development, research, and distribution channels.	No	Each retains	Variable	Co-development agreements
Licensing	A contractual form whereby one company grants another the right to use patents, trademarks, microbial strains, or technologies in exchange for royalty payments.	No	Maintained by the licensor	For the duration of the contract	Use of university strains
Consortium	A form of temporary cooperation in which companies join together to carry out a specific project, without forming a new legal entity. It is widely used in research and development (R&D) and in projects financed by public or international funds.	No	Maintained	Usually temporary	R&D consortia FINEP
Spin-off	Creation of a new company from a division, technology, or asset of a parent institution or company. Often related to the academic environment, it is a fundamental mechanism for transferring scientific knowledge to the market	Yes	Independent or linked	Permanent	Academic startups

Table 1. Main types of corporate relationships.

innovation, the Vittia Group acquired the startup Agro21, which specializes in aerial application of macrobiological products by drones, consolidating its presence in precision agribusiness. The company owns the largest biological control factory in Latin America, with an annual production capacity of up to 10 million kg of biological inputs, which places it in a strategic position in the global growth of the sector (VITTIA, 2024; VITTIA, 2025; AGROPAGES, 2025).

Cogny, a Brazilian company with a significant presence in South America, can be defined as an unconventional holding company, consolidated in 2022, bringing together the bioinput companies Simbiose, Bioma, Biagro, and BioGrass, plus Simbiose Jet from the application machinery sector and Alado Logística. Together, they have a strong appeal for science-based innovation ( ), as was the case with the launch of the first microbial phosphorus provider, Biomaphós(*) ,developed in partnership with Embrapa (COGNY, 2025). The group is an example of the trend toward mergers between companies in complementary areas to promote accelerated growth.

Biofirst, which began its journey as Biobest in Belgium, founded in 1987 with a focus on bee pollination and biocontrol in horticulture, grew organically until the 2020s, when it began rapid expansion through the partial or full acquisition of companies. Noteworthy is the acquisition of Plant Products and BioWorks, opening up markets in North and South America with Biotrop between 2022 and 2023 (BIOFIRST, 2025), and is now considered one of the largest in the sector.

Corteva Agriscience was created in 2019 from the merger of the agricultural segments of Dow AgroSciences and DuPont, two century-old American companies that have profoundly marked the history of science applied to agribusiness. Dow AgroSciences originated as a subsidiary of the Dow Chemical Company, founded in 1897, and established itself as a benchmark in pesticides, seeds, and crop protection solutions. DuPont, created in 1802 initially as a gunpowder manufacturer, expanded throughout the 20th century into various areas, including agrochemicals and plant biotechnology. In the area of bio-inputs, the company intensified its activities in the 2010s, investing in microbiological solutions focused on nutrition and biocontrol. Among its main strategic moves are the acquisition of the Stoller Group, a leader in plant physiology and biostimulants with a strong presence in Latin America and the United States, and Microbiológica in Brazil, a pioneer in the development of inoculants and biofertilizers for biological nitrogen fixation and phosphorus solubilization. Globally, it has also established partnerships with biotechnology startups and co-development projects in agricultural microbiology, consolidating a robust portfolio of biostimulants, inoculants, and biocontrol agents (CORTEVA, 2024; AGROPAGES, 2025).

Syngenta, whose origins date back to the traditional Swiss chemical companies Ciba and Geigy, which merged with Sandoz in 1996, received its current name in 2000 when the agricultural divisions of Novartis and AstraZeneca merged, forming one of the largest global companies in the sector. Since then, it has built a diversified portfolio that combines seeds, pesticides, and, increasingly, bio-inputs. Its trajectory in biologicals gained momentum in the 2010s, with growing investments in microbiology and agricultur , inoculants, and biocontrol solutions. In 2017, it merged with ChemChina, expanding its presence in Asia and its global strategy. In 2020, with the acquisition of Valagro (Italy), a leader in biostimulants and plant nutrition, it consolidated its position as one of the leading bioinput companies in the world.

Since then, the company has established strategic partnerships with biotechnology startups and research centers, strengthening its performance in biocontrol and biological fertilization. Today, as part of the Syngenta Group, the company is positioned as a leader in the transition to regenerative agriculture, with one of the most comprehensive portfolios of biostimulants, inoculants, biofertilizers, and biocontrol agents available globally (SYNGENTA, 2024; VALAGRO, 2023).

Novonesis, created in 2024 through the merger between Novozymes A/S, a global leader in industrial enzymes and biosolutions, and Chr. Hansen Holding A/S, a leader in microbial cultures and probiotics, has established itself as one of the largest global companies dedicated exclusively to sustainable biotechnology. Novozymes, which originated in 1920 as part of Novo Nordisk, has distinguished itself over the decades in enzymes applied to food, renewable energy, and agriculture, pioneering the development of inoculants and biofertilizers in partnership with large multinationals such as Monsanto (later acquired by Bayer). Chr. Hansen, founded in 1874 in Denmark, built its track record in applied microbiology, expanding its operations from dairy cultures to nutrition and agricultural biocontrol solutions. With the merger, Novonesis now has one of the most comprehensive portfolios of inoculants, biofertilizers, biostimulants, and microbial biosolutions, with strong investment in regenerative agriculture and the valorization of agro-industrial waste. Today, it is positioned as a global leader in the advancement of bio-inputs and the bioeconomy, integrating cutting-edge science and large-scale sustainability (NOVONESIS, 2024).

In general, the trajectory of the main companies in the sector shows that the corporate evolution of agricultural bio-inputs is intrinsically linked to M&A strategies and other collaborative arrangements. The consolidation of acquisitions of specialized companies, the formation of technological partnerships, and the creation of new legal entities through mergers or spin-offs demonstrate that innovation in this segment depends not only on scientific capacity but also on business coordination on a global scale. This dynamic movement has accelerated access to new markets, expanded R&D networks, and diversified portfolios, placing companies in a strategic position to meet the demands for sustainability and regenerative agriculture. Thus, understanding this logic of corporate interaction is essential to analyze both the results achieved so far and the future prospects of the bioinputs sector.

INDUSTRY OUTLOOK

The global bioinputs market is experiencing continuous growth, driven by both regulatory pressures and demands from consumers and supply chains for more sustainable agricultural practices. Some regions are expected to experience more rapid growth, such as Brazil, which had an average annual growth rate of 21% between 2021 and 2024, four times higher than the world average (REUTERS, 2024; CROPLIFE BRASIL, 2025; MARKET AND MARKETS, 2025). This growth reflects sector consolidation, marked by mergers and acquisitions, as observed in leading companies (KOPPERT, 2025; BIOFIRST, 2025; VITTIA, 2025).

In addition, there is a trend toward change in commercial positioning, with the inclusion of bio-inputs in technology packages that aim to integrate integrated pest management and nutrition programs, regeneration of degraded areas, and sustainable production systems. In this context, biologicals are applied in a complementary manner to lower-risk chemical pesticides and fertilizers, composing technological packages that aim at greater

stability of results in the field (OWEN et al., 2015; FREIRE et al., 2020).

Another trend is the intensification of interactions between companies and scientific and technological institutions (STIs) as a way of integrating scientifically sound technologies into companies. Arrangements such as acquisitions, joint ventures, strain licensing, and R&D consortia have been recurrent in accelerating the transfer of technologies from the laboratory to the market (HOWARD, 2009; SOUZA et al., 2020). One example is the evolution of Cogny, which integrated bio-input and logistics companies, developing in partnership with Embrapa the microbial phosphorus provider Biomaphós® (COGNY, 2025).

Other companies, such as Koppert, have been licensing strains isolated and studied by research institutions, such as the strains *Trichoderma harzianum* ESALQ-1306, marketed as Trichodermil®, *Beauveria bassiana* ESALQ-PL63, marketed as Boveril® (including Boveril Evo), and *Metarhizium anisopliae* ESALQ-E9, marketed as Metarril® E9 (DOU). Demonstrating another trend, multinational companies have been seeking strains adapted to local operating conditions, unlike what is observed for conventional synthetic pesticides. In the latter case, molecules developed in research centers concentrated in the US and Europe are imported by various regions around the world, requiring only the adaptation of agronomic practices, such as dosage adjustment, and efficacy studies for local pests.

Technological advances have been classified into generations of bio-inputs, as described in Table 2 and in the text that follows.

The first generation of bio-inputs was marked by the use of individual strains of microorganisms and natural extracts with direct action on pests, diseases, or nutrition. Classic examples include *Bradyrhizobium* spp.-based inoculants for soybeans and the first bioinsecticides based on *Bacillus thuringiensis* (Bt) and entomopathogenic viruses (baculoviruses) (MARRONE, 2019; HUNGRIA et al., 2016).

The second generation includes multifunctional products based on combinations of microorganisms or microorganisms that produce multiple beneficial metabolites. The definition of multifunctionality by the European Biostimulants Industry Council (EBIC, 2016) consolidated this view. An example is the Dual Force® inoculant (Stoller), which combines *Azospirillum brasilense* and *Bradyrhizobium japonicum,* or the biological fungicide Schoker® (Agrivalle), formulated with *Bacillus amyloliquefaciens* and *Trichoderma harzianum*, which denote the trend toward co-formulations to broaden the spectrum of action (AGRIVALLE, 2025).

The third generation introduced advances in formulation, with the use of osmotic protectors, polymer encapsulation, and inert carriers that prolong viability and allow tank compatibility (MORAIS et al., 2021). An example is MTP (Microencapsulation Technology for Protection) technology, applied in some Serquímica Group products. The improvements aim at longer shelf life, stability against environmental stresses, and the possibility of large-scale use, with the goal of increasing farmer confidence and reducing variability in results.

The fourth generation now integrates digital and precision management programs, with products that combine low-risk chemical pesticides and microorganisms, supported by decision-making software (OWEN et al., 2015; FREIRE et al., 2020). In other words, it is the insertion of biologicals into the concept of "agriculture 4.0," aligned with real-time data and integration with sensors and digital platforms.

Generation	Characteristics	Examples	Reference
1st generation	Use of microorganisms or isolated extracts, with direct action on pests, diseases, or nutrition.	- *Bradyrhizobium* spp. for soybeans - *Bacillus thuringiensis* (Bt) - Baculovirus (entomopathogenic virus)	Marrone (2019); Hungria et al. (2016)
2nd generation	Multifunctional products, with combinations of microorganisms or production of multiple metabolites.	- Dual Force® (*Azospirillum brasilense* + *Bradyrhizobium japonicum*) - Schoker® (*Bacillus amyloliquefaciens* + *Trichoderma harzianum*) -(*Beauveria bassiana* + *Metarhizium anisopliae*) BioOlimpo®	EBIC (2016); Agrivalle (2025); Biotrop (2025)
3rd generation	Innovation in formulation, ensuring longer shelf life, stability, and tank compatibility.	- Encapsulated and stabilized formulations of microorganisms -Metashield® (Microencapsulation technology)	Morais et al. (2021)
4th generation	Integration with digital/4.0 agriculture, combining biologicals, low-risk chemicals, and decision-making software.	- Biologicals integrated with sensors and digital platforms - Hybrid products (chemicals + biologicals) in management programs	Owen et al. (2015); Freire et al. (2020)

Table 2. Technological generations of agricultural bio-inputs

The most advanced generation, called the fifth generation, involves the use of synthetic biology to redesign the metabolic pathways of microorganisms, ensuring greater predictability and production of metabolites of interest, and nanotechnology for controlled delivery and protection of assets (SAHA et al., 2023; SOUZA et al., 2020).

Another trend is the search for compatibility between bio-inputs and conventional synthetic inputs, especially for crops that have a history of intensive use of synthetic pesticides. According to Owen et al. (2015), biological products should not replace chemicals but act in an integrated manner. This trend has been observed in the agricultural products market, for example, in BASF's Muneo® BioKit, which contains the insecticides alpha-cypermethrin and fipronil, the fungicide pyraclostrobin, and the nitrogen-fixing bacterium *Nitrospirillum amazonense.*

In short, the global bioinputs market is consolidating itself as one of the central pillars of the transition to sustainable agricultural systems, supported both by the expansion of specialized companies and by the engagement of multinationals and ICTs in the transfer and co-development of technologies. The progressive advancement in "generations" of bio-inputs shows a trajectory of sophistication, from isolated microorganisms to synthetic biology and nanotechnology solutions, which allow for greater precision, stability, and multifunctionality. This evolution, combined with the trend toward integrating biologicals into technology packages and management programs, reinforces the strategic role of bio-inputs not only as alternatives but as essential complements to conventional inputs. In this scenario, it is clear that scientific innovation, linked to partnership models between companies and ICTs and market demands,

will be decisive in maintaining growth above the global average and consolidating bio-inputs as key technologies in the agriculture of the future.

CONCLUSIONS

The corporate evolution of agricultural bio-inputs highlights a sector in full transformation, in which science, business strategy, and regulation converge to redefine the technological basis of agriculture. The combination of above-average global growth, consolidation through M&A, and expansion of alliances between companies and ICTs has accelerated the expansion of microbiological and biochemical solutions for nutrition and control, with strong traction in Europe and North America and growing momentum in Asia-Pacific and Latin America. In this context, Brazil stands out as a hub of innovation and adoption in major crops, combining scientific capabilities, an industrial base, and an evolving regulatory environment.

From a competitive standpoint, the sector experienced organic growth centered on pioneers seeking alternatives to agrochemicals until the 2000s, when the sector underwent exponential growth driven by corporate interactions and the entry of large agrochemical corporations. Since then, the trajectories of global and regional leaders show that acquisitions, mergers, joint ventures, licensing, and consortia are key instruments for accessing strains, R&D platforms, channels, and manufacturing capabilities.

This corporate logic has expanded portfolios, shortened development cycles, and enabled "chemical + biological + digital" technological integrations in management packages. At the same time, it brings risks of concentration, dependence on a few assets, and technical-regulatory information asymmetries between markets, which demands transparency, comparable field performance metrics, and robust governance over intellectual property and the responsible use of microorganisms.

There has also been a major technological increase, from "first-generation" products (isolated strains) to multifunctional, microencapsulated formulations and, progressively, solutions enabled by synthetic biology and nanotechnology, coupled with digital agriculture and decision models.

Finally, the consolidation of bio-inputs as a pillar of regenerative agriculture depends on integrating scientific and technological innovation with scalable business models and policies that encourage decarbonization, efficient use of resources, and productive resilience. If Brazil converts its scientific and industrial advantages into world-class standards in quality, reliability, and cost, it will tend to assume a global leadership role not only as a market but also as an exporter of technology, manufacturing, and best practices, contributing to more sustainable, predictable, and competitive agriculture.

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