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Article

Advances and applications of Biotechnology in Agribusiness: an analysis of scientific production

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Abstract: Biotechnology is a multidisciplinary area that uses biological systems, living organisms and derivatives to modify specific products and processes. In agribusiness, Biotechnology plays a fundamental role in large-scale food production, being considered essential to face food crises. This bibliometric study aims to analyze and present the advances and applications of Biotechnology in the agribusiness sector, using the scientific production available in the main Web of Science database from 2018 to 2023. Biotechnology applied to agriculture encompasses genetic engineering techniques to improve plants, animals and microorganisms. In addition to contributing to food security, this area is aligned with several Sustainable Development Goals of the United Nations 2030 Agenda. It was found that Biotechnology is a transversal theme that covers more technical areas, with a mix of topics such as nanotechnology, genetic engineering, regulatory issues, risks and positive and negative impacts, innovation, forms of seed reproduction, sustainability and green applications. Authors, institutions and countries that stood out are from: United States, China, India, United Kingdom, Brazil, Korea, Poland, France and Germany. This research demonstrated advances and applications in order to reduce negative risks, innovations arising from new techniques and the technical and legal challenges faced by researchers in this field of study and provided valuable insights, contributing to the development of Biotechnology applied in agribusiness, promoting not only scientific and technological advances, but also addressing social and environmental issues. In addition to demonstrating that biotechnological applications in agribusiness range from genetic improvements in agricultural crops to the creation of biodegradable materials and sustainable solutions.

Keywords: green biotechnology; agribusiness; biotechnology advances; biotechnology applications in agriculture; bibliometrics

1 Introduction

Biotechnology is a multidisciplinary area that uses biological systems to create or modify products and processes. According to the United Nations Convention on Biological Diversity, it involves any technological application that uses living organisms for these purposes (United Nations Convention on Biological Diversity, 1992). For the United States Department of Agriculture (USDA), agricultural biotechnology focuses on the use of tools or techniques combined with genetic engineering to improve products, organisms, plants or animals for specific agricultural uses (United States Department of Agriculture, 2023).

Color classification is adopted in biotechnology to organize its various areas of activity and it is known as the “Rainbow code of Biotechnology” and categorizes the field as follows: Green (agriculture and agribusiness), Yellow (nutrition and food), Red (medicine and human health), Gray (environmental protection and sustainability), Blue (marine environments), Brown (dry and desert regions), Gold (bioinformatics), Black (bioterrorism and its investigations), Violet (ethical issues), and Orange (scientific dissemination) (DaSilva, 2004; Kafarski, 2012; Sá; Francisco; Bourguignon, 2021). This classification helps to provide a clear and organized view of the different areas of research and application of biotechnology, highlighting its multidisciplinarity and importance in different contexts.

This variety of applications and of research fields indicate that Biotechnology can be analyzed under the focus of Information Science because it allows the investigation of process and properties of information since its origin, the treatment, access, utilization and storage, what contributes to the scientific and technological solution constructions (Amaral; Matias; Sarvo, 2024). One of the research fields is agribusiness development where Biotechnology plays an important role, based on the inputs, in the agricultural mechanization, technologies, food safety and packaging of perishable products, that contributes to the productivity and competitiveness (Lokko *et al.*, 2018). Agribusiness is an important sector in the Brazilian economy and Biotechnology contributes with innovation, research and more technologies (Vellani Júnior *et al.*, 2022).

As highlighted by Machado (2021), the performance of Brazilian agribusiness during the covid-19 pandemic was remarkable, with record exports and production in 2020, representing 26.1% of the Gross Domestic Product (GDP) according to data from the Centro de Estudos Avançados em Economia

Aplicada (CEPEA) in partnership with the Confederação da Agricultura e Pecuária do Brasil (CNA). Several studies were carried out to measure the performance of agribusiness in Brazil, among them Moura and Caregnato (2011) analyzed patent networks to understand the relationships between Brazilian researchers in Biotechnology, while Linares (2015) used the Gephi software to study technological development routes. Perea, Gaviria and Redondo (2020) carried out a bibliometric analysis of bioeconomy research networks, using the VOSviewer and bibliometrix software. In turn Khan (2024) evaluate the challenges and future perspectives related to bioremediation used in hospital waste while Vellani Júnior *et al.* (2022) investigated the advances of patents and the technological development of agribusiness in Biotechnology as a way to demonstrate the influence on the increase of agricultural productivity in Brazil.

This research focuses on Green Biotechnology, related to agribusiness. According to Barros and Coffani (2022), agribusiness integrates agriculture and business, encompassing economic activities linked to the cultivation of land and natural resources, both plant and animal. The Bioeconomy, as described by the European Commission, involves the production and conversion of renewable biological resources into food, feed and other products (Silva; Pereira; Martins, 2018). Reim, Parida and Sjödin (2019) highlight the barriers to economic growth with renewable biological sources and the need for circular business models. Medina, Rotondo and Rúben-Rodríguez (2024) highlight the difficulties in developing countries to identify suitable technologies in bioinputs, despite innovations such as biofertilizers and biopesticides. However, it is essential to also consider the risks associated with these biotechnology practices, especially with regard to the possibility of accidental contamination of the environment, rural workers or food with microorganisms due to the use of products that may offer low efficacy, for example, which could harm Brazil's reputation in the international market if contaminated food is exported (Barros; Coffani, 2022).

Regarding agribusiness, there are also concerns related to the problems of agroterrorism, a subsector of bioterrorism that aims to damage the agricultural sector through the intentional release of biological agents or toxins. These actions can result in problems for human, animal or environmental health, in addition to harming both the financial sector and food safety. These hostile actions can be adopted by different actors for reasons ranging from financial and personal gains to the destabilization of the sector itself (World Organisation for Animal Health, 2020).

On the other hand, sustainable Biotechnology seeks to conserve resources, protect and monitor the environment and waste management. To achieve a more sustainable future, Biotechnology must integrate with the fields of society, economy and environment, developing ecologically correct processes, such as biofertilizers, biopesticides, monitoring and conservation of biodiversity, bioremediation, genetically modified organisms (GMO), in addition to the use of energy renewable sources, whether in the production of biofuels or in the generation of electrical energy (Singh, 2017).

Biotechnology, as an interdisciplinary field, plays a fundamental role in the advancement of various areas, including the different sectors that make up agribusiness. In agriculture, genetic modification stands out as a crucial technology, making it possible to create new plants with greater productivity and resistance, as well as reproduction techniques, such as tissue culture, which speed up the development of desirable varieties. The application of biotechnological biocides and fertilizers is also gaining ground, promoting more sustainable alternatives with less environmental impact (Vellani Júnior *et al.*, 2022).

In the environmental field, the development of sustainable techniques through biotechnology is essential for conserving biodiversity and mitigating environmental impacts. Bioremediation of contaminated soils and wastewater treatment are examples of how these technologies can restore ecosystems and contribute to a more balanced and ecologically correct development (Vellani Júnior *et al.*, 2022; Judijanto; Auliani, 2024).

In the food and beverage industry, biotechnology has made a significant contribution to food safety and food preservation. The production of fermented foods and the composition of protein-based products are examples of how biotechnology is improving both the nutritional quality and durability of products, meeting the growing demand for safer and more sustainable solutions in the food market (Vellani Júnior *et al.*, 2022; Altarturi *et al.*, 2023; Arthur *et al.*, 2024).

A sub-theme indirectly related to biotechnology, but which appears in the studies by Altarturi *et al.* (2023) and Arthur *et al.* (2024), is the application of digital technologies and the computerization of the sector, including the adoption of solutions such as IoT, drones, autonomous vehicles, artificial intelligence and e-commerce. These technological applications have the potential to significantly transform the sector, automating processes and increasing operational efficiency.

Thus, bringing a different perspective to existing bibliometric studies (Moura; Caregnato, 2011; Linares, 2015; Perea; Gaviria; Redondo, 2020; Vellani Júnior *et al.*, 2022; Altarturi *et al.*, 2023; Khan, 2024; Arthur *et al.*, 2024; Judijanto; Auliani, 2024), this study adopts a specific approach to the relation between Biotechnology and agribusiness themes, combining different free softwares, as presented in the study by Ruas and Pereira (2014), that assists researchers not so involved with information technology and computing.

With this in mind, some of the empirical laws of bibliometrics considered in this study, which are intrinsically linked to the foundations of information science, include Lotka's Law, which proposes estimating the scientific relevance of authors based on their productivity, and Zipf's Law, which analyzes the frequency of words in texts in order to verify their importance within that context (Guedes, 2012), and which, along with Bradford's Law, about the description of articles dispersion of a specific discipline in the journals, are the most widely used laws in bibliometrics according to Bufrem and Prates (2005) and Guedes (2012).

It is worth highlighting the United Nations 2030 Agenda, with its Sustainable Development Goals (SDGs). According to information from the organization in Brazil, Brazilian agribusiness partners are engaged with the goals of the Agenda at different levels. In particular, one of the main partners, the Food and Agriculture Organization of the United Nations (FAO), has directed investments to achieve the following SDGs: (1) No Poverty, (2) Zero Hunger and Sustainable Agriculture, (5) Gender Equality, (12) Responsible Consumption and

Production, (14) Life Below Water and (15) Life on Land (Nações Unidas Brasil, 2023).

The central question of this study is: What are the advances and applications of Biotechnology used by the agribusiness sector, based on the scientific production available on the Web of Science (WoS)? Aiming to present the advances and applications related to Biotechnology used by agribusiness, focusing on the scientific production available in the main base of the Web of Science, using a methodology based on what was exposed by Ruas and Pereira (2014), which uses free software for analysis of data. This approach aims to offer a deeper and more differentiated analysis.

In this way, the analysis of scientific literature can contribute to applications and advances related to the Biotechnology aspect used by the agribusiness sector, favoring understanding and insights for new research in favor of science, human well-being and society in general.

2 Material and methods

This study is a bibliometric research carried out in the main Web of Science (WoS) database. As a method, the bibliometric analysis provides several overviews that shed light and enriches the matter studied (Lyu; Liu; Yao, 2023).

The WoS was chosen due to its reliable indexing and high rate of metadata in all publications (Stahlschmidt; Stephen, 2020; Stephen; Stahlschmidt; Hinze, 2020). To address Biotechnology applied to agribusiness, several criteria were adopted, summarized in the research protocol presented in Chart 1.

Chart 1 - Research Protocol

Theme	Advances and applications of Biotechnology with a focus on agribusiness
Search Question	What are the advances and applications of Biotechnology employed by the agribusiness sector, based on the scientific production available on the Web of Science (WoS)?
General Objective	This work seeks to present and analyze, through bibliometric research, what are the advances and applications of Biotechnology in the agribusiness sector
Data Base	Web of Science
Research Strategies	Specific keyword combination such as: (agricultural biotechnology OR green biotechnology) AND (advance* OR appli* OR agribusiness)

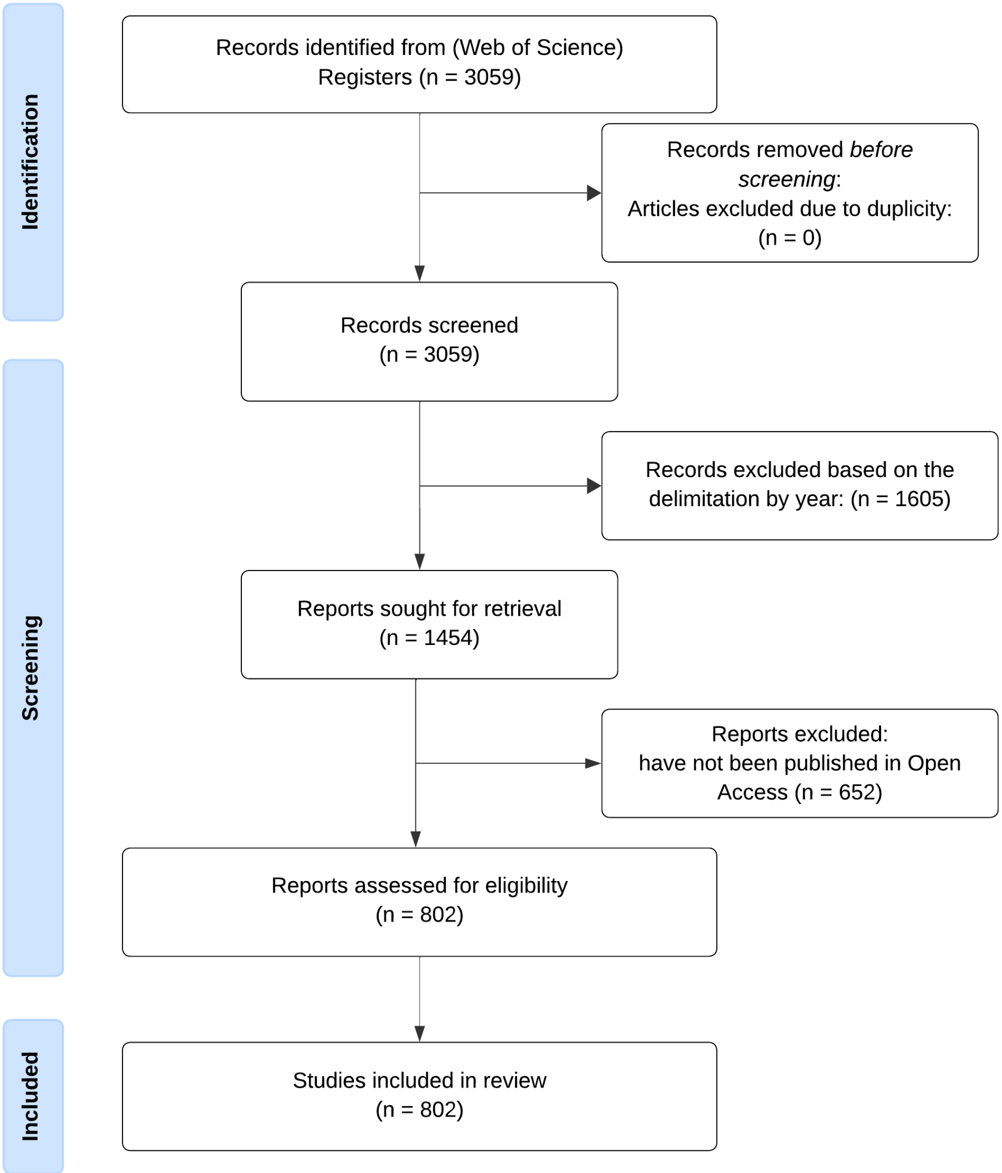
Search Field	Title of articles, abstracts and keywords of the authors.
Inclusion Criteria	Articles and publications between 2018 and 2023
Exclusion Criteria	Articles that were inconsistent with the objectives of the study, outside the specified period or that had not been published in open access

Source: Drawn up by the authors.

The search is restricted to articles published in scientific journals with open access, in any language and with a delimitation of the period from 2018 to 2023 in order to cover only the most recent studies in the area with a view to analyzing the advances arising from the Biotechnology used in the agribusiness sector. The results obtained in January 2024, in the Web of Science database, totaled 802 articles eligible for this research.

The flowchart in Figure 1 was created to demonstrate the selection of articles based on the concepts of PRISMA-2020 (Page *et al.*, 2021), which is also a useful method for studies other than systematic review, as it demonstrates the entire flowchart for selecting articles eligible for analysis. The selection resulted in 3.059 articles identified by defined keywords, of which 1.605 were removed due to delimitation by year (2018 to 2023). 1454 documents remained, which were again delimited, with the removal of 652 articles that were not published in open access. Thus, 802 articles remained eligible for abstract analysis using the Iramuteq software, which works in its analyses based on Zipf's law.

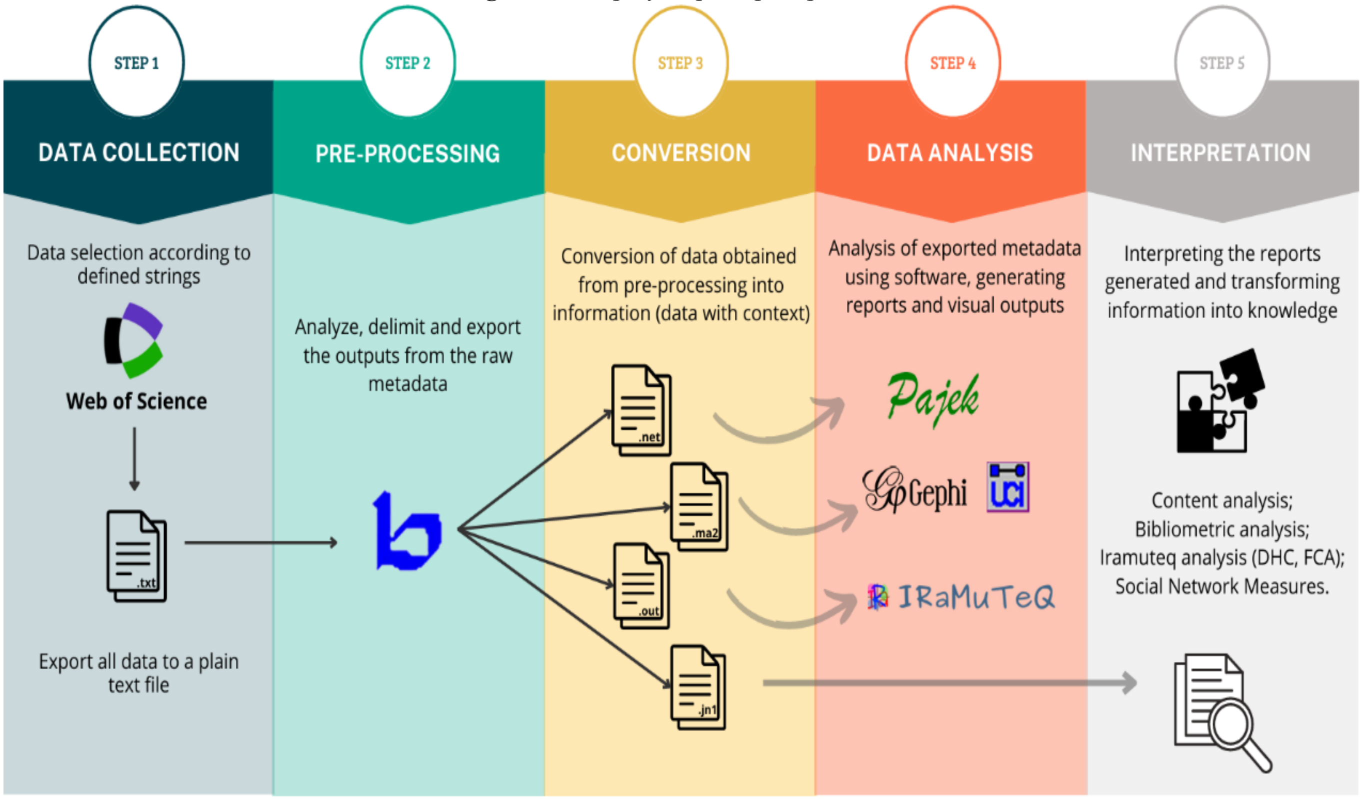
Figure 1 - Article selection flowchart



Source: Drawn up by the authors.

For the analysis, all metadata available in the Web of Science database were exported through a plain text file related to the selected articles, which were pre-processed by the Bibexcel software in order to recover only the metadata explored in subsequent analyses. This step-by-step process can be seen in more detail in Figure 2, which shows the step-by-step process adopted by the authors, from data collection (step 1), through data pre-processing (step 2), the necessary conversions (step 3) and the separation of specific metadata for each type of analysis, then on to data analysis (step 4) using the software adopted in this study, up to the interpretation of all this data (step 5) and its presentation in the following section. Not all the softwares presented in Figure 2 were utilized in this study, since the process has a broad potential and it is yet being developed by the authors.

Figure 2 - Step by step adopted process



Source: Drawn up by the authors.

The objective was to identify and indicate possible applications, trends or advances in relation to the proposed topic, as well as analyze possible contributions, in addition to raising awareness among the actual and the future researchers about the importance and need for a greater focus on research aimed at applications of Biotechnology. This metadata was also analyzed using the Biblioshiny web tool, created for the Bibliometrix library developed in the R programming language, as a way of verifying and guaranteeing the quality of the metadata explored, in addition to enabling various bibliometric surveys (Aria; Cuccurullo, 2017).

3 General overview of the scientific production analyzed

In relation to bibliometric analysis, Table 1 presents a balance of scientific production divided into three themes: (1) authors, (2) institution, (3) country, each with their respective numbers of articles published in the period from 2018 to 2023.

Table 1 - General Overview of Scientific Production

Author	Amount	Institution	Amount	Country	Amount
Iqbal Hmn	4	Egyptian Knowledge Bank (EKB)	46	United States	91
Pereira Jfb	4	University Of California (UC)	46	China	82
Xu Y	4	United States Department of Agriculture (USDA)	25	India	51
Babalola Oo	3	Centre National de la Recherche Scientifique (CNRS)	23	Italy	46
Baier T	3	National Research Centre (NRC)	23	United Kingdom	37
Glick Br	3	Chinese Academy of Sciences (CAS)	22	Germany	36
Hua X	3	University of California Berkeley (UCB)	20	Brazil	27
Huang Zx	3	Egyptian Knowledge Bank (EKB)	18	Korea	26
Kouisni L	3	University of California System (UCS)	18	Poland	24
Lee Jh	3	United States Department of Energy (DOE)	17	France	23

Source: Research data.

In Chart 2, the result of the biblioshiny Three-Field Graph was used, which evaluates the relationship between the selected fields (Kumar *et al.*, 2021). Therefore, the selected fields are limited to the most frequent words in the abstracts, titles and keywords of the authors, institutions and countries that published the most, as listed in Table 1. Thus, indicating some of the applications, study focus and some resulting advances of Biotechnology applied in agribusiness.

Chart 2 - Focus of study of main authors, institutions and countries

Author	Study focus	Institution	Study focus	Country	Study focus
Iqbal	Bioremediation; Biocatalysis; Circular economy; Genetic	EKB	Nanotechnology; Enzymes; Green synthesis	United States	Synthetic biology; Microalgae; Genetic engineering
Pereira	Sustainable; Plants; Review; Application	UC	Microalgae; Gene editing; Nanoparticles	China	Bioremediation; Green synthesis; Nanotechnology
Xu	Gene; Products; Food; Environment;	USDA	Genome editing; Food; Environment	India	Circular economy; Enzymes; Crispr
Babalola	Microalgae; Plant; Environment; Food;	CNRS	Biocatalysis; Green chemistry; Genetic	Italy	Circular economy; Microalgae; Sustainability
Baier	Crispr; Genetic engineering; Gene; Sustainable	NRC	Nanoparticles; Enzymes; Green synthesis	United Kingdom	Microalgae; Crispr; Circular economy
Glic	Environment; Gene; Plants	CAS	Bioremediation; Genome editing; Plants	Germany	Microalgae; Bioremediation; Biocatalysis
Hua	Production; Green; Development	UCB	Synthetic biology; Genetic; Microalgae	Brazil	Circular economy; Crispr; Nanotechnology
Huang	Gene; Potential; Green	EKB	Silver nanoparticles; Green chemistry; Gene	Korea	Microalgae; Enzymes; Sustainable
Kouisni	Plant; Food; Sustainable	UCS	Genetic engineering; Sustainability; Plant	Poland	Crispr; Enzymes; Green synthesis
Lee	Bioremediation; Plant; Environment	DOE	Gene editing; Sustainability; Microalgae	France	Plants; Sustainability; Circular Economy

Source: Research data.

The data reveals an annual growth of 12.89% in scientific production. International co-authorship accounts for 35.91% of the total, with only 44 articles having a single author, resulting in an average of 5.61 co-authors per document. The concentration of published papers is notably higher in the United States, China, and India. This is also evident in the institutions with the highest number of publications, although the leading authors were affiliated with institutions in Mexico, Brazil, and China at the time of submission. The predominant themes in the publications include critical areas of environmental sustainability such as bioremediation, biocatalysis, and the circular economy, as well as advancements in emerging technologies like gene editing and genetic engineering. This thematic diversity highlights the complexity and interdisciplinary nature of the field, alongside a global commitment to addressing pressing environmental and social challenges through innovative solutions.

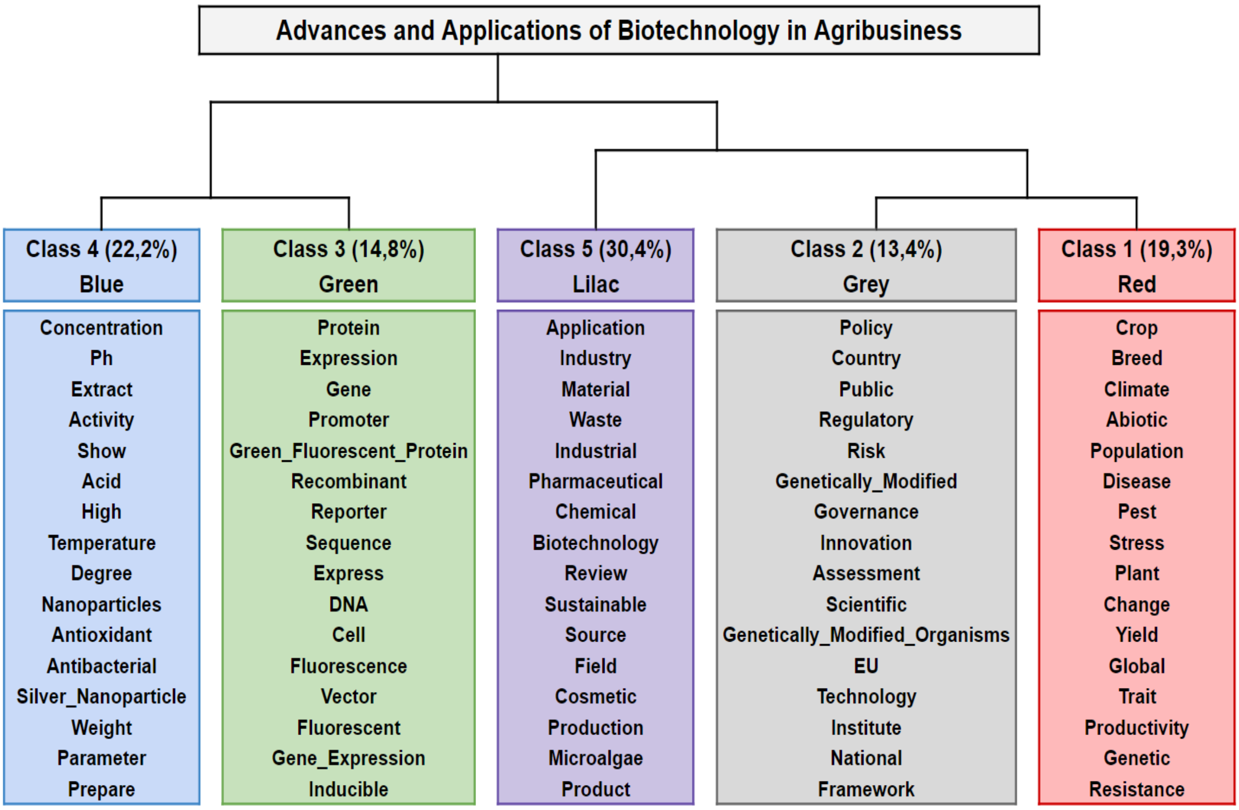
4 Results of the textual analysis of Biotechnology applied in Agribusiness

For the preliminary content analysis, the abstracts of all selected articles were exported using the Bibexcel software and then formatted according to the specificities necessary for the analyzes in the Iramuteq software. Iramuteq, which is based on the R and Python programming languages, was used in this study to analyze the textual corpus of abstracts.

The analyzes presented are: the Descending Hierarchical Classification (DHC) that groups active words into classes according to their incidence in the abstracts and the descriptives of the Correspondence Factor Analysis (CFA) as a way of categorizing the proximity of the textual corpus in relation to DHC (Camargo; Justo, 2013).

Regarding the DHC, 98% of the text segments of the abstracts were classified, thus representing 4875 of 4.974 text segments classified in one of the classes. Therefore, it is noted that the division suggested by the software covers five classes, which are identified by colors that correspond to sets of words with different frequencies and focus, as shown in Figure 3.

Figure 3 - Descending Hierarchical Classification (DHC)



Source: Drawn up by the authors based on data from the Iramuteq software.

Therefore, the classes with the highest frequency are classes five (Lilac - 30.4%) and four (Blue - 22.2%), followed by classes one (Red - 19.3%), three (Green - 14.8%) and two (Grey - 13.4%), the software still suggests that classes one and two are subclasses within class five. With regard to the word sets presented, it is possible to preliminarily check the focus of each of the classes, represented as follows:

a) class four (Blue) - it holds words related to concentration of compounds, measurements, weights, sizes, temperature, as well as references related to nanoparticles, antioxidants, acids, indicating more technical terms of the area;
b) class three (Green) - it follows the same line as the previous class, presenting also technical terms, but in the line of genes, proteins, cells,

DNA and words underlying the theme as recombinant, coding, sequence, genetic expression;

c) class five (Lilac) - presents more general terms such as application, which is one of the focuses of this work, industry, materials, waste, sustainability, cosmetics and green applications;
d) class two (Grey) - being a subclass within class 5 presents terms linked to regulatory issues, genetically modified organisms, policies, risks, innovation and governance;
e) class one (Red) - in turn, it presents terms related to agricultural production, climate, reproduction, changes, stress, diseases, demonstrating concerns about production itself.

Classes indicate that the subjects, in macro form, are technical terms related to biotechnology (class four and three), materials and applications (class five) and risks, innovation, diseases and production (class one e two). It is important to highlight that the word “advances” is related to the themes: industry, materials, waste, sustainability, cosmetics and green applications. All classes indicate words that are related to the advances of Biotechnology, such as: nanoparticles, antioxidants, acids (class four); dna, genetic expression (class three); sustainability, green applications (class five); innovation and risks (class two) and climate, diseases, among others (class one).

As mentioned above, the Correspondence Factorial Analysis (CFA), illustrated in Figure 4, uses the same classification as the DHC, using the complete abstracts for this classification. In this way, it is possible to observe the overall proximity between the themes, according to the focal relationship of the CFA classes presented.

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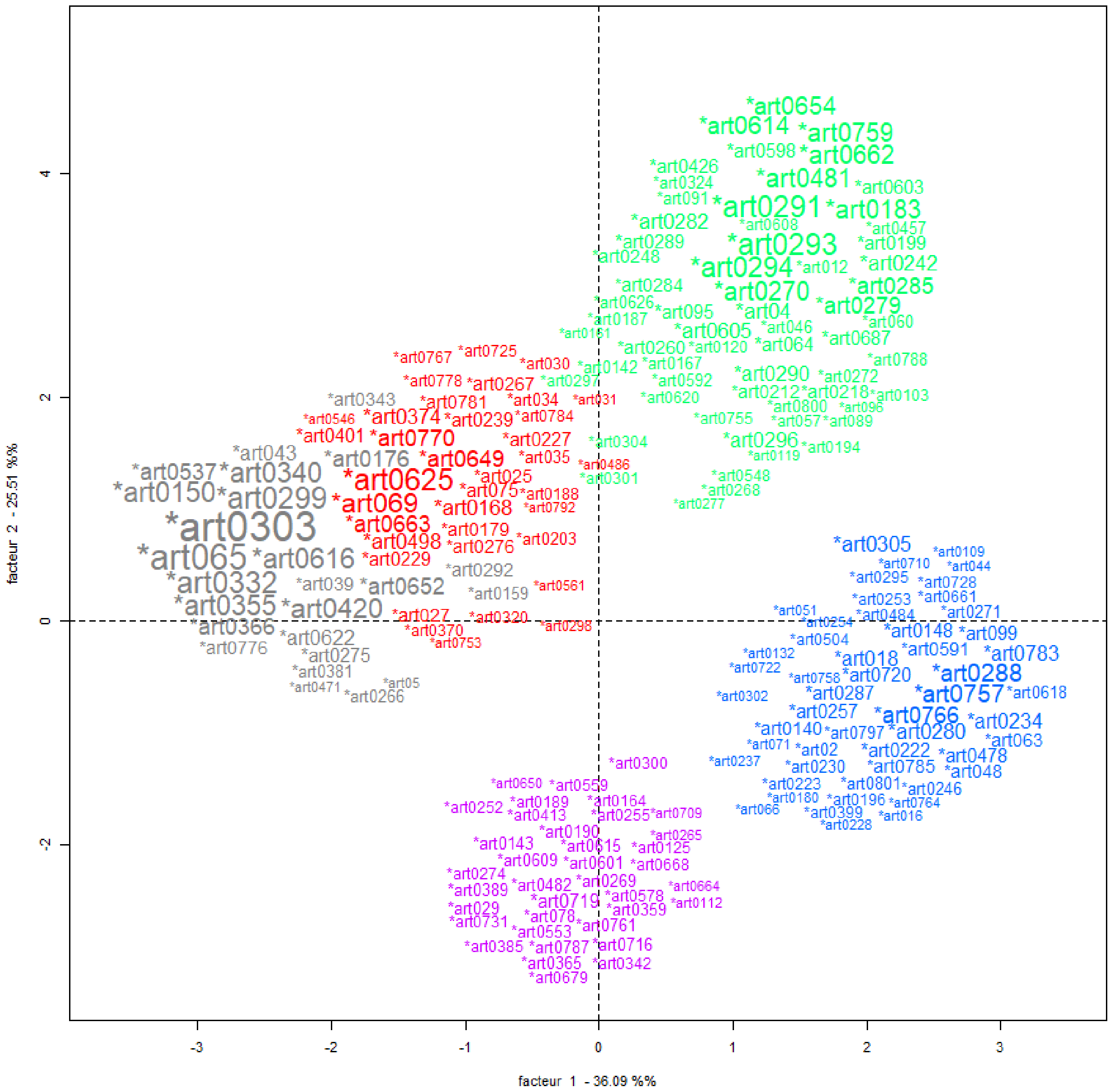
Figure 4 - Correspondence Factorial Analysis (CFA) of articles



Source: * Drawn up by the authors using Iramuteq software.

For the subsequent analysis, the classification presented in the CFA was considered, which made it possible to select articles within each class in order to understand how the topic develops. In total, 30 articles were selected, covering all five classes suggested by the Iramuteq software. It should be noted that, in summary, the articles cover a wide variety of topics relevant to Biotechnology applied to both agribusiness and other areas.

In this way, it is possible to observe the global proximity between the themes, according to the focal relationship of the CFA classes presented. In view of the analysis of the articles and the classifications suggested by the Iramuteq software, it can be seen that, in summary, the articles cover a wide variety of topics relevant to biotechnology applied to both agribusiness and other areas. Chart 3 below summarizes some of the various applications or advances discussed, offering a synthesized view of the main innovations and discoveries in the area and showing impacts of Biotechnology development as mentioned by Judijanto and Auliani (2024) on biotechnological research, which demonstrates a first vision in search of solving the problem of this research by mapping the development of the area. For example, authors emphasize as future research, biodiversity and microalgae studies that is shown in Iramuteq class grey and green (Chart 3). Papadopoulou *et al.* (2021) highlighted the theme sustainability as a main recurring concept as it is presented in lilac class "Carbon-based Nanoparticles for Food Safety and Sustainability".

Chart 3 - Summary of the analyzed articles

Iramuteq Class	Synthesis of applications or advances
Red	Assessment of the resistance of lizards in genetically modified plantations Advances in genetic improvement used in winter wheat Advances and applications of metabolomics and cheminformatics Advances in wheat genetic improvement Advances in genetic editing Advances in productivity and stress tolerance in alpha plantations
Grey	Advances in genetic engineering linked to green algae Implementation of governance legislation for GMOs Public acceptance of genetically modified crops Need for greater transparency on biotechnological processes Innovative process of extraction of polyphenols from plant waste Development of Biotechnology around the world and in Ukraine
Green	Biodegradable biopolymers potentials Identification of a Pv11 cell promoter Research on marine phages Efficient nanobiohybrids Analysis of the transcription of the plastidial gene of the kiwi Genetic editing using green algae

Blue	Reduction of the concentration of heavy metals in corn Multiplication of shoots in oregano cultivation Research with gene promoters in transgenic rice Solvent made from menthol Increased dry weight of onions Phosphate solubilization based on natural coal nanoparticles and microparticles
Lilac	Metal nanocomposites hydrogeles Carbon-based Nanoparticles for Food Safety and Sustainability Use and advances of microorganisms for agricultural applications Biomaterials based on silk fibroin that can be applied to various areas with technological advances Air filtering by biopolymers Bioprocesses for the production of vitamin E

Source: Research data.

The results found relate in part to what was presented in the bibliometric studies presented previously by Vellani Júnior *et al.* (2022), Altarturi *et al.* (2023), Arthur *et al.* (2024) and Judijanto and Auliani (2024), highlighting more specific applications in some areas, such as Carbon-based Nanoparticles for Food Safety and Sustainability, or applications other than those mentioned by the authors, such as the use of metabolomics and cheminformatics, legislation on GMOs, the need for transparency and public acceptance of biotechnological processes, air filtration by biopolymers and biodegradable biopolymers. While related topics focus on the use of microorganisms for agricultural applications, bioprocesses, genetic improvement and advances in productivity through multiplication using the callus culture technique. This suggests a response to the problem question of this study, although it is not limited to these applications or advances. It is important to note that this analysis is based on a selection of 30 articles and the information presented in Figure 3, Chart 2 and Chart 3.

In this way, the wide range of applications and advances present in the area of Biotechnology applied to agribusiness is evident, as highlighted in the texts analyzed. The multidisciplinary approach is remarkable, ranging from the resistance of caterpillars in genetically modified crops to the production of biomaterials and biodegradable biopolymers. Genetic advances in wheat and alfalfa, as well as gene editing and the use of metabolomics demonstrate the potential for increasing productivity and stress tolerance in crops. Furthermore, genetic engineering in green algae, the reduction of heavy metals in corn and the multiplication of sprouts in oregano cultivation are examples of innovations that transcend agribusiness, reflecting in areas such as sustainability and food security. The implementation of governance legislation for GMOs and public acceptance of these crops also highlights the importance of ethical and transparency issues. Thus, it appears that Biotechnology applied to agribusiness not only drives scientific and technological advances, but also integrates social and environmental aspects, reaffirming its relevance and multidisciplinary impact.

Another essential point is to consider the challenges, risks or impacts, whether positive or negative, related to the topic. Although these words do not appear significantly in DHC in relation to other words, they are recurrent in classes one (red) and two (gray), with an incidence of "impact" (148), "challenge" (201) and "risk" (101). When analyzing the focus of each of these words, Chart 4 is adopted in order to summarize their uses.

Chart 4 - Focus of study of main authors, institutions and countries

Word	Reference	Word usage focus
Impact	(Kržišnik; Gonçalves, 2023)	adversely impact the ecosystems they inhabit.
	(Calabi-Floody *et al.*, 2018)	provide food security without impacting environmental safety
	(Zilberman; Holland; Trilnick, 2018)	agricultural biotechnology is diverse with applications having different potential impacts
	(Giraldo *et al.*, 2019; Hallerman *et al.*, 2022; Wray-Cahen *et al.*, 2022; Tan *et al.*, 2018; Glavič *et al.*, 2023)	reduction of environmental impact
Challenge	(Kabange *et al.*, 2022)	addressing current global environmental challenges towards sustainable agriculture
	(Huppertz *et al.*, 2023)	challenges in agricultural production and food security
	(Kostina-Bednarz; Płonka; Barchanska, 2023)	one of the main challenges of agriculture today is to obtain higher yields from crops
	(Nuccio *et al.*, 2018; Mat Jalaluddin; Othman; Harikrishna, 2019; Wong *et al.*, 2022)	Technical, practical or regulatory challenges
Risk	(Chowdhury *et al.*, 2022)	lead compounds can pose a high risk to humans
	(Buzzo *et al.*, 2023)	antibiotics, can pose serious risks for the emergence of multi-resistant microorganisms
	(Gage; Schwartz-Lazaro, 2019; Wei *et al.*, 2024)	minimize risks to human health and the environment
	(Wu, 2022)	good agricultural and manufacturing practices reduce the risks of mycotoxins

Source: Research data.

With this, it is noted that both the word "risk" and the term "impact" can reflect negative or positive points, while "challenges" are confined to the central focus of the area, related to technical or regulatory issues to the expected result without compromising sustainability or food security, which is consistent with the ideas of Singh (2017) and Vellani Junior (2022) presented earlier and with the analysis from the selected articles.

5 Conclusion

With this, it is concluded that although the central theme of the present study focuses on the applications and advances of biotechnology used in agribusiness, the theme becomes transversal, covering more technical areas, with a mixture of areas such as nanotechnology, passing through themes within genetic engineering, regulatory issues, risks, innovation, ways of seed reproduction, sustainability and green applications. Authors, institutions and countries that stood out are from: United States, China, India, United Kingdom, Brazil, Korea, Poland, France and Germany.

The diversity of applications and technical advances in Biotechnology used by agribusiness, it is clear, according to the classification made using the Iramuteq software, that some of these applications correlate between the general definitions of the classes. For example, the red class is associated with general concerns in the field, the gray class is related to regulatory policies, the green class refers to genetic engineering terms, the blue class addresses technical terms and measurements, while the lilac class encompasses general questions focused on the application of the area itself.

Specifically in relation to "risks" and "impacts", it is noted that both words may have a double meaning among the articles analyzed. It can refer to a positive risk or impact, such as reducing risks to human health or reducing environmental impact, or to a negative risk or impact, such as risks to human health or impact on ecosystems. Meanwhile, "challenges" are more focused on technical applications of Biotechnology or legal challenges.

Thus, it is clear that Biotechnology not only drives scientific and technological advances, but also integrates social and environmental aspects, reaffirming its relevance and multidisciplinary impact presented previously. This study demonstrates that biotechnological applications in agribusiness range from genetic improvements in agricultural crops to the creation of biodegradable materials and sustainable solutions. Through detailed analysis of articles and classifications carried out by the Iramuteq software, it is clear that advances in this area not only increase productivity and resistance of plantations, but also promote environmental sustainability and food security. Furthermore, the implementation of governance legislation and public acceptance of genetically modified crops highlight the importance of ethical issues and transparency in biotechnological processes. In this way, this research portrays the comprehensive benefits of Biotechnology, highlighting its crucial role in sustainable development and especially in agricultural innovation.

The study has limitations when analyzing only articles from a database, which may result in the loss of information from other works not indexed in the Web of Science. It is recommended that future research use the same methodology presented in Figure 2 with the use of Bibexcel software, as it allows for a broad analysis of the metadata present in the articles submitted, as well as checking the possibility of including other databases that work with the same step-by-step approach and a broader period of time. It is also essential to investigate advances and applications related to protection against bioterrorism, which were not covered in this selection and analysis of articles, as well as other relevant fields of Biotechnology such as health, marine life, bioinformatics, among others. Recognizing the cross-cutting applications of Biotechnology and its importance in different areas is crucial for a comprehensive understanding of the topic, providing valuable insights for new research and contributing to advances in science and the well-being of society.

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Avanços e aplicações da Biotecnologia no Agronegócio: uma análise da produção científico

Resumo: Biotecnologia é uma área multidisciplinar que utiliza sistemas biológicos, organismos vivos e derivados para modificar produtos e processos específicos. No agronegócio, a Biotecnologia desempenha papel fundamental na produção de alimentos em larga escala, sendo considerada essencial para enfrentar crises alimentares. Este estudo bibliométrico tem como objetivo analisar e apresentar os avanços e aplicações da Biotecnologia no setor do agronegócio, utilizando a produção científica disponível na principal base de dados Web of Science de 2018 a 2023. A Biotecnologia aplicada à agricultura engloba técnicas de engenharia genética para melhorar plantas, animais e microrganismos. Além de contribuir para a segurança alimentar, esta área está alinhada a diversos Objetivos de Desenvolvimento Sustentável da Agenda 2030 das Nações Unidas. Constatou-se que a Biotecnologia é um tema transversal que abrange áreas mais técnicas com uma mescla de tópicos como nanotecnologia, engenharia genética, questões regulatórias, riscos, impactos positivos e negativos, inovação, formas de reprodução de sementes, sustentabilidade e aplicações verdes. Os autores, instituições e países que se destacaram são de: Estados Unidos, China, Índia, Reino Unido, Brasil, Coreia, Polônia, França e Alemanha. Esta pesquisa demonstrou os avanços e aplicações para reduzir riscos negativos, inovações advindas de novas técnicas e os desafios técnicos e legais enfrentados por pesquisadores neste campo de estudo e forneceu *insights* valiosos, contribuindo para o desenvolvimento da Biotecnologia aplicada no agronegócio, promovendo não apenas avanços científicos e tecnológicos, mas também abordando questões sociais e ambientais. Além de demonstrar que as aplicações biotecnológicas no agronegócio abrangem desde melhoramentos genéticos em culturas agrícolas até a criação de materiais biodegradáveis e soluções sustentáveis.

Palavras-chave: biotecnologia verde; agronegócio; avanços da biotecnologia; aplicações da biotecnologia na agricultura; bibliometria

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