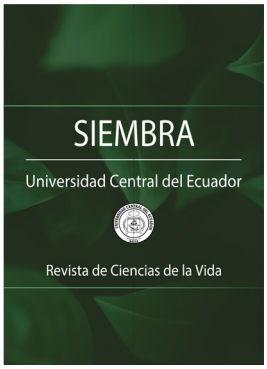
On-farm bioinputs production in Latin American agriculture: Advances and trends



Biopreparados en la agricultura latinoamericana: Avances y tendencias

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Abstract

Due to challenges related to sustainability and environmental protection, artisanal biopreparations, based on natural ingredients and ancestral methods, have emerged as a viable alternative to the use of traditional agrochemicals. This study identified research trends, collaborations and areas of greatest interest using tools such as the Lens® database and Bibliometrix® software. Our results revealed that Brazil is the leader in scientific production of biopesticides, followed by Cuba, Colombia, and Mexico. Also, the most studied bio-preparation is "bokashi", mainly used in vegetable crops. Although most publications are scientific articles, there is a lack of informative material, which hinders the adoption of these products by farmers. The results showed that there is a need to improve dissemination of information and collaboration between researchers and farmers, delaying investments in applied research to accelerate the adoption of sustainable technologies, and maximize benefits of biopreparations in agriculture. The analysis identified gaps in the assessment of the environmental sustainability of biopreparations, providing opportunities for future research.

Keywords: on-farm bioinputs, agriculture, agroecology, microorganisms.

Resumen

Debido a los retos relacionados con la sostenibilidad y la protección del medio ambiente, los biopreparados artesanales, elaborados a partir de ingredientes naturales y métodos ancestrales, han emergido como una alternativa viable al uso de los agroquímicos convencionales. Este estudio identificó las tendencias de investigación, colaboraciones y áreas de mayor interés utilizando herramientas como la base de datos Lens® y el software Bibliometrix®. El análisis de los resultados reveló que Brasil lidera en la producción científica sobre biopreparados, seguido por Cuba, Colombia y México. Asimismo, el biopreparado más estudiado es el «Bokashi", usado principalmente en cultivos de hortalizas. Aunque la mayoría de las publicaciones son artículos científicos, se identificó una escasez de material divulgativo, que dificulta la adopción de estos productos por parte de agricultores. El análisis de la información ob-

tenida demostró que es necesario promover la divulgación y colaboración entre investigadores y agricultores, así como invertir en investigación aplicada para acelerar la adopción de tecnologías sostenibles y maximizar los beneficios de los biopreparados en la agricultura. Además, permitió identificar vacíos en la evaluación de la sostenibilidad ambiental de los biopreparados, lo que abre oportunidades para futuras investigaciones.

Palabras clave: bioinsumo artesanal, agrícola, agroecología, microorganismos.

1. Introduction

Latin American agriculture faces several challenges related to sustainability, environmental protection and food security. Traditional agricultural practices are insufficient and inefficient to address these problems in a sustainable manner. In addition, the demand for a large amount of food production, together with the high cost of chemically synthesized agricultural inputs, creates the need to generate alternatives, allowing farmers to obtain good yields and profitability without polluting the environment, while reducing production costs.

In this context, artisanal biopreparations, defined as "substances and mixtures of plant, animal or mineral origin present in nature that have nutritive properties for plants, or insect repellents and attractants for the prevention and control of pests" (Promoción del Desarrollo Sostenible [IPES] / Food and Agriculture Organization of the United Nations [FAO], 2010), represent a viable and ecological alternative for the management of soil fertilization and control of pests of interest in agricultural crops. These inputs, made from natural ingredients, native microorganisms, natural extracts and ancestral methods, have gained acceptance among farmers due to their ease of preparation, low cost and ability to reduce dependence on synthetic agrochemicals (Pylak et al., 2019).

In the last decade, the development and use of biopreparations in agriculture has increased due to the adoption of sustainable practices. Since the COVID-19 pandemic (year 2020), the production of agroecological inputs by farmers themselves has been key to maintaining production, as trade restrictions limited access to agricultural inputs such as chemical fertilizers (FAO, 2020). The pandemic has mainly affected smallholder farmers, due to increased prices of agricultural inputs and disruption in the supply chain of products such as urea, potassium, ammonia and phosphate, all common in conventional agriculture (Hermann-Bandera et al., 2023). For this reason, biopreparations become an alternative to reduce the effects on the environment caused by the excessive use of chemicals, and at the same time, contribute positively to the quality of crop production. The combined implementation of traditional knowledge and practices with agroecological practices has allowed farmers to improve the health and productivity of their crops (Temegne et al., 2021).

However, the lack of unified information on the preparation, use, dosage, cultivation and quality of biopreparations continues to increase. Therefore, the objective of the present study was to identify the advances and development in the use of artisanal biopreparations in Latin American agriculture through a bibliometric analysis. This study uses information tools to analyze scientific publications on the application of biopreparations in various crops of agricultural interest and their use in Latin America. This systematic analysis made it possible to identify research trends, areas of greatest interest, collaborations between institutions, and the impact of this research on agricultural practice.

2. Materials and Methods

The information search strategy consisted of sequential activities, following the PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analysis*) methodology (Rethlefsen & Page, 2022), which is described in Figure 1. The focus of this study was to characterize and analyze the trends of scientific and academic records available on biopreparations in agriculture, an emerging topic disseminated through academic documents, audiovisual material, and digital platforms, in Latin America over the last 20 years. In order to restrict the review to scientific and academic content, the Lens® database was selected as the search engine. This scientific and technological meta-search engine covers articles, abstracts of events, communications, books and theses, and offers dynamic tools for the management and analysis of academic literature.

Figure 1. Flowchart of information retrieval and systematic analysis. Created using Smartdraw® *software.*

2.1. Design of the search equation and identification of records

A brainstorming exercise was carried out to identify key words related to the topic of interest, defining them in Spanish because the review focuses on the state of the literature in Latin American countries. Additionally, the inclusion and exclusion criteria established in Table 1 were considered.

Table 1. Exclusion and inclusion criteria for information search in the Lens® database

Inclusion or exclusion criteria	Lens® Database
Time period	Not aplicable
Language	All languages
Area of knowledge	Documents focused on agricultural and basic sciences
Key words in	Title
Countries of interest	Mexico, Belize, Costa Rica, El Salvador, Cuba, Guatemala, Honduras, Nicaragua, Panama, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela.

In the construction of the search equations, several text configurations were made, where the search criteria were arranged in groups that were related through a Boolean operator. In this case the "OR" operator, which selects the documents that contain at least one of the specified words (Flórez Martínez et al., 2022). For this research, the equation, elaborated with criteria included (search by sensitivity) and not included (search by specificity) in the agricultural thesaurus, was as follows:

- (biopreparation OR supermagro OR "mountain microorganisms" OR biols OR "organic preparation" OR "microbial* broths" OR "broth of microorganisms" OR biofabrica OR "plant extract" OR "organo-mineral broth" OR "sulfocalcic broth" OR bokashi OR "native microorganisms" OR "artisanal bioinput" OR "potassium soap").

2.2. Screening, suitability assessment and inclusion

The metadata obtained (n = 110) from the Lens® database were analyzed in Excel by creating a separate file.

In this file, key information was extracted from each bibliographic record, including the type of publication, classification, main topic or research objective, focus on biopreparations, sector of use, type and classification of the biopreparation, name of the biopreparation, crop in which it is applied, end user, as well as quality analysis and evaluation parameters (Figure 1). Based on this information, the exclusion criteria were reapplied, considering only those records relevant to the subject of biopreparations in the agricultural sector. Likewise, duplicate records or records that were not available for consultation were excluded. After this process, a total of n = 52 records were identified, specific to biopreparations in agriculture.

2.3. Information analysis

In the bibliometric analysis (phase one) of all registered publications (n = 110), the scientific analysis software Bibliometrix® was used to identify the historical behavior of the publications, the primary sources, the main authors, the countries with the highest scientific production and the main publications. In addition, a diagram of trending topics was generated, which made it possible to evaluate the importance of the topic and its degree of development.

A qualitative and quantitative synthesis and analysis of the selected records (phase two) (n = 52) was also carried out to describe how the information on agricultural biopreparations is covered. First, the distribution of the publication types, work classifications, and biopreparation types and names was determined. Subsequently, the crop where the biopreparations were used and the relationship between the user and the type of publication were analyzed. The quality parameters evaluated in the different studies were also characterized.

3. Results and Discussion

3.1. Phase one: bibliometric analysis

The bibliometric analysis revealed a trend in the publication of documents during the last three decades, including book chapters, scientific articles and a large amount of uncatalogued, or possibly grey literature. It was observed that the number of publications has fluctuated significantly during the period analyzed, showing peaks and troughs reflecting different moments of academic interest or activity on the subject (Figure 2). This analysis showed that, most of the publications were scientific articles (71), with a notable peak in 1998, when 14 articles and one book chapter were published. Between 2005 and 2011, there was a steady increase in uncatalogued papers, peaking in 2010 with six uncatalogued papers and three articles. Whereas 2007 stood out for its high productivity with seven articles and three uncatalogued papers. In recent years the trend has been more stable, with a slight increase in 2019 when two articles and three uncatalogued papers were published. It should be noted that, despite the variability in the number of publications, book chapters have been scarce, with only one publication in 1998.

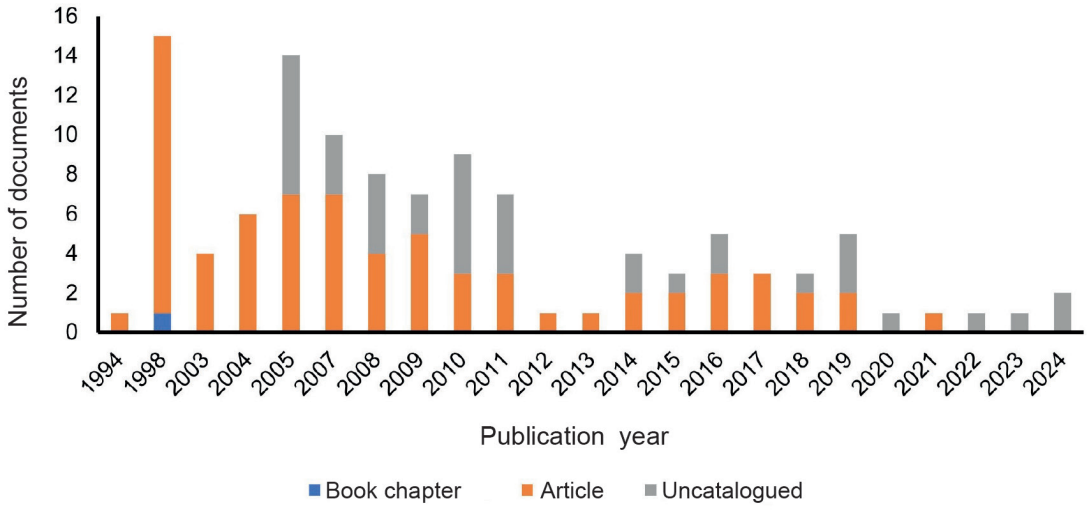

Figure 2. Number of documents published annually.

Of the total number of records obtained through bibliometric analysis, more than 30% of the publications come from Brazil, with a total of 37 documents. Cuba represents 15.25% of the publications with 18 documents, followed by Colombia and Mexico, each with 12.71% and 15 publications. Peru has nine publications, equivalent to 7.63%, and Costa Rica has six publications (5.08%). Less than 5% of the documents come from countries such as Chile and Ecuador, each with four publications (3.39%). Argentina, Bolivia, Paraguay and Venezuela contributed two papers each (1.69%). Finally, Puerto Rico and the United States have one document issued from each country, representing less than 1% of the total number of publications per country of origin. (Figure 3).

Figure 3. Number of publications by country of origin. The flags identified with the green symbol indicate the countries whose publications include biopreparations for agricultural use.

Of the 110 records identified in the database, 71 were classified as scientific articles. The total of these articles were published in 64 different Latin American scientific journals. As described in Table 2, Terra Latinoamericana is the journal with the largest number of articles focused on this topic with three published articles (3/71; 4.22%). Within the top 10 journals, only five journals have published two articles with interest in biopreparations, while the remaining journals have published only one article (3/71; 4.22%).

This bibliometric indicator suggests that scientific production on the subject of biopreparations does not belong only to one field of study, and agrees with the research areas identified through the bibliometric analysis. These correspond to agronomy (44.5%), which involves topics focused on the development of agricultural inputs such as biofertilizers and agricultural practices such as composting; biological sciences (37%), which includes topics in the areas of microbiology, genetics and ecology; and finally chemistry (17%), where topics such as mineralization and production processes are identified (Figure 4).

Table 2. Journals with the highest number of articles with interest in biopreparations for agricultural use.

Top	Journal title	Number of articles	Indexed database	SJR	SJR Best Quartile	Country
1	*Revista Terra Latinoamericana*	3	Latindex Doaj Scopus	0,3	Q4	México
2	*Acta Scientiarum - Agronomy*	2	Latindex Doaj Scopus	0,34	Q2	Brasil
3	*Pastos y Forrajes*	2	Latindex Doaj Scopus	0,27	Q3	Colombia
4	*Revista de Agricultura Neotropical*	2	Latindex	0,16	Q4	Brasil
5	*Revista Cubana de Química*	2	Latindex	No clasificada		Cuba
6	*Steviana*	2	Latindex	No clasificada		Paraguay

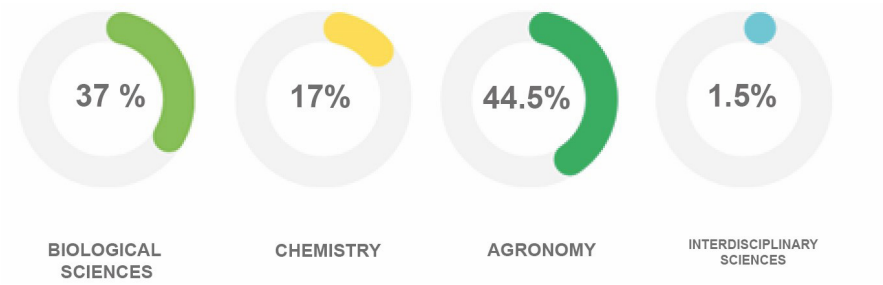

Figure 4. Classification of publications (n=110) by field of study.

The article with the highest number of citations (37) was *"Bokashi as an Amendment and Source of Nitrogen in Sustainable Agricultural Systems: a Review*" by Quiroz and Céspedes (2019), and was published in the *Journal of Soil Science and Plant Nutrition*. Second "*Net mineralization nitrogen and soil chemical changes with application of organic wastes with 'Fermented Bokashi Compost*" of Boechat et al. (2013), published in *Acta Scientiarum* with 32 citations. Jaramillo-López et al.'s (2015) article, titled "*Impacts of Bokashi on Survival and Growth Rates of Pinus pseudostrobus in Community Reforestation Projects*", had the third highest number of citations (18). In the top five articles with the highest number of citations, it was identified that the interest is focused on the amendment called Bokashi, which is a type of fertilizer that has a high content of organic matter and nutrients necessary for plants, and has high porosity and a high water retention capacity (Quiroz & Céspedes, 2019).

3.2. Phase 2: Qualitative synthesis of selected information

Of the 52 records (n = 52) selected in Phase 2, a classification was made by type of biopreparation, name of biopreparation, crop on which it was evaluated, and the subject of the study. For this last parameter, the records were classified into: biological activity in the field, biological activity in the greenhouse, production process, quality of biopreparations, among others (Table 3).

The systematic review of scientific literature revealed an increase in the number of records published over time, showing a productivity peaks in 2019 and 2023 (Figure 5). The vast majority of documents correspond to articles published in scientific journals and, in smaller proportion, undergraduate theses (2020), conference abstracts (2019) and scientific notes (2016) were found. This demonstrates the importance that the production and evaluation of biopreparations is having in Latin America. with a scientific, academic and institutional approach. However, the development of this study also highlighted an important limitation: scientific information on the subject is dispersed, which makes it difficult to access and systematize, as pointed out by Sánchez-Llevat et al. (2022). The results found are also an indication of the increase in the use of biopreparations, as indicated by Azizbekyan (2019).

Table 3. Bibliographic records (n=52) selected for their specificity in biopreparations for agricultural use.

Country	Subject	Type of biopreparation	Name of biopreparation	Crop (if applicable)	References
Cuba	Biological activity	Biological	Efficient microorganisms	Common bean	Cueto Yglesias & Mesa Reinaldo (2018).
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	*Beta vulgaris*	Silva et al. (2018)
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	*Mentha suaveolens*	Moreira da Silva et al. (2023).
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	Corn (*Zea mays)*	Baldotto, & Baldotto (2016)
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	*Origanum vulgareL*	Wenneck et al. (2023)
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	Not applicable	Boechat et al. (2013).
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	*Pereskia aculeata* Plum.	Milene Silverio et al. (2021)
Mexico	Bioremediation	Biological	Microbial broth	*Erythrina americana*	Mendoza Sánchez et al. (2017)
Cuba	Biological activity	Biological	EM broth (efficient microorganism)	*Daucus carota*, L	Núñez Sosa et al. (2017)
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	*Brassica oleracea* var. *Capitata*	Xavier et al. (2019).
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	*Alibertia edulis*	Santos et al. (2019b)
Mexico	Biological activity	Mixed biological -Mineral	Bokashi	*Pinus pseudostrobus*	Jaramillo-López et al. (2015).
Cuba	Biological activity	Mineral	Biobrás16	Rice (*Oryza sativa*)	Morejón (2004).
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	Tomate (*Solanum lycopersicum*)	da Costa et al. (2013)
Argentina	Public policy	Not applicable	Not applicable	Not applicable	Ferraris et al. (2021)
Brazil	Waste utilization	Mixed biological -Mineral	Bokashi	*Copaifera langsdorffii*	Boechat et al. (2020)
Peru	Selection of microorganisms	Biological	*Trichoderma*	Potato	Mamani-Rojas et al. (2012)
Brazil	Bioremediation	Mixed biological -Mineral	Mountain microorganisms	Bell pepper	Paredes Pita et al. (2024)
Mexico	Biopreparation production	Mixed biological -Mineral	Not applicable	Not applicable	Rojas-Espinoza et al. (2023)
Colombia	Biological activity	Mineral	Not applicable	Coffee	Cabrera Marulanda et al. (2018)
Mexico	Biological activity	Biological	Not applicable	Chick pea	Oliva-Ortiz et al. (2017)
Mexico	Act large-scale production	Organic	Not applicable	Chile	Huez-Lopez et al. (2008)
Costa Rica	Biological activity	Organic	Bokashi	Plantain	Cerrato et al. (2007)
Cuba	Biopreparation production	Mixed biological -Mineral	FerKiASerT and *Trichoderma harzianum* A-34	Caupí bean	Hernández-García et al. (2020)
Cuba	Field biological activity	Biological	Native microorganisms (*Brevibacillus borstelensis*)	Long bean	Bayard-Vedey y Orberá-Ratón (2020)
Brazil	Biological activity	Organic	Bokashi	*Alibertia edulis*	Santos et al. (2020)

Country	Subject	Type of biopreparation	Name of biopreparation	Crop (if applicable)	References
Cuba	Waste utilization	Biological	Efficient microorganisms	Not applicable	Liriano González et al. (2018)
Brazil	Biopreparation production	Mixed biological -Mineral	Supermagro	Passion fruit	Rodrigues et al. (2009)
Brazil	Biological evaluation under field conditions	Organic	Bokashi	Pink pepper (*Campomanesia adamantium*)	Santos et al. (2019a)
Brazil	Biopreparation production	Biological	Supermagro EM broth	Ornamental plant *Gladiolus* sp.	Hermann-Bandera et al. (2023)
Brazil	Field biological activity	Mixed biological -Mineral	Bokashi	Not applicable	Scotton et al. (2017)
Ecuador	Greenhouse production and evaluation of biopreparations	Biological	Biol artisanal	Cocoa *(Theobroma cacao* L)	Vera Chang & Salazar Pacheco (2021)
Bolivia	Biopreparation production and use	Mixed biological -Mineral	Bokashi	*Atriplex hortensi*	Chambi Zubieta et al. (2019)
Ecuador	Biological activity	Mixed biological -Mineral	Bokashi Organic fertilizer	Not applicable	Pincay-Cantos et al. (2023)
Costa Rica	Biological activity	Mixed biological -Mineral	Bokashi	Not applicable	Leblanc et al. (2005)
Colombia	Biological activity	Mixed biological -Mineral	Supermagro	Water melon (*Citrullus lanatus*)	González et al. (2015)
Brazil	Biopreparation production	Mixed biological -Mineral	Bokashi	Non applicable	Lopes Pereira et al. (2022)
Chile	Field evaluation	Mixed biological -Mineral	Compost Bokashi Efficient microorganisms	Broccoli *Brassica oleracea* var. *italica*	Peralta-Antonio et al. (2019)
Argentina	Biopreparation production and evaluation	Organic	Nettle slurry	Lettuce (*Lactuca sativa*)	Chimento et al. (2019)
Chile	Bio activity	Mixed biological -Mineral	Bokashi	Not applicable	Quiroz & Céspedes (2019)
Chile	Biological activity	Mixed biological -Mineral	Worm-compost tea	Lettuce (*Lactuca sativa*)	Bonillo et al. (2015).
Brazil	Biological activity	Mixed biological -Mineral	Bokashi	Cucumber (*Cucumis sativus*)	Santos et al. (2021)
Chile	Biological activity	Mixed biological -Mineral	Bokashi Phosphoric rock	Parsley (*Petroselinum crispum*)	Maass et al. (2020).
Chile	Biological activity	Mixed biological -Mineral	Bokashi	Radish (*Raphanus sativus*)	Quiroz & Flores (2019).
Mexico	Biological activity	Biological	Native microorganisms Compost	Quinua (*Chenopodium quinoa*)	Galecio-Julca et al. (2023)
Cuba	Biological activity	Biological	Native microorganisms	Onion	Castellanos González et al. (2018).
Colombia	Biological activity	Mixed biological -Mineral	Bokashi	Lettuce	Lima et al. (2022)
Mexico	Bioremediation	Biological	Microorganisms	Not applicable	Juárez Lucas et al. (2021)
Mexico	Biological activity	Mixed biological -Mineral	Bokashi	Tomato	López Tolentino et al. (2023)

Country	Subject	Type of biopreparation	Name of biopreparation	Crop (if applicable)	References
Brazil	Biological activity	Mixed biological -Mineral	Supermagro	Passion fruit	Cavalcante et al. (2011)
Ecuador	Biological activity	Mixed biological -Mineral	Not applicable	Not applicable	Orellana et al. (2013)
Brazil	Biological activity	Mixed biological -Mineral	Supermagro	Not applicable	Ruiz et al. (2016)

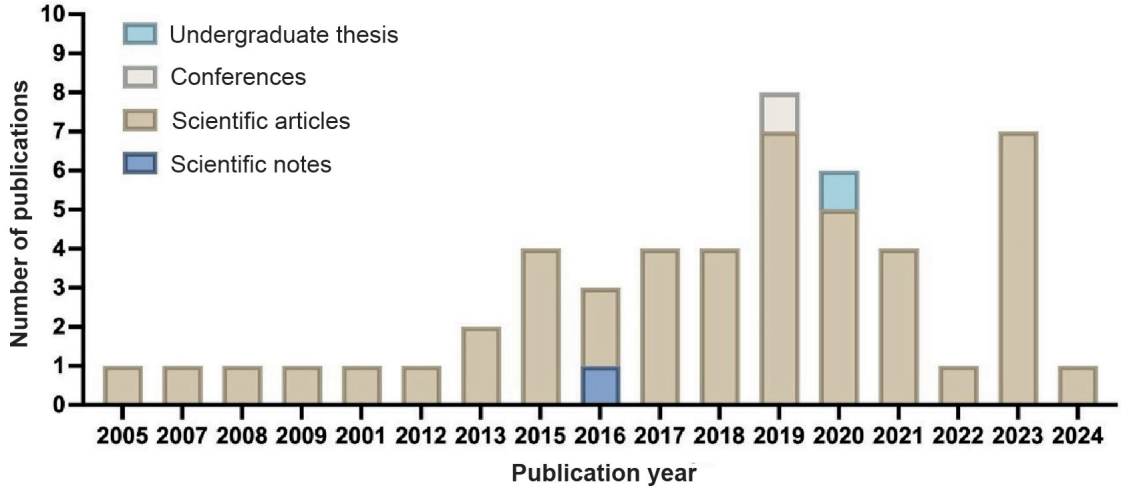

Figure 5. Annual distribution of records obtained through the systematic information review process.

According to the classification of biopreparations, it is evident that, scientific articles predominate over other types of publications such as scientific notes, undergraduate theses, conference proceedings and informative articles (Figure 6). Regarding preparations with inoculant activity, 21 scientific articles were reviewed compared to one informative article; and 38 scientific articles on biopreparations with the capacity to promote plant growth. Biopreparations with biocontrol purposes (four scientific articles) and biofertilizers (21 scientific articles, four scientific notes and undergraduate theses) were those with the lowest number of publications in this regard.

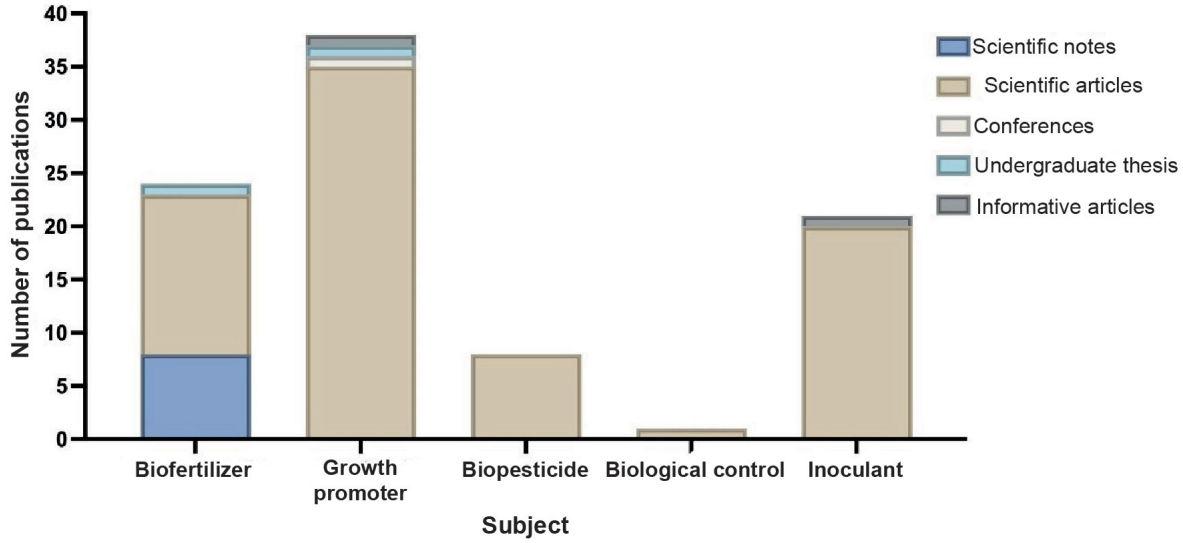

Figure 6. Documentary typology with respect to the classification of biopreparations in Latin America.

The literature on biopreparations is characterized by a predominance of scientific articles, which reflects the progress and rigor of research in this field, mainly in Latin America. This trend offers solid and validated knowledge on the development and performance of biopreparations, generating confidence about their efficacy and safety. However, the scarcity of informative material limits access to information for farmers and the general public, making it difficult for them to understand and adopt these preparations.

To address this challenge, it is proposed to encourage the publication, such as those mentioned above (scientific notes, undergraduate theses and informative articles) and others that are more accessible to producers, such as videos, manuals and primers. Additionally, it is imperative to promote collaboration between researchers, extensionists and farmers in order to translate scientific knowledge into practical solutions for crop management with the application of biopreparations.

Finally, the need to invest in applied research and development of biopreparations is highlighted. This would accelerate the adoption of these sustainable technologies, and bring concrete benefits to farmers and consumers. The synergy between research, dissemination and practical application is essential for biopreparations to reach their full potential in sustainable agriculture

The present bibliometric analysis shows the number of publications related to different types of biopreparations in Latin America. Other biopreparations, such as "Compost", "Phytomass E", "Supermagro" and "EM microbial broth" have a significant number of publications, although considerably fewer than Bokashi.

The least studied biopreparations, with only one or two publications, include "Biol artesanal", "Sulfocalcium broth", "*Trichoderma sp*. ", "Vegetable extract", "FerKIA SerT", "*Brevibacillus borstelensis*", 'P1', "Nettle slurry", "Compost tea", "Biobras 16", "Mountain microorganisms", "Organic residues", "Organo-mineral fertilizer natura (FOMIN)", "Humic acids", "*Bacillus sp*. ", 'P2', "Albio Root", "Active sludge", "Worm-compost tea" and "Amino acids by enzymatic hydrolysis" (Figure 7). This analysis suggests a preference or greater research on some specific biopreparations, such as Bokashi, over others within the Latin American scientific community.

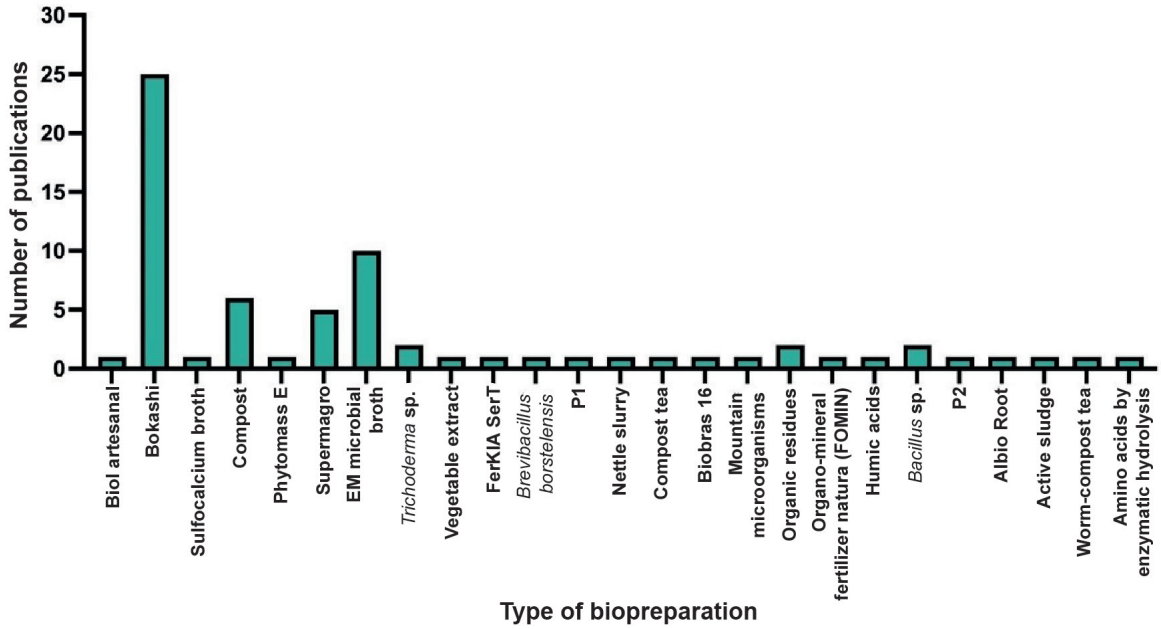

Figure 7. Distribution of publications by type of on-farm bioproducts.

The analysis showed that biopreparations are mainly used in vegetable crops (54%), representing more than half the total. Fruit trees and transitional crops are also significant applications, accounting for 29% of the total publications analyzed. Aromatic and forestry crops have a moderate use (5%), while cocoa, flowers, and tubers have a lesser use.

Furthermore, it was found that 96% of the consulted documents corresponded to research topics in academic and institutional contexts. The others were review records (two documents) in the form of scientific articles focused on themes such as nutrient enrichment, crop yield and characteristics, the sequential preparation of the biopreparation, and its dosage in cultivated soil.

Regarding the scientific literature on the quality control of biopreparations, the evaluated parameters that were evaluated were classified into 12 (Figure 8). Most of the observed variables corresponded to the study of biological activity (71.6%), concerning the characteristics of the plants obtained, crop productivity, and soil improvement. The parameter with the highest number of contributions falls within the category of biological activity, directed at the physiological and phenological development of the plants obtained in the crops where biopreparations were used (35 records), followed by the evaluation of photochemical development (seven records) and the chemical composition of the biopreparation (six records).

As shown in Figure 8, the technical parameters specific to the quality control of the biopreparation (chemical composition, physical parameters, and microbiological composition, in that order) were presented in a smaller proportion (21%) compared to those of biological activity. This result demonstrates the low characterization carried out on this type of products, given the artisanal nature of their production. It was also found that the evaluation of environmental variables and technical-economic feasibility represents 7.4% of the total records analyzed. The scarcity of research on these topics is likely attributable to the accessibility of the materials and their inherent properties. This suggests that the products in question are environmentally friendly and have low production costs. No studies were found relating to environmental sustainability, such as life cycle assessments or carbon footprint measurements in the manufacturing process or the use of biopreparations. However, the generation of contributions on these topics would confer a competitive advantage at the academic and institutional level, primarily for the purpose of verifying the reduction of environmental impact during production and implementation.

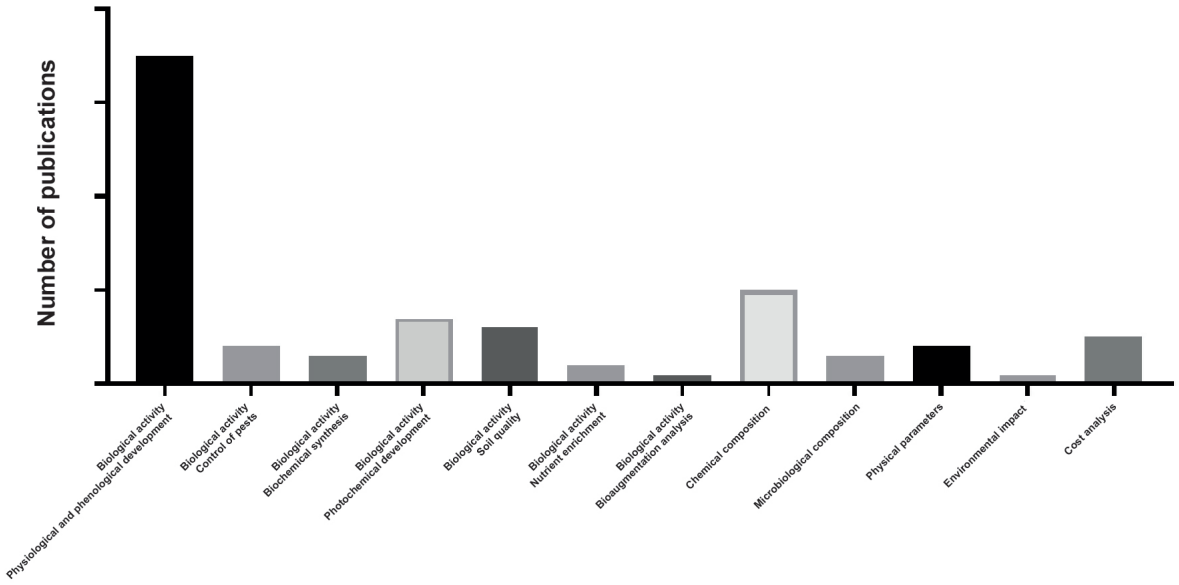

Figure 8. Thematic distribution of scientific information related to agricultural biopreparations.

The thematic distribution map allows for the categorization of the main research topics into two dimensions. The relative importance of each topic in the research field is established by the first dimension, relevance (degree of centrality), while the second dimension (degree of density) establishes the progress and breadth of knowledge generated in the research field. The four analysis quadrants are the result of the interaction of these two dimensions and are classified as follows: i) Driving topics; ii) Basic and transversal topics; iii) Emerging or declining topics; and iv) Niche or specialized topics.

Based on the analysis of the distribution or cluster map (Figure 9), the quadrants of the Cartesian plane represent the evolution and development of the analyzed topics. Topics with a higher degree of relevance (vertical axis), where there is a greater number of bibliographic references, are associated with the influence of fermentation on fertilizer, followed by publications related to biorefineries, although with a smaller number of publications. Regarding the advancement in generated knowledge, bokashi organic fertilizer is represented by a significant number of publications, although the number of publications associated with the effect of bokashi

with algae of the genus *Tetraselmis* and processed nutrients.

Topics with greater relevance and development found in the *Motor Themes* quadrant correspond to the application of native microorganisms, bokashi organic fertilizer, document management of bioprepared products, and the influence of fermentation on fertilizer. Relevant topics with stability in the generation of publications, located in the *Basic and Cross-cutting Themes* quadrant, are mainly found in publications related to Supermagro, potassium biofertilizers, and plant extracts. Regarding topics with a high degree of research development, but whose relevance in the research field is still not high, located in the *Niche Topics* quadrant, are the publications related to the production of cover crops for fertilization (cobertura adubação produção). In this same category, and in transition from topics with low relevance and development, are publications related to the effect of bokashi with algae of the genus *Tetraselmis*. As for topics with low relevance and development, but with the potential to become basic or transversal topics, located in the Emerging or Declining Topics quadrant, with a small number of publications, are those topics related to soil, doses, nutrients produced, and biofactories.

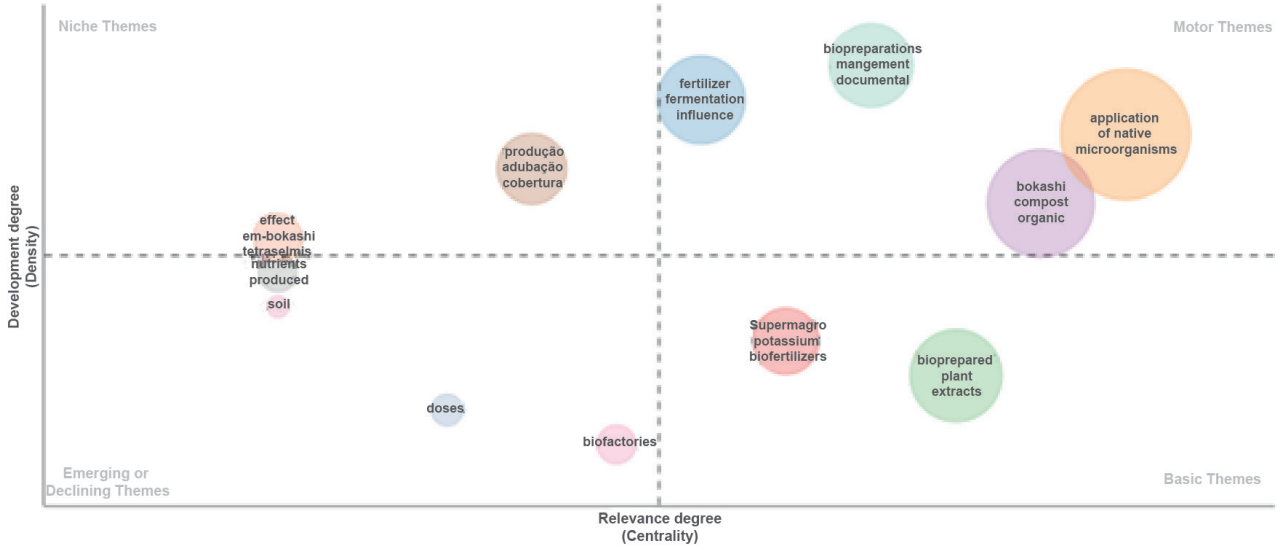

Figure 9. Thematic map of topic distribution. Elaborated from the Lens database. Date of consultation 30 August 2024. Elaborated in Bibliometrix 4.1.1 processing software.

4. Conclusions

The bibliometric analysis indicated a growing interest in artisanal biopreparations in agriculture in Latin America. Brazil leads the scientific production on this topic, followed by Cuba, Colombia and Mexico. There has been an upward trend in the number of publications on this topic was observed in the last decades, being remarkable in 2019. The most studied biopreparation was "Bokashi", mainly used in vegetable crops, suggesting its potential as a sustainable alternative to traditional agrochemicals.

Most of the publications found consisted of scientific articles, indicating a rigorous approach to biopreparations research. However, a scarcity of informative material was identified, possibly hindering the adoption of these practices by farmers. This gap between scientific research and practical application points to the need for improved knowledge transfer and collaboration between researchers, extensionists and farmers.

Most of the studies focused on evaluating the biological activity of biopreparations, particularly their impact on the physiological and phenological development of plants. However, a lack of research was detected in aspects such as environmental impact, life cycle assessment and carbon footprint measurement in the production and use of biopreparations. These areas represent an important opportunity for future research, which could strengthen the adoption of biopreparations as a sustainable alternative in Latin American agriculture.

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Contributor roles

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- Liz Alejandra Uribe-Gutiérrez: data curation, formal analysis, methodology, visualization, writing - original draft, writing - revision & editing.
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- Mauricio Camelo-Rusinque: data curation, formal analysis, methodology, visualization, writing - original draft, writing - revision & editing.
- Erika Patricia Martínez-Lemus: data curation, formal analysis, methodology, visualization, writing - original draft, writing - revision & editing.
- María Victoria Zuluaga: visualization, writing - original draft, writing - review & editing.

Ethical Implications

Ethics approval not applicable.

Conflicts of Interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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