Biotechnology Research and Innovation, 2025, 9(2): e2025006. https://doi.org/10.4322/biori.00062025

SBBiotec
SOCIEDADE BRASILEIRA DE BIOTECNOLOGIA

Biotechnology
Research & Innovation
www.biori.periodikos.com.br

REVIEW ARTICLE

Unveiling the role of xanthan gum in agriculture: a scientometric exploration of its progress and sustainable potential

Deborah Lizama Boettcher[a], Débora Bohrer de Lima[a], Andreia Anschau[a], Paula Fernandes Montanher[a], Débora Gonçalves Bortolini[a,b,*], Patricia Manuitt-Brito[a], Nédia de Castilhos Ghisi[a], Gustavo Henrique Couto[b], Maria Giovana Binder Pagnoncelli[b]

[a]Postgraduate Program in Biotechnology, Universidade Tecnológica Federal do Paraná – UTFPR, Rodovia da Boa Esperança, km 04, P.O. Box 157, Zip Code 85660-000, Dois Vizinhos, PR, Brazil
[b]Postgraduate Program in Biotechnology, Department of Chemistry and Biology, Universidade Tecnológica Federal do Paraná – UTFPR, Rua Deputado Heitor alencar Furtado, 5000, Zip Code 81280-340, Curitiba, PR, Brazil

HIGHLIGHTS

- Xanthan gum emerges as a sustainable alternative to synthetic agrochemicals
- Scientometric analysis reveals rising interest in xanthan gum applications
- Brazil, China, and India lead research on xanthan gum in agriculture
- Keyword trends shift from production to sustainable agricultural uses
- Agro-waste-based xanthan gum supports eco-friendly farming solutions

Received 11 July, 2025; Accepted 07 October, 2025.

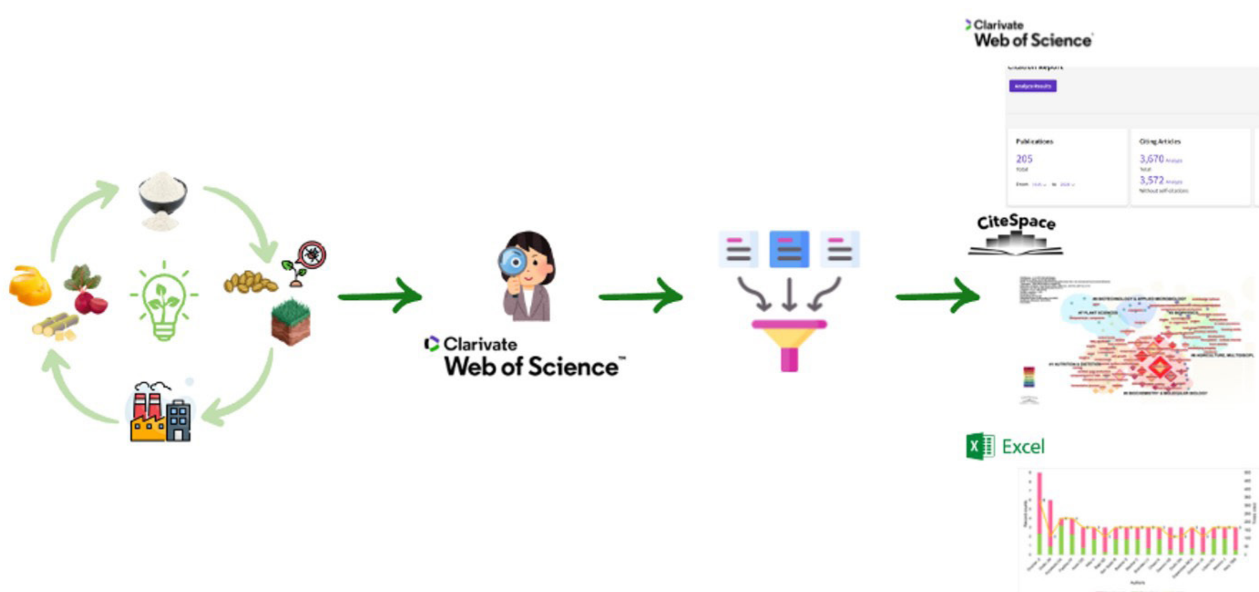
KEYWORDS
Xanthomonas campestris;
Biopolymer;
Agro-industrial waste;
Agricultural efficiency.

Abstract: Agricultural intensification has led to severe environmental impacts, including soil degradation, biodiversity loss, water pollution, and increased greenhouse gas emissions. The intensive use of agrochemicals contributed to a significant ecological imbalance, which encouraged the search for natural and more environmentally safe alternatives. Synthetic compounds, including polymers used in agriculture, are widely applied as physical and chemical modifiers. They acted by improving moisture retention, controlling the release of nutrients, and enhancing the adherence of pesticides to plants. However, these compounds posed environmental challenges. In this context, the transition to natural alternatives becomes essential, A promising option is xanthan gum, a microbial polysaccharide produced by *Xanthomonas* spp., which improves the flowability of fertilizers and pesticides, increases soil water retention, optimizes seed coating, and contributes to the biological control of pests. Its production from agro-industrial residues reduces environmental impacts and promotes the reuse of by-products. This study conducted a scientometric analysis to investigate the potential of xanthan gum derived from agro-industrial waste in agriculture. Documents were selected based on specific inclusion criteria: only studies addressing xanthan gum in agriculture and sustainability, including its production from agro-industrial residues or its environmental impact, were considered.

*Corresponding author.
E-mail: debortolini@gmail.com (D. G. Bortolini).

A double review by the authors ensured the accuracy of the selection. Data was collected from the Web of Science™ database tableusing combinations of keywords related to xanthan gum, sustainability, and agro-industrial waste. Publications from 1995 to 2024, comprising a total of 193 papers, were analyzed to provide a comprehensive overview of the research evolution and the significant expansion in studies on xanthan gum and sustainability in agriculture, spanning nearly three decades. CiteSpace and Microsoft Excel software were used to map trends, authors, and countries that are most productive in the field. Additionally, a complementary patent search was conducted in the Derwent Innovations Index using the keywords *xanthan gum* and *agriculture*. After applying refinement and exclusion criteria, 447 patents were selected and analyzed according to year, country, and application area of xanthan gum. The results indicate significant growth in research on agricultural applications of xanthan gum, with notable contributions from Brazil, China, and India. Keyword analysis reveal an evolution in the research focus from production optimization to sustainable applications, such as water recovery and waste utilization. The findings highlight xanthan gum as a viable alternative for making agriculture more productive and sustainable, standing out as an innovative biopolymer for the sector's future. This growing scientific interest is also reflecte in technological innovations, with China leading the way and other countries presenting complementary profiles tailored to their specific agricultural needs.

Graphical Abstract



Introduction

Global population growth continues to challenge food security, necessitating advancements in agricultural productivity to meet the growing demand for food. The Malthusian Theory, developed in the late 18th century, warned of a potential imbalance between population growth and food production. However, technological innovations have revolutionized agriculture, enabling a significant increase in crop yields and mitigating many of the challenges anticipated by Malthus (Veshapidze et al., 2022). Currently, the global population exceeds 8 billion, with projections indicating it will reach 8.5 billion by 2030 and 9.7 billion by 2050 (United Nations, 2022). Simultaneously, global primary crop production reached 9.9 billion tonnes in 2023, representing a 28% increase since 2010, primarily driven by growth in cereal production (Food and Agriculture Organization, 2023). However, while agricultural production is sufficient to meet food demand, challenges such as distribution inequalities, economic access, and food waste hinder food security. Estimates indicate that 13.2% of food is lost postharvest before reaching retail markets, while 19% is wasted across various stages of the consumption chain (Roser et al., 2023).

Beyond concerns over food waste, intensive agricultural practices also raise environmental issues. Excessive use of synthetic inputs, such as fertilizers, pesticides, and synthetic polymers, can degrade soil fertility and negatively impact underground biodiversity, which is essential for maintaining ecological balance (Sofo et al., 2020). The significant decline in pollinators, particularly bees, due to habitat destruction and improper use of agrochemicals poses a serious risk to agricultural yields and ecological balance (Nicholson et al., 2024; Willis Chan et al., 2019).

Synthetic polymers play a crucial role in agriculture by modifying physical and chemical properties to enhance soil moisture retention, regulate nutrient release, and improve pesticide adhesion to crops. However, their limited biodegradability and potential for ecosystem contamination pose environmental concerns. As a result, there is an increasing demand for sustainable alternatives that maintain agricultural effectiveness while reducing ecological harm (Mansoor et al., 2022).

Therefore, the advancement of agricultural efficiency increasingly depends on incorporating novel high-performance materials capable of modifying the physicochemical properties of soil, water, fertilizers, and plant protection agents (Berninger et al., 2021). Natural polysaccharides encompass a wide array of biopolymers sourced from renewable origins, including terrestrial plants (e.g., pectin, guar gum), microbial fermentation (e.g., xanthan gum), marine algae (e.g., alginate and carrageenan), and animal-derived sources (e.g., chitosan and gelatin) that offer a sustainable alternative to synthetic polymers (Nobre et al., 2015). Their potential to enhance both sustainability and crop productivity lies in their inherent biodegradability, which reduces environmental impact and aligns with eco-efficient agricultural practices (Berninger et al., 2021; Hassanisaadi et al., 2023; Vandermeulen et al., 2022). Xanthan gum, a microbial polysaccharide produced by *Xanthomonas* spp. It stands out through aerobic fermentation for its unique properties. This high-molecular-weight biopolymer, with a white or light-yellow powder appearance, exhibits pseudoplastic behavior as a non-Newtonian fluid, and is biocompatible, biodegradable, thermally stable, water-soluble, and non-toxic (Nasrabadi et al., 2016).

Due to these characteristics, xanthan gum has numerous applications in the cosmetics, food, pharmaceutical, and petrochemical industries (Bhat et al., 2022). Agriculture improves the fluidity of fertilizers and pesticides, ensuring uniform distribution of components (Zhang et al., 2023, 2024). Its rheological properties increase the adhesion of pesticides to crops (Rosalam & England, 2006) and improve water retention and soil characteristics (Sorze et al., 2023). Furthermore, xanthan gum effectively controls pests and diseases by encapsulating biological control microorganisms (NanGong et al., 2021) and in seed coating, optimizing their development (Vijayalakshmi et al., 2024). Given the growing interest in sustainable agricultural solutions, producing xanthan gum from agro-industrial waste is an interesting alternative. These residues, such as sugarcane bagasse, cornstarch, whey, and vegetable leftovers, are low-cost carbon and nitrogen sources but have a high organic load and can cause environmental impacts when improperly disposed of Wani et al. (2021). Therefore, using these materials as a substrate for xanthan gum fermentation contributes to the sustainability of agriculture and represents a way of reusing these residues (Santos et al., 2016).

Despite growing interest in agricultural applications of xanthan gum, comprehensive reviews on its sustainable production and practical benefits in agriculture remain limited. The scientometric analysis is invaluable for systematically assessing research trends and knowledge gaps within the scientific community, thereby effectively guiding future investigations. To address this gap, a scientometric study of 193 publications from the Web of Science™ (1995-2024) was conducted, with documents selected based on inclusion criteria targeting studies on xanthan gum in agriculture and sustainability, including its production from agro-industrial waste or its environmental impact. A double review by the authors ensured the accuracy of the selection. This analysis presents an in-depth study to elucidate global research trends, identify prominent knowledge gaps, and highlight the potential of xanthan gum in agriculture, as well as its production from agro-industrial waste. Additionally, its impact on the efficiency of agricultural inputs and the sector's sustainability is examined. Based on data from publications, institutions, international cooperation, and keywords, the study highlights the relevance of xanthan gum as a promising biopolymer in promoting sustainable agricultural practices. Complementarily, a patent study of 447 documents (1995-2024) was conducted, providing a broader insight into technological developments and innovations that support the increasing importance of xanthan gum in agricultural applications. This insight reveals how scientific information has been transformed into technological solutions, products, and procedures, positioning xanthan gum as a sustainable alternative in agricultural systems.

Data acquisition and methods

Searches were conducted in the Clarivate Analytics – Web of Science™ database to ensure a comprehensive review of all documents related to the topic. The following keywords and Booleans were used for the search: TS = (xanthan gum AND (agriculture OR cultivation) AND pesticide AND emulsion AND formulation), AND TS = (xanthan gum AND (agriculture OR cultivation) AND (seed coating OR seed encapsulation) AND germination).

Documents were selected based on specific criteria, with only those addressing xanthan gum in agriculture and sustainability included, whether through agro-industrial waste or its environmental implications. A double review by the authors was carried out to ensure this selection. One hundred ninety-three documents were selected for analysis, with publications ranging from 1995 to 2024. The sequence for obtaining and selecting the documents is detailed in Figure 1.

After refinement, the data were exported from WoS and analyzed using CiteSpace and Microsoft Excel software, which enabled the extraction and evaluation of the results presented in figures. Microsoft Excel® was used to generate graphs that examine the evolution of publications and citations over time, identify trends, and show the H-index, an indicator of impact and author productivity.

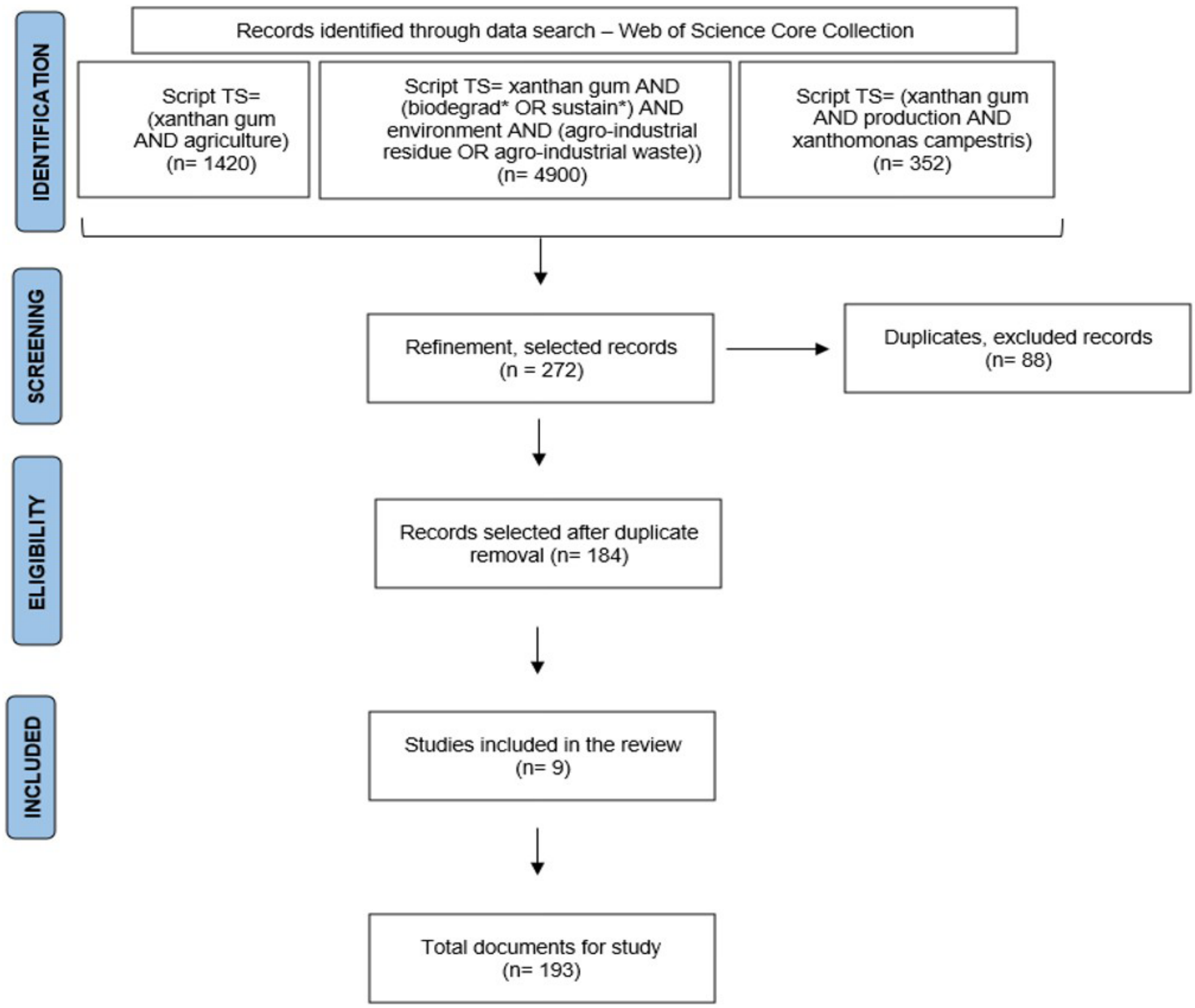


Figure 1. Data acquisition flow for scientometric analysis.
Note: A new search carried out during the searching process resulted in new 9 papers, which were included in scientometric study.

CiteSpace® is a scientific visualization software that generates network maps to analyze cocitation and co-occurrence patterns between authors, institutions, countries, keywords, and references, organizing them into thematic clusters (Chen, 2006; Xie, 2015). The generation of maps in CiteSpace® was made possible by setting criteria for selecting the data needed to form the citation and co-occurrence networks, as shown in Table 1. The selection criteria utilize global structural indicators, such as Modularity (Q) and Silhouette (S), to assess the strength of a network's division into clusters and the quality of clustering. High Q values indicate a strong internal connection within clusters and a limited number of connections between them, demonstrating well-defined groupings (Chen, 2016). The S coefficient (-1 to 1) measures the similarity of nodes within a cluster. Values close to 1 indicate well-defined clusters, values near 0 suggest items at the border, and negative values indicate incorrect allocation. However, S is only consistent if the clusters have similar sizes, ensuring homogeneity in the analysis (Chen, 2016).

When evaluated together, these structural indicators demonstrate good consistency in clustering, and their correlation confirms the robustness of the analysis. However, Q and S may be sensitive to the selection criteria configurations, which influence the amount of data processed in the free version of the software and are crucial for the evaluation.

Patent search and analysis

Additionally, a complementary patent search was carried out in the Web of Science™ Derwent Innovations Index. The keywords used were *xanthan gum AND agriculture*, which initially retrieved 512 patent documents. To refine the results, these keywords were combined with the International Patent Classification (IPC), as detailed in Table 2.

The time interval considered was from 1995 up to the end of 2024. After a double review by the authors, 447 patents were selected and analyzed using Microsoft Excel®. The inclusion criteria were the same as those applied in the scientometric study. In contrast, the exclusion criteria comprised duplicate records, patents without a main IPC, and those not addressing the application of xanthan gum in the development of the described technology. Furthermore, specific keywords were applied to ensure the inclusion of patents covering both the direct use of xanthan gum in agricultural technologies and its role in preparatory stages for obtaining such applications (Table 3).

Table 1. Selection Criteria and Global Network Structural Indicators.

Graphical Representation	Time Slice Length	Selection Criteria				Network Structural Indicators		
		Top N[1]	LRF[2]	L/N[3]	LBY[4]	Q[5]	S[6]	Harmonic Mean (Q, S)
Countries - Figure 5	1995-2024 (1 year)	50	2.5	10	5	0.5903	0.874	0.7047
Authors - Figure 7	1995-2024 (12 years)	10	2.5	10	5	0.9528	1	0.9758
Keyword clusters - Figure 8	1995-2024 (5 years)	10%*	2.5	10	5	0.7092	0.8845	0.7872
Citation bursts - Figure 9	1995-2024 (5 years)	15	2.5	10	5	0.8342	0.9682	0.8962
Keyword timeline - Figure 10	1995-2024 (5 years)	15	2.5	10	5	0.8342	0.9682	0.8962

[1]Levels of the most cited or most frequent items in each time slice (where *, represents the percentage of the most cited and frequent items, with a maximum of 100 items selected per slice); [2]Link Retention Factor; [3]Maximum number of links per node; [4]Look Back Years; [5]Modularity; [6]Silhouette.

Table 2. IPC codes, descriptions, and number of retrieved and included documents (1995-2024).

IPC	Description	Documents Retrieved	Documents Included
A01N	Compositions for protecting plants or controlling harmful organisms, utilizing substances that are not primarily pharmaceutical or cosmetic	338	316
A01P	Compositions with biocidal, pest-repellent, pest-attractant, or plant growth regulatory activity.	253	235
A01C	Planting, sowing, and fertilizing; include methods and apparatus for treating seeds, roots, or similar materials before sowing or planting.	15	13
A01G	Horticulture: cultivation of vegetables, flowers, rice, fruit, vines, hops, or seaweed; forestry; watering.	37	32
C08B	Polysaccharides; derivatives thereof; includes processes of extraction, preparation, derivatization, fractionation, isolation, purification, or degradation.	7	5
C08L	Compositions of macromolecular compounds; includes compositions of polymers.	36	29
C01G	Compounds containing metals; includes compounds of metals such as copper, mercury, and others.	7	7
C09K	Materials for miscellaneous applications not provided elsewhere; includes materials for applications such as sealing, drilling fluids, and others.	24	19
C05G	Fertilizers; includes specific types of fertilizers.	63	61
C05F	Fertilizers; includes specific types of fertilizers.	24	24
C12N	Microorganisms or enzymes include genetically modified microorganisms.	23	15
C12P	Preparations of substances of microorganisms; includes preparations of substances produced by microorganisms.	9	5

Table 3. Application axes of xanthan gum in agriculture and main associated functions/keywords.

Area of Application	Main functions / Keywords
Fertilization	Biofertilizer / organic fertilizer; controlled nutrient release; smart fertilizer; micronutrient encapsulation; chelating agent; nutrient retention.
Biological control/pests	Biopesticide / natural pesticide; biological control agent; microorganism encapsulation; controlled release of actives; leaf adhesiveness; protective biofilm; fixation agent on plant surfaces.
Product formulation	Plant biostimulant/soil conditioner; natural emulsifier/formulation stabilizer; rheology modifier / viscosifier / flow controller; compatibilizer of actives (salts, electrolytes, microorganisms); natural dispersant/suspension stabilizer; encapsulation of active ingredients (including herbicides); sedimentation control; thermal and freeze–thaw stability.
Support and release systems	Polymeric matrix / biodegradable support; agricultural hydrogel / water-retaining hydrogel; encapsulation structure; biopolymeric/protective film; seed coating and encapsulation; seed protective biofilm/pathogen protection; mulching / organic mat / sustainable physical barrier; moisture/water retention; adsorption of nutrients/metals/contaminants.

Results and discussion

The search yielded 193 documents, comprising 185 articles, 12 conference papers, and one early-access article. Of these, 187 are in English and 6 are in Portuguese. The number of publications and citations of the documents between 1995 and 2024 is presented in Figure 2.

From 1995 until approximately 2009, the number of publications was relatively low, ranging from 0 to 5 per year. The articles primarily focused on using agro-industrial waste for xanthan gum production but also addressed soil treatment with xanthan gum and pesticide formulations.

From 2010 onwards, there was a more consistent growth in the number of publications, although with some fluctuations over the years. In 2019, a new increase was observed, followed by a sharp decline in 2020, which may be related to the COVID-19 pandemic. During this period, much research was redirected toward addressing the challenges of the health crisis, which may have resulted in a reduction in scientific output in areas not directly related to the pandemic. By 2021, the number of publications began to rise again, indicating a resumption of research in other fields. In 2022, this growth was even more significant, a trend that continued in 2023, suggesting increased interest and relevance of studies on using xanthan gum in agriculture and waste valorization for production. However, in 2024, there was a slight decline, with the number of publications dropping from 24 to 20. This decrease may be associated with the article life cycle, changes in areas of interest, delays in the review and publication process, as well as factors such as stricter editorial policies and the time it takes for research to be indexed, which may have impacted the full accounting of published works. Despite fluctuations over the years, the observed reduction was not drastic, especially compared to previous periods, such as 2021 and 2022, which recorded 9 and 14 publications, respectively. Thus, Figure 3 presents the evolution of publications related to the topic over the past 10 years. This trend shows a general upward trend in the number of publications over the years, despite occasional fluctuations. This pattern suggests that the field will continue to expand, and academic productivity is likely to remain high in the years to come.

The number of citations between 1995 and 2013 fluctuated, with peaks and drops, showing no consistent growth and remaining relatively low. Starting in 2014, a more stable increase was observed, which intensified between 2021 and 2024, culminating in over 600 citations in 2024.

The significant growth in citations in recent years reflects the impact and quality of the published research, consolidating the topic as an area of growing scientific relevance that attracts more attention from the academic community and fosters international collaborations. Even with the slight reduction in the number of publications in 2024, the increase in citations in that year indicates that previous works had a significant impact, reinforcing the importance and influence of the topic in scientific research. Furthermore, the high demand and utilization of these studies, as evidenced by the number of citations, show that interest in the field remains strong, even in the face of a slight decline in academic output, as shown in Figure 4.

The Web of Science Core Collection boasts an extensive repository, comprising 22,000 journals, 149,000 books, and 308,000 conference proceedings, which have expanded significantly in recent years due to the substantial increase in global publications. BRICS countries (Brazil, Russia, India, China, and South Africa) have played an essential

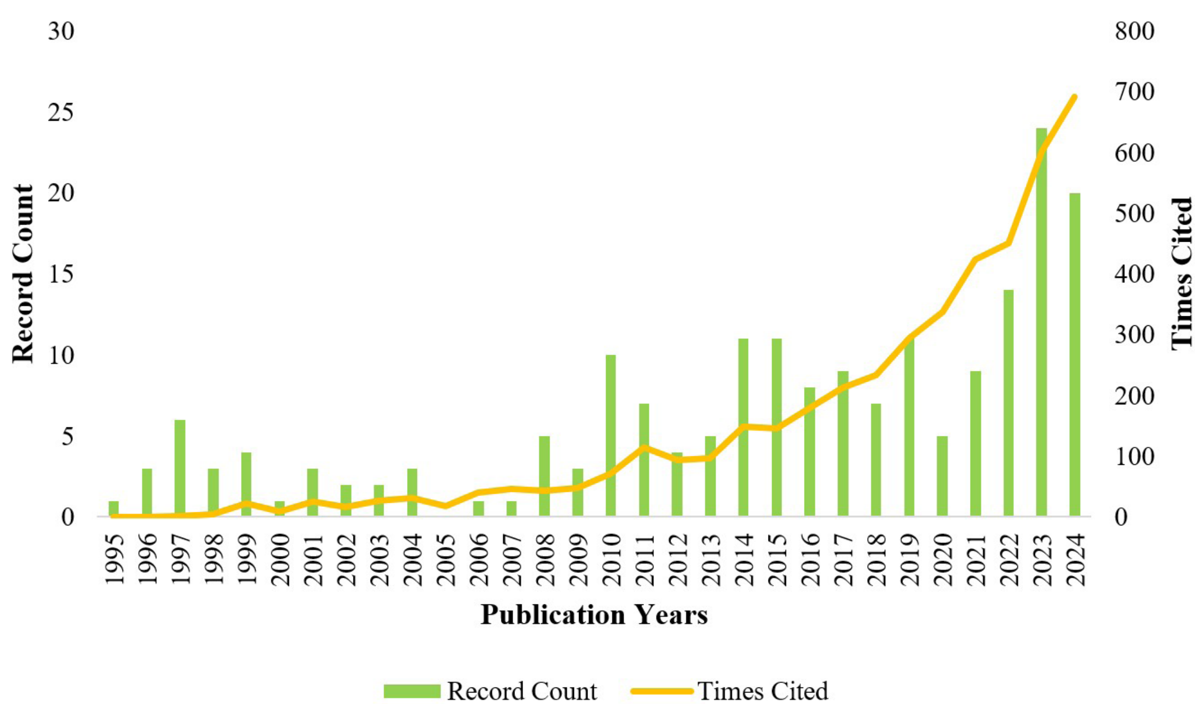


Figure 2. Publications and Citations in WoS from 1995 to 2024.

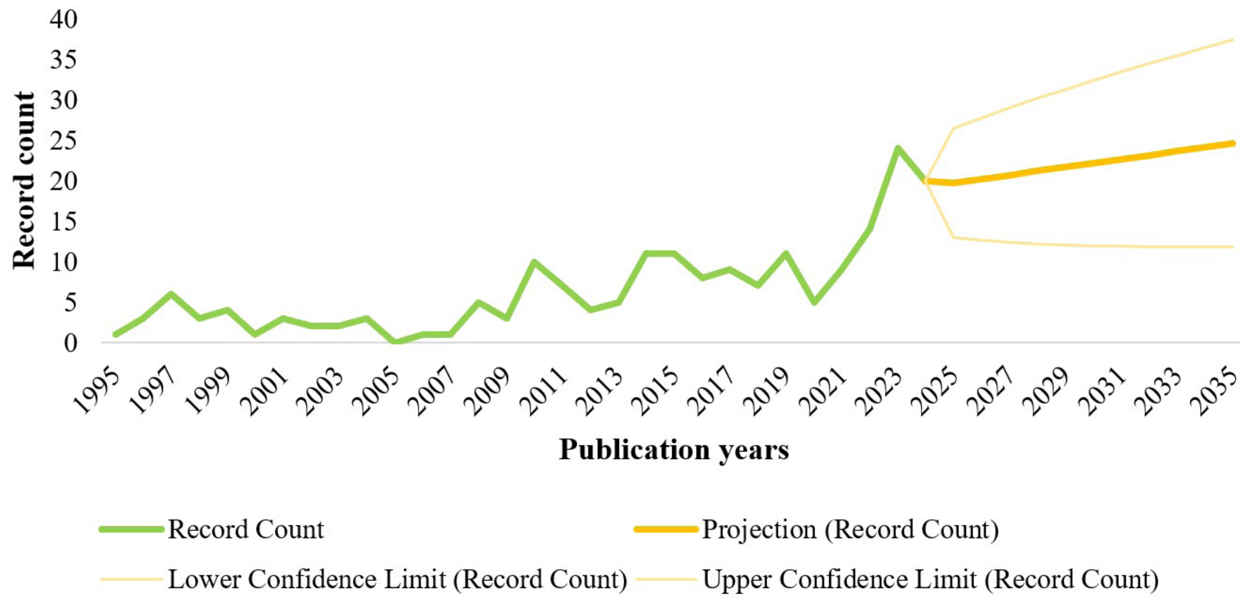


Figure 3. Publication Trend over 10 Years.

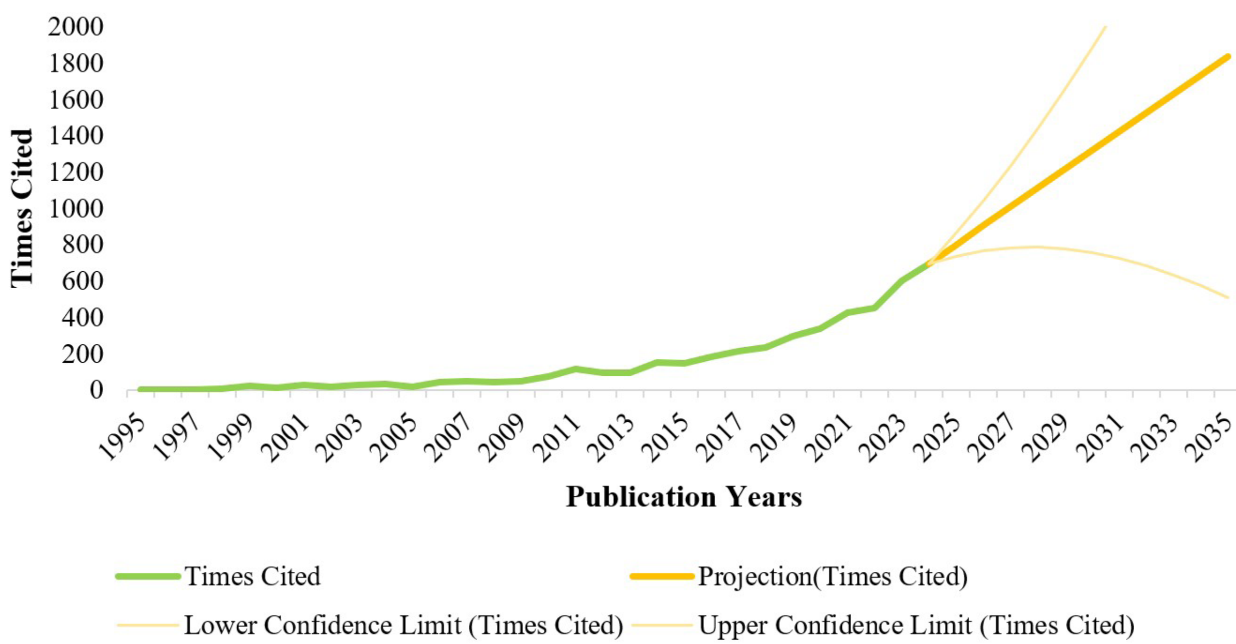


Figure 4. Citation Trend over 10 Years.

role in this context, increasing their research output from 24.2% in 2014 to 40% in 2023 (Clarivate, 2024). In addition, BRICS countries stand out in some areas, as they prioritize emphasizing and addressing the United Nations Sustainable Development Goals (SDGs), which align with the research of this study, such as Zero Hunger, Health and Well-Being, and Life Below Water. Agriculture, one of the main pillars in the fight against hunger, also plays a central role in the search for more sustainable approaches, directly impacting other mentioned SDGs (Clarivate, 2024). Agriculture, one of the main pillars in the fight against hunger, also plays a central role in the search for more sustainable approaches, directly impacting other mentioned SDGs (Clarivate, 2024). Thus, Figure 5 illustrates the global scenario of cooperation and collaboration between countries on this topic. The nodes display concentric rings, indicating the co-occurrence order of items, which varies from cold colors (older) to warm colors (more recent). The size of the nodes reflects the frequency

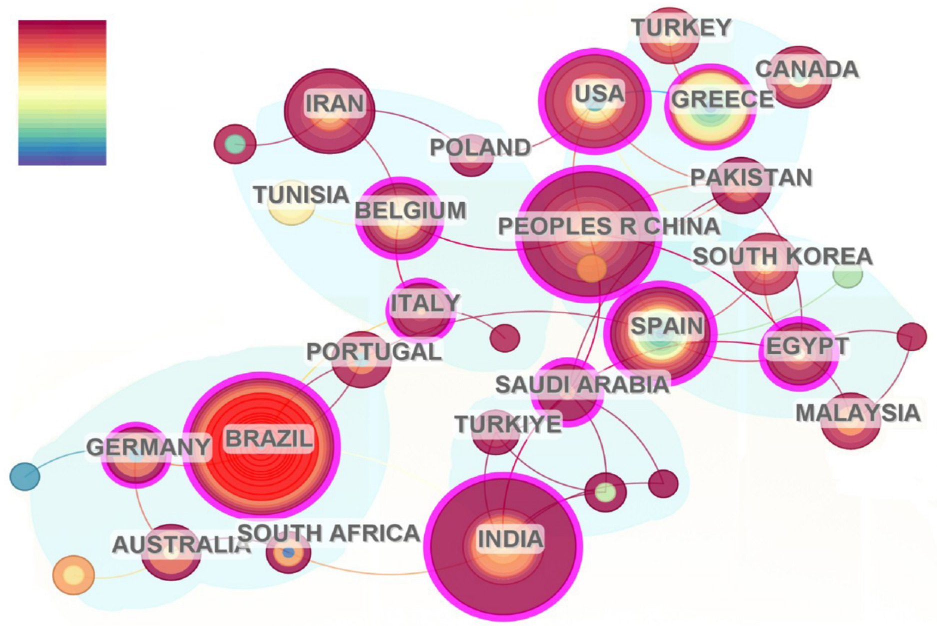


Figure 5. Main Cooperation and Collaboration Networks Between Countries.

of occurrence. It can be observed that the continents most represented are Europe and Asia, while in the Americas, Brazil stands out the most.

India leads with 32 articles, 10 of which were published in 2024, highlighting the current interest in xanthan gum, particularly for seed and fruit coatings, as well as its use in removing heavy metals resulting from pesticide use (Bajaj et al., 2024; Kashaudhan et al., 2025). China follows with 30 articles focusing on the stability and effectiveness of pesticides, with most publications occurring in 2023 and 2024 (Zhang et al., 2023, 2024). Both India and China stand out in agricultural production. India, the second-largest agricultural producer and the most populous country, faces the challenge of feeding over one billion people.

China, the largest global producer, faces a similar challenge as the second most populated country (Food and Agriculture Organization, 2023). This context explains the increase in studies in India and China focused on agricultural improvement and the use of biotechnologies, such as xanthan gum. With large populations and food production challenges, both countries seek innovative solutions to improve product quality, efficiency, and mitigate the environmental impacts of pesticides.

Brazil, on the other hand, has a total of 24 articles published between 1997 and 2023, with a focus on sustainability and the use of agro-industrial waste in xanthan gum production (Silva et al., 2018; Jesus et al., 2023; Mesomo et al., 2009). Furthermore, Brazil was the only country to show a burst (5.22), highlighting articles with a significant increase in citations, represented by the red color (Chen et al., 2010), occurring between 2004 and 2016, a period during which there was a sudden increase in the frequency of citations of Brazilian works. During this burst, the study by Silva (Silva et al., 2009), which used whey to produce xanthan gum from *Xanthomonas campestris*, was the most cited, with 94 out of 468.

Other studies also stood out during the same period, using agro-industrial residues such as apple juice, cassava bagasse, cocoa shells, and especially whey and sugarcane bagasse. In the Brazilian context, research on these residues is particularly relevant, as in 2023, the country produced 782 million tons of sugarcane, generating approximately 218 million tons of sugarcane bagasse (Vandenberghe et al., 2022). Likewise, cheese is widely produced and consumed in Brazil, resulting in a large amount of waste, primarily in the form of whey. Approximately 10 liters of milk are required to produce one kilogram of cheese, with 90% of this amount corresponding to whey (Steffens et al., 2020).

The betweenness centrality, highlighted by the pink halo, demonstrates its relevance in the cocitation network (Liu et al., 2015). According to CiteSpace (2024), nodes with high betweenness centrality (i.e., above 0.1 and 0.2, depending on the network size and connection distribution) typically link two or more large groups within a network. They are considered crucial for connecting and understanding different areas of knowledge in a holistic manner. In this sense, countries with high centrality, represented by nodes with an external pink halo, include Saudi Arabia (0.29), the United States (0.29), Brazil (0.27), the People's Republic of China (0.25), Belgium (0.25), Egypt (0.24), India (0.23), and Spain (0.20).

The collaboration lines, with colors ranging from cold (older partnerships) to warm (more recent collaborations), allow the assessment of the collaboration period and identify clusters of countries that collaborate more intensively with each other. Such collaborations reflect common and/or specific research areas. Brazil maintains collaborations with European countries such as Portugal and Germany. European countries also establish partnerships with Asian nations such as Saudi Arabia, South Korea, Iran, Pakistan, and India, as well as collaborations with North America, including the United States and Canada.

Although African countries like South Africa and Egypt are present, they do not collaborate, preferring partnerships with nations from Asia, Europe, and Oceania. In summary, there is greater collaboration between European and Asian countries, with scarce interactions involving South and North American countries. Figure 6, in turn, presents the authors who have published the most on the subject over these years, linking each one to the number of publications, total citations, and their respective H-indexes.

The authors who stood out the most are Janice Druzian, Jelema Dodic, Francine Padilha, and Dimitrios Kyriakidis. With publications between 2007 and 2018, Brazilian Janice Druzian has an H-index of 7 and a total of 137 citations, demonstrating the consistency and impact of her work over these 11 years, making her the second most cited researcher in the field. Among her studies, a notable one with 38 citations evaluates the fermentation of agro-industrial lignocellulosic residues by different strains of *Xanthomonas campestris* (Silva et al., 2018). Other highlighted studies include the fermentation of cassava whey, whey, and cocoa peel (each with 16 citations) and the use of apple juice residues (24 citations) (Diniz et al., 2012; Druzian & Pagliarini, 2007; Nery et al., 2008). Her other works, with between 6 and 8 citations each, continue along the same research line, focusing on the fermentation of second-generation biomass (Assis et al., 2014; Gomes et al., 2015). This event highlights that Brazil is a significant contributor to scientific research, as it is among the countries with the highest publication output, ranking 13th globally (Clarivate, 2024). The authors who stood out the most are Janice Druzian, Jelema Dodic, Francine Padilha, and Dimitrios Kyriakidis. With publications between 2007 and 2018, Brazilian Janice Druzian has an H-index of 7 and a total of 137 citations, demonstrating the consistency and impact of her work over these 11 years, making her the second most cited researcher in the field. Among her studies, a notable one with 38 citations evaluates the fermentation of agro-industrial lignocellulosic residues by different strains of *Xanthomonas campestris* (Silva et al., 2018). Other highlighted studies include the fermentation of cassava whey, whey, and cocoa peel (each with 16 citations) and the use of apple juice residues (24 citations) (Diniz et al., 2012; Druzian & Pagliarini, 2007; Nery et al., 2008). Her other works, with between 6 and 8 citations each, continue along the same research line, focusing on the fermentation of second-generation biomass (Assis et al., 2014; Gomes et al., 2015). This reinforces that Brazil is a major contributor to scientific research, as, overall, it is among the countries with the highest publication output, ranking 13th globally (Clarivate, 2024).

Jelema Dodic has an H-index of 3 and 53 citations. Four of her six articles on the fermentation of winery wastewater for xanthan gum production were published in 2017, 2019, 2022, and 2024, with 12, 31, 3, and 0 citations, respectively, which indicates that her research on biomass remains current (Trivunović et al., 2022, 2024). The other two articles, from 2017 and 2018, on wastewater from vegetable oil industries, received 7 and 0 citations. Although her H-index is not high, many of these articles are recent, which may explain the still-limited impact of her research; this impact could gain more visibility over time. Francine Padilha published four articles between 2009 and 2023, garnering 131 citations, which nearly surpass Janice Druzian's total citations. Notably, one of her works on the use of whey for xanthan gum production received 94 citations (Silva et al., 2009), a significant achievement for the researcher. Another prominent author is Dimitrios Kyriakidis, who published only three articles between 1997 and 2003, but has the highest number of citations, with 163. Additionally, he was one of the pioneers in studying the production of xanthan gum from whey (Liakopoulou-Kyriakides et al., 1997).

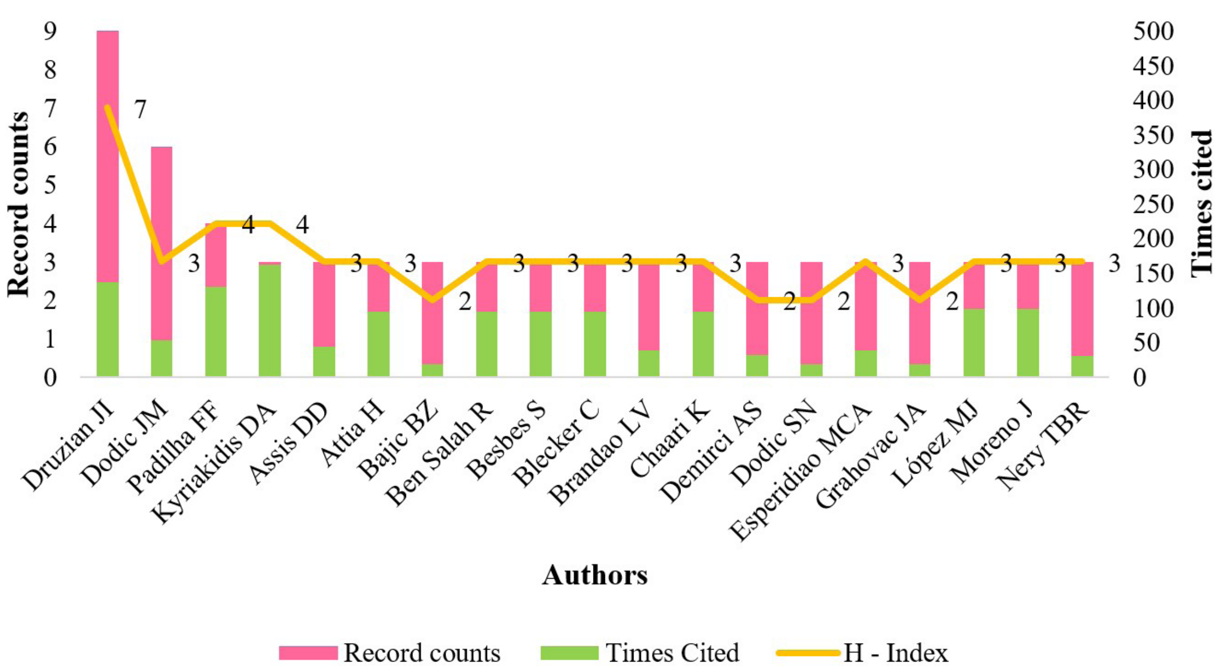


Figure 6. Total Publications, Citations, and H-index of the 15 Most Productive Authors on the Topic.

Figure 7 summarizes the principal authors, grouped by clusters of keywords, and the frequency of their publications over the years evaluated. The lines connecting the nodes indicate collaboration between authors, allowing the identification of groups of researchers who published together or collaborated on their studies (Liu et al., 2015).

Regarding the number of publications, the most relevant authors can be identified by the size of the nodes. Thus, Druzian, Kyriakidis, and Padilha stand out as the authors who publish the most on the topic. On the other hand, the node representing Dodic does not reflect the frequency (6) of their publications during the studied period, which happens because CiteSpace® does not recognize variations (such as Jelena Docid and Jelena M. Dodic.) of their name in each paper, classifying them as different authors, which highlights a limitation of the software in identifying and organizing author data.

The links between authors indicate collaboration, reflected in the focus of their research. Kyriakidis, is associated with the largest cluster, "#0 X. campestris", due to their work on the genetic modification of *Xanthomonas campestris* for xanthan gum production. Druzian, Padilha and Dodic are linked to the cluster "#1 cheese whey", which, although not limited to the use of cheese whey, explores xanthan gum production from waste, with whey being a standard reference in the research.

Figure 8 presents the co-occurrence of keywords separated into keyword clusters, ranging from the largest cluster (#0) to the smallest (#9). The most co-occurring keywords are xanthan gum (81), *Xanthomonas campestris* (41), optimization (20), gum (15), and fermentation (13). Additionally, some keyword nodes feature an external pink halo, representing the centrality of mediation, which indicates the significant importance of these words to the topic. The keywords with the highest centrality are fermentation (0.2), xanthan gum (0.15), recovery (0.14), *Xanthomonas campestris* (0.14), biosynthesis, and whey (0.13, respectively).

The largest cluster, identified by the keyword *Xanthomonas campestris*, is accompanied by the following related terms: *Xanthomonas campestris*, optimization, growth, fermentation, xanthan gum, and waste. The articles forming this cluster refer to the use of the *Xanthomonas* bacterium for the production of xanthan gum from waste (Li et al., 2022), the removal of pollutants with the help of xanthan gum (Kaur & Sud, 2024), and the study of *Xanthomonas* mutants, analyzing their effects on xanthan production and virulence in plants (Katzen et al., 1998). These keywords reflect the use of this bacterium for xanthan gum production, addressing its growth, fermentation, and process optimization, as well as the utilization of waste and the study of bacterial mutation and its impact on plant virulence.

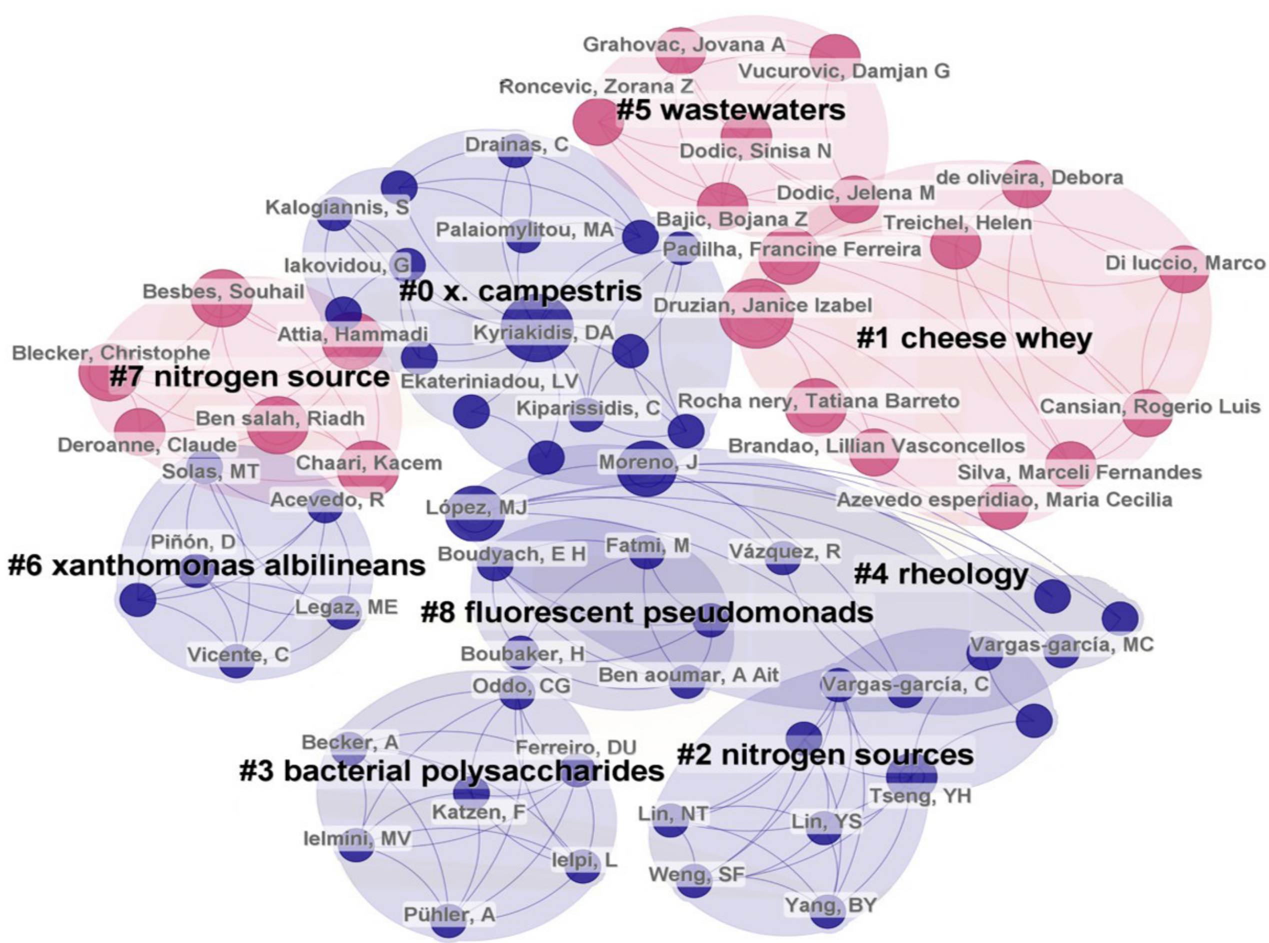


Figure 7. The principal authors organized into keyword clusters.

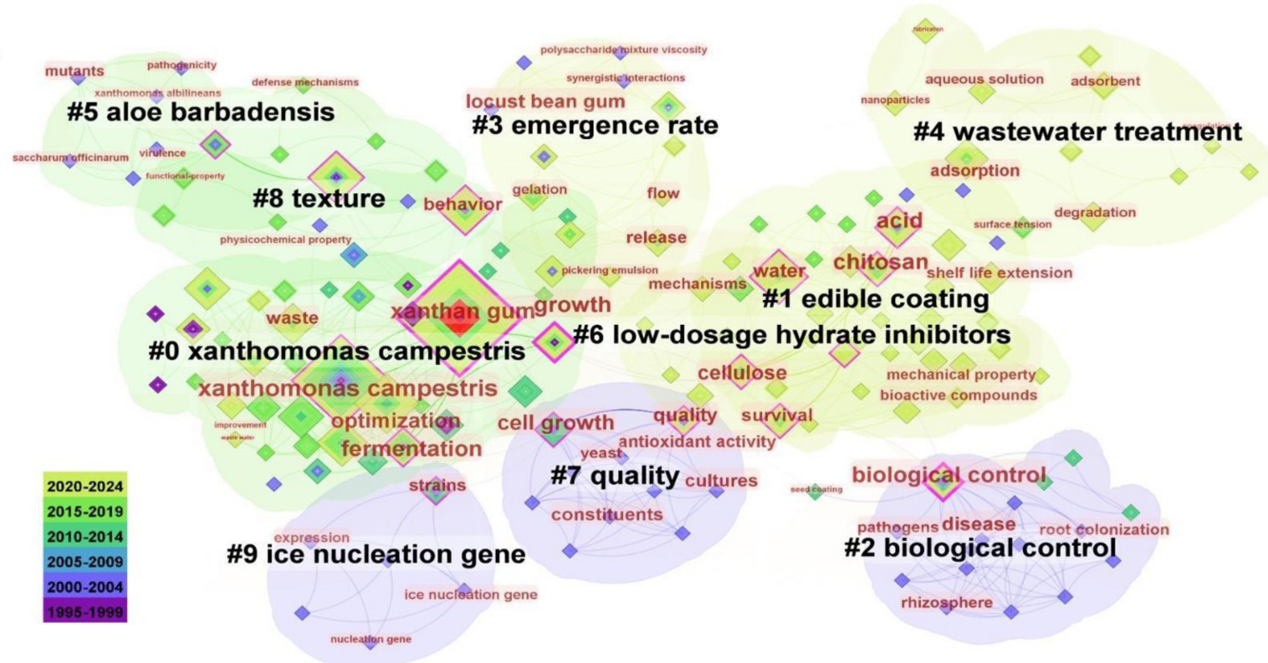


Figure 8. Co-occurrence of keywords organized into keyword clusters.

The second-largest cluster, called Edible Coating, was generated by the keywords chitosan, water, shelf life extension, acid, and mechanisms. The articles representing this cluster studied the use of xanthan gum as a coating for different types of fruits (Gautam et al., 2024; Soppelsa et al., 2023) and seeds (Swaminathan et al., 2016) to prolong shelf life. These articles examine the mechanisms of coating formulations utilizing xanthan gum, which can be combined with other polymers to enhance product shelf life.

The ten clusters highlight the relevance of xanthan gum in agriculture and sustainability, addressing topics such as the genetic manipulation of *Xanthomonas campestris* to optimize its production, the use of waste in manufacturing, and process optimization. They also emphasize its rheological properties, its combinations with other polymers, and the quality of xanthan gum. Furthermore, its various agricultural applications are explored, ranging from planting improvements to the treatment of effluents generated by farming activities. However, although clusters #0 and #1 are indeed the largest groupings, with 133 and 37 papers, respectively, the other modules (e.g., #2 (7), #3 (21), #4 (18), #5 (19), #6 (19), #7 (8), #8 (15), and #9 (3)) have unequal sizes.

There are several reasons why the cluster sizes may not follow a growing order. The data distribution, where more frequent keywords (e.g., *Xanthomonas campestris* and xanthan gum) occur more frequently compared to others (e.g., adsorption, mechanical/physicochemical properties), may result in clusters of different sizes (Chen, 2016). Additionally, each paper can contribute to the formation of one or more clusters, such as the paper "Facile removal of emerging pollutants using mesoporous TiO_2 nanoparticles synthesized via xanthan gum templated greener protocol" (Kaur & Sud, 2024), which contributed to the formation of clusters #0, #4, and #6.

Also, specific clustering algorithms (e.g., graphs) do not always form modules of uniform sizes, especially when dealing with complex data. Configuration parameters, filters, and selection criteria should also be set consistently to obtain appropriate cutoff limits and bond strengths for the dataset size and the weights required by the software. Otherwise, the generation of collaboration and citation networks may vary, resulting in the formation of distinct clusters, as exemplified in Figure 8, where selection criteria influence the organization of the networks (Chen, 2016).

Another important aspect is the bursts of keyword citations, represented by their respective strength values, the publication year of the paper, and the start and end periods of the burst (Figure 9). The keywords with the highest bursts are: xanthan gum (4.71), water (4.58), waste (4.10), recovery (3.76), and optimization (3.72).

With this, it can be observed that some keywords are quite representative of this topic, exhibiting significant expression in terms of frequency, centrality, and citation bursts, as shown in Figures 8 and 9. For example, "xanthan gum" has a high frequency and centrality, in addition to a citation burst between 2020 and 2024, indicating that, despite being widely studied over the years, there is currently great interest in its production, particularly in new applications.

The keywords "Xanthomonas campestris" and "fermentation," although not showing citation bursts, have high frequency and centrality and are directly associated with the production of xanthan gum. On the other hand, the keywords "optimization" and "recovery" exhibit citation bursts in the periods from 2011 to 2024 and from 2010 to 2019, respectively, reflecting interest in improving the production and/or properties of the gum and utilizing it in soil and water recovery processes.

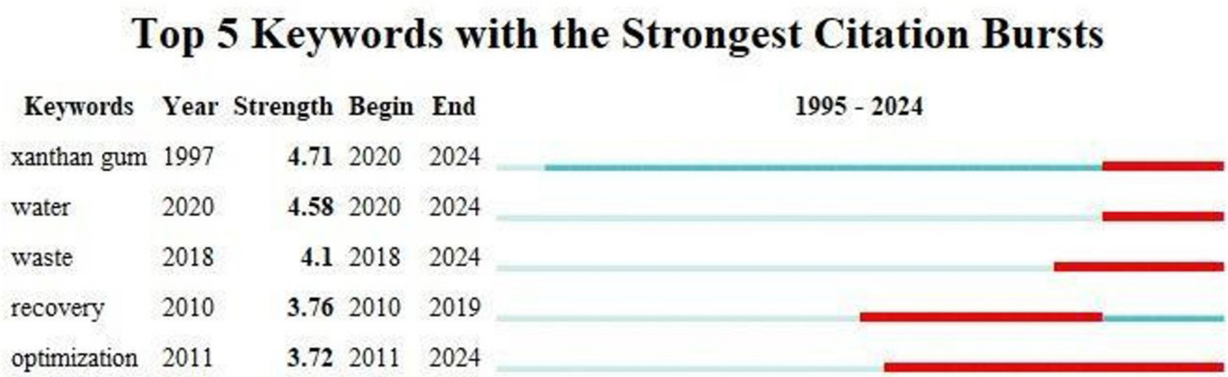


Figure 9. Citation Bursts Related to Keywords.

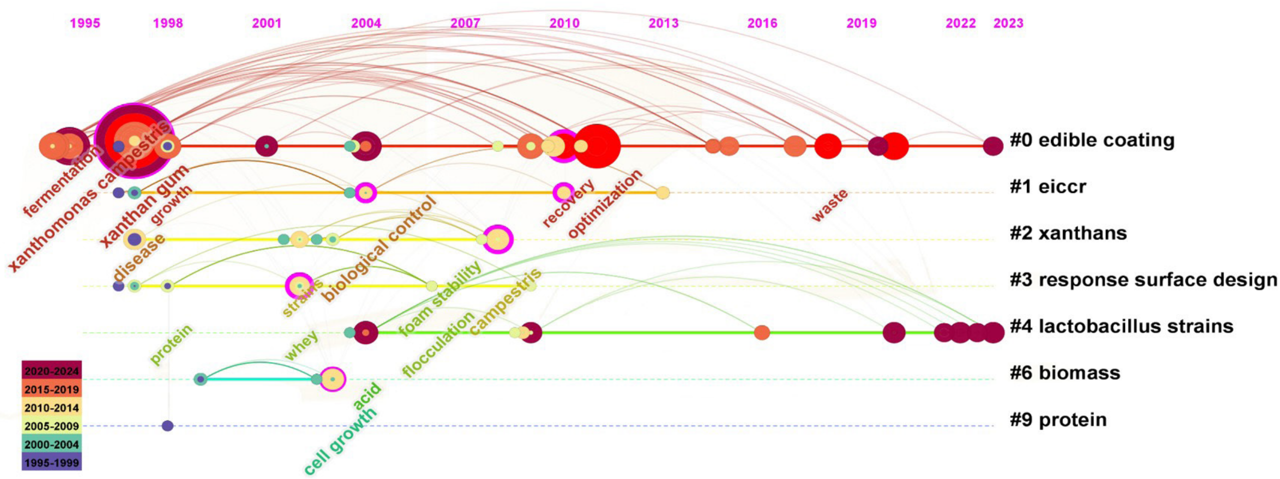


Figure 10. Timeline of Keywords.

Finally, "waste" and "water" have bursts in similar periods, from 2018 to 2024 and from 2020 to 2024, highlighting a trend in research towards developing xanthan gum applications in water recovery, effluent treatment, and the use of agro-industrial waste. Thus, Figure 10 illustrates the timeline associated with the keywords, with their respective citation bursts already presented.

These data track the development of research related to xanthan gum. Initially, the focus was on improving production and recovery processes, as indicated by the bursts of "optimization" and "recovery" between 2010 and 2024. This result reflects the scientific community's initial efforts to understand and establish the theoretical and practical foundations of the topic, which remain relevant today. Subsequently, interest expanded to practical and sustainable applications, such as water recovery and waste utilization, as evidenced by the surge in "waste" and "water" mentions between 2018 and 2024. This shift suggests a transition in the research focus from a technical approach to a broader and more applied perspective, considering both environmental and economic impacts. In addition to the growing number of studies on the application of xanthan gum in agriculture, this interest is also evident in the field of technological innovation, as reflected in the increasing number of patent filings. These records demonstrate not only the advancement of scientific knowledge but also its translation into practical products, processes, and solutions. Between 1995 and 2024, 447 patents related to the topic were filed, highlighting its importance for the development of new technologies in the sector.

Upon examining the distribution of these records, it is noticeable that the number of patents per year, as shown in Figure 11a, remained relatively low between 1995 and 2006. From 2007 onwards, there was a gradual increase, albeit irregular. In 2016, a significant jump occurred, with 43 filings, followed by intermediate values between 2017 and 2021. In recent years, growth intensified again, reaching 38 filings in 2022, 59 in 2023, and 49 in 2024. This pattern reflects a typical evolution of emerging technologies: initial private interest and academic use are followed by peaks of innovation as practical applications are consolidated, primarily driven by growing demand for sustainable, efficient, and eco-friendly agricultural solutions.

Patent analysis reveals that China stood out in terms of the number of filings, with 234 applications, accounting for 52.35% of the total. Next were the United States (52; 11.63%), India (32; 7.16%), and Japan (31; 6.94%) (Figure 11b). Looking at

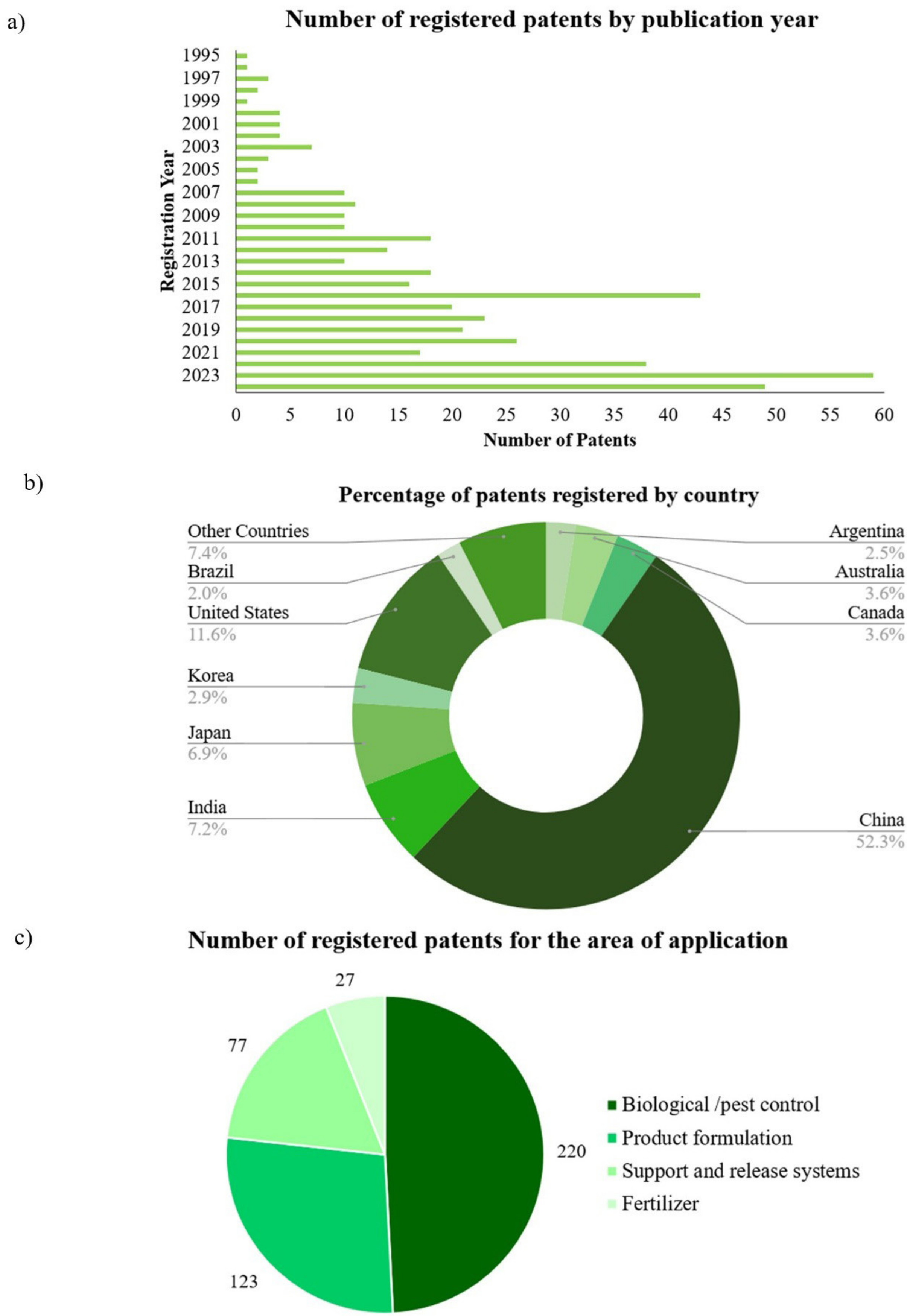


Figure 11. Overview of agricultural xanthan gum patents by year, country, and application area.

filings by application area (Figure 11c), the Biological Control/ Pest group stands out with 220 patents, followed by Product Formulation (123), Support and Release Systems (78), and Fertilizers (19). Chinese leadership in this group is evident, as 137 of the 220 patents belong to China, highlighting its central role in developing solutions for sustainable agriculture. This prominence is directly related to its status as the world's largest agricultural producer, which necessitates striking a balance between high production and lower environmental impact.

China's technological prominence is also reflected in scientific output. The country published 30 articles, primarily between 2023 and 2024, focusing on the use of xanthan gum to enhance the stability and efficacy of pesticides, which demonstrates the connection between scientific production and technological development, with patents aimed at pest control. This relationship becomes even clearer when analyzing the temporal trend of patents. Most Chinese filings occurred after 2007, with a notable increase of 43 patents in 2016, including 33 that were Chinese. More recently, in 2023 and 2024, 108 patents were filed, 53 of them from China (Figure 11a). This pattern aligns with the increase in scientific publications during the same period, showing a direct link between academic advances and technological innovation. In this way, China consolidates a consistent strategy of integrating science and technology, accounting for nearly half of all analyzed filings. On the other hand, other countries show distinct and complementary profiles. The number of patents filed by the United States (11.63%) (Figure 11b) is mainly concentrated in Biological Control/ Pest and Product Formulation (Figure 11c). This diversified profile reflects its tradition in agricultural innovation and the development of broad-spectrum inputs. India exhibits a predominance in biocontrol and formulations (Figure 11c), aligning with its specific needs for seed and fruit protection, which indicates coherence between recent scientific production and the country's patent filings. Japan, although with a smaller volume of filings, consistently makes a notable contribution. Its focus is balanced among biocontrol, release systems, and product formulations (Figure 11c), confirming its role as a relevant actor in the development of applied technological solutions. Although with low participation, Brazil (2%) shows a relationship between scientific publications and patents (Figure 11b). Initially, studies focused on utilizing agro-industrial residues to produce xanthan gum. Between 2013 and 2023, interest in producing products from xanthan gum, particularly in Fertilizers and Product Formulation, increased, as evidenced by the number of patents filed (Figure 11c). This transition reflects the conversion of applied research into commercial technological solutions, albeit in an incipient manner compared to developed countries.

Conclusion

This study presents a comprehensive analysis of the sustainable applications of xanthan gum in agriculture, highlighting its remarkable growth since 2022. Although previous research existed, recent interest has increased significantly, particularly in areas such as improving fertilizer flowability, seed encapsulation, biological pest control, and utilizing agro-industrial residues for sustainable production.

Investigation of collaboration networks highlights Brazil, India, and China as the main contributors in this field, with Brazil standing out for its scientific advances focused on sustainability and more efficient agricultural practices.

The evolution of research focus is evident in keyword trends, which have shifted from refining production techniques to exploring sustainable applications, including water treatment and the valorization of agro-industrial residues.

Patent analysis confirms these trends: biological control leads in filings, driven primarily by China, while the United States, India, and Japan adopt diversified strategies tailored to their respective agricultural demands. Although Brazil has a smaller share, it shows alignment between science and technology, with potential for growth in sustainable applications. Global trends in xanthan gum use in agriculture shape the pace and nature of technological innovations in each country.

As a result, xanthan gum is increasingly recognized as a sustainable biopolymer, driven by advancements in agricultural innovations and the utilization of agricultural residues. The expansion of international partnerships, the deepening of research efforts, and the application of technological innovations are crucial to maximizing its role in advancing sustainable agriculture.

Conflict of interests

The authors declare that they have no conflict of interest.

Funding: The authors acknowledge the financial support by the Brazilian Federal Agency for Support and Evaluation of Graduate Education: National Council for Scientific and Technological Development (CNPq), Brasilia, Brazil (http://cnpq.br/) and Education Coordination for the Improvement of Higher Education Personnel CAPES Finance Code 001, Brasilia, Brazil (www. capes.gov.br). This research was supported by the CAPES through scholarships awarded to D. L. Boettcher (Grant No. 88887.712593/2022-00), D. B. Lima (Grant No. 88887.952327/2024-00), D. G. Bortolini (Grant No. 88887.078507/2024-00), and P. E. Manuitt-Brito (Grant No. 88887.918045/2023-00). This research also receives support by the CNPq through scholarships awarded to N. C. Ghisi (Grant No. 309230/2021-7).

Acknowledgements

The authors acknowledge the support from Postgraduate Program in Biotechnology (PPGBIOTEC)/Federal University of Technology – Parana (UTFPR).

References

Assis, D., Costa, L. A., Campos, M. I., Souza, C. O. D., Druzian, J. I., Nunes, I., & Padilha, F. F. (2014). Influência da natureza do rejeito agroindustrial fermentado por *Xanthomonas axonopodis* pv. Manihotis nas propriedades das gomas xantana resultantes. *Polímeros*, *24*(2), 176-183. http://doi.org/10.4322/polimeros.2014.064.

Bajaj, K., Kumar, A., Gill, P. P. S., Jawandha, S. K., & Kaur, N. (2024). Xanthan gum coatings augmented with lemongrass oil preserve postharvest quality and antioxidant defence system of Kinnow fruit under low-temperature storage. *International Journal of Biological Macromolecules*, *262*(Pt 1), 129776. http://doi.org/10.1016/j.ijbiomac.2024.129776. PMid:38281532.

Berninger, T., Dietz, N., & González López, Ó. (2021). Water-soluble polymers in agriculture: Xanthan gum as eco-friendly alternative to synthetics. *Microbial Biotechnology*, *14*(5), 1881-1896. http://doi.org/10.1111/1751-7915.13867. PMid:34196103.

Bhat, I. M., Wani, S. M., Mir, S. A., & Masoodi, F. A. (2022). Advances in xanthan gum production, modifications and its applications. *Biocatalysis and Agricultural Biotechnology*, *42*, 102328. http://doi.org/10.1016/j.bcab.2022.102328.

Chen, C. (2006). CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, *57*(3), 359-377. http://doi.org/10.1002/asi.20317.

Chen, C. (2016). *CiteSpace: A practical guide for mapping scientific literature*. New York: Nova Science Publishers.

Chen, C., Ibekwe-SanJuan, F., & Hou, J. (2010). The structure and dynamics of cocitation clusters: A multiple-perspective cocitation analysis. *Journal of the American Society for Information Science and Technology*, *61*(7), 1386-1409. http://doi.org/10.1002/asi.21309.

CiteSpace. CiteSpace. Betweenness Centrality. 2024. Available on: https://citespace.podia.com/glossary-betweenness_centrality.

Clarivate. (2024). *Panorama das mudanças na pesquisa no Brasil*. https://www.clarivate.com

Diniz, D. D. M., Druzian, J. I., & Audibert, S. (2012). Produção de goma xantana por cepas nativas de *Xanthomonas campestris* a partir de casca de cacau ou soro de leite. *Polímeros*, *22*(3), 278-281. http://doi.org/10.1590/S0104-14282012005000032.

Druzian, J. I., & Pagliarini, A. P. (2007). Produção de goma xantana por fermentação do resíduo de suco de maçã. *Food Science and Technology*, *27*(1), 26-31. http://doi.org/10.1590/S0101-20612007000100005.

Food and Agriculture Organization. (2023). *The state of food and agriculture 2023*. Rome: FAO.

Gautam, A., Gill, P. P. S., Singh, N., Jawandha, S. K., Arora, R., Singh, A., & Ajay, (2024). Composite coating of xanthan gum with sodium nitroprusside alleviates the quality deterioration in strawberry fruit. *Food Hydrocolloids*, *155*, 110208. http://doi.org/10.1016/j.foodhyd.2024.110208.

Gomes, G. V. P., Assis, D. D. J., Silva, J. B. A., Santos-Ebinuma, V. D. C., Costa, L. A. S., & Druzianl, J. I. (2015). Obtaining xanthan gum impregnated with cellulose microfibrils derived from sugarcane bagasse. *Materials Today: Proceedings*, *2*(1), 389-398. http://doi.org/10.1016/j.matpr.2015.04.042.

Hassanisaadi, M., Saberi Riseh, R., Rabiei, A., Varma, R. S., & Kennedy, J. F. (2023). Nano/micro-cellulose-based materials as remarkable sorbents for the remediation of agricultural resources from chemical pollutants. *International Journal of Biological Macromolecules*, *246*, 125763. http://doi.org/10.1016/j.ijbiomac.2023.125763. PMid:37429338.

Jesus, M., Mata, F., Batista, R. A., Ruzene, D. S., Albuquerque-Júnior, R., Cardoso, J. C., Vaz-Velho, M., Pires, P., Padilha, F. F., & Silva, D. P. (2023). Corncob as carbon source in the production of xanthan gum in different strains *Xanthomonas* sp. *Sustainability*, *15*(3), 2287. http://doi.org/10.3390/su15032287.

Kashaudhan, K., Pande, P. P., Sharma, J., Shankar, R., Nath, A., Chaurasiya, A., & Kushwaha, N. (2025). Synthesis and characterization of Xanthan Gum Xanthates and their application for toxic metal ion removal from synthetic wastewater. *Journal of Dispersion Science and Technology*, *46*(12), 1954-1968. http://doi.org/10.1080/01932691.2024.2373932.

Katzen, F., Ferreiro, D. U., Oddo, C. G., Ielmini, M. V., Becker, A., Pühler, A., & Ielpi, L. (1998). *Xanthomonas campestris* pv. campestris *gum* mutants: Effects on xanthan biosynthesis and plant virulence. *Journal of Bacteriology*, *180*(7), 1607-1617. http://doi.org/10.1128/JB.180.7.1607-1617.1998. PMid:9537354.

Kaur, A., & Sud, D. (2024). Facile removal of emerging pollutants using mesoporous TiO2 nanoparticles synthesized via xanthan gum templated greener protocol. *International Journal of Environmental Science and Technology*, *21*(5), 5127-5148. http://doi.org/10.1007/s13762-023-05358-x.

Li, Z.-X., Chen, J.-Y., Wu, Y., Huang, Z.-Y., Wu, S.-T., Chen, Y., Gao, J., Hu, Y., & Huang, C. (2022). Effect of downstream processing on the structure and rheological properties of xanthan gum generated by fermentation of *Melaleuca alternifolia* residue hydrolysate. *Food Hydrocolloids*, *132*, 107838. http://doi.org/10.1016/j.foodhyd.2022.107838.

Liakopoulou-Kyriakides, M., Tzanakakis, E. S., Kiparissidis, C., Ekateriániadou, L. V., & Kyriakidis, D. A. (1997). Kinetics of xanthan gum production from whey by constructed strains of *Xanthomonas campestris* in batch fermentations. *Chemical Engineering & Technology*, *20*(5), 354-360. http://doi.org/10.1002/ceat.270200513.

Liu, Z., Yin, Y., Liu, W., & Dunford, M. (2015). Visualizing the intellectual structure and evolution of innovation systems research: A bibliometric analysis. *Scientometrics*, *103*(1), 135-158. http://doi.org/10.1007/s11192-014-1517-y.

Mansoor, Z., Tchuenbou-Magaia, F., Kowalczuk, M., Adamus, G., Manning, G., Parati, M., Radecka, I., & Khan, H. (2022). Polymers use as mulch films in agriculture: A review of history, problems and current trends. *Polymers*, *14*(23), 5062. http://doi.org/10.3390/polym14235062. PMid:36501456.

Mesomo, M., Silva, M. F., Boni, G., Padilha, F. F., Mazutti, M., Mossi, A., De Oliveira, D., Cansian, R. L., Di Luccio, M., & Treichel, H. (2009). Xanthan gum produced by *Xanthomonas campestris* from cheese whey: Production optimisation and rheological characterisation. *Journal of the Science of Food and Agriculture*, *89*(14), 2440-2445. http://doi.org/10.1002/jsfa.3743.

NanGong, Z., Li, T., Zhang, W., Song, P., & Wang, Q. (2021). Capsule-C: An improved *Steinernema carpocapsae* capsule formulation for controlling *Agrotis ipsilon* Hufnagel (Lepidoptera: Noctuidae). *Egyptian Journal of Biological Pest Control*, *31*(1), 148. http://doi.org/10.1186/s41938-021-00492-5.

Nasrabadi, T., Ruegner, H., Sirdari, Z. Z., Schwientek, M., & Grathwohl, P. (2016). Using Total Suspended Solids (TSS) and Turbidity as proxies for evaluation of metal transport in river water. *Applied Geochemistry*, *68*, 1-9. http://doi.org/10.1016/j.apgeochem.2016.03.003.

Nery, T. B. R., Brandão, L. V., Esperidião, M. C. A., & Druzian, J. I. (2008). Biossíntese de goma xantana a partir da fermentação de soro de leite: Rendimento e viscosidade. *Química Nova*, *31*(8), 1937-1941. http://doi.org/10.1590/S0100-40422008000800004.

Nicholson, C. C., Knapp, J., Kiljanek, T., Albrecht, M., Chauzat, M.-P., Costa, C., De La Rúa, P., Klein, A.-M., Mänd, M., Potts, S. G., Schweiger, O., Bottero, I., Cini, E., De Miranda, J. R., Di Prisco, G., Dominik, C., Hodge, S., Kaunath, V., Knauer, A., Laurent, M., Martínez-López, V., Medrzycki, P., Pereira-Peixoto, M. H., Raimets, R., Schwarz, J. M., Senapathi, D., Tamburini, G., Brown, M. J. F., Stout, J. C., & Rundlöf, M. (2024). Pesticide use negatively affects bumble bees across European landscapes. *Nature*, *628*(8007), 355-358. http://doi.org/10.1038/s41586-023-06773-3. PMid:38030722.

Nobre, C., Cerqueira, M. Â., Rodrigues, L. R., Vicente, A. A., & Teixeira, J. A. (2015). Production and extraction of polysaccharides and oligosaccharides and their use as new food additives. In A. Pandey, R. Höfer, M. Taherzadeh, K. Madhavan Nampoothiri & C. Larroche (Eds.), *Industrial biorefineries & white biotechnology* (pp. 653-679). Amsterdam: Elsevier. http://doi.org/10.1016/B978-0-444-63453-5.00021-5.

Rosalam, S., & England, R. (2006). Review of xanthan gum production from unmodified starches by Xanthomonas compestris sp. *Enzyme and Microbial Technology*, *39*(2), 197-207. http://doi.org/10.1016/j.enzmictec.2005.10.019.

Roser, M., Ritchie, H., & Rosado, P. (2023). *Food supply*. https://ourworldindata.org/food-supply

Santos, F. P., Oliveira Junior, A. M., Nunes, T. P., Silva, C. E. F., & Abud, A. K. S. (2016). Bioconversion of agro-industrial wastes into xanthan gum. *Chemical Engineering Transactions*, *49*, 145-150. http://doi.org/10.3303/CET1649025.

Silva, J. A., Cardoso, L. G., Assis, D. J., Gomes, G. V. P., Oliveira, M. B. P. P., Souza, C. O., & Druzian, J. I. (2018). Xanthan gum production by *Xanthomonas campestris* pv. Campestris IBSBF 1866 and 1867 from lignocellulosic agroindustrial wastes. *Applied Biochemistry and Biotechnology*, *186*(3), 750-763. http://doi.org/10.1007/s12010-018-2765-8. PMid:29728963.

Silva, M. F., Fornari, R. C. G., Mazutti, M. A., De Oliveira, D., Padilha, F. F., Cichoski, A. J., Cansian, R. L., Di Luccio, M., & Treichel, H. (2009). Production and characterization of xantham gum by *Xanthomonas campestris* using cheese whey as sole carbon source. *Journal of Food Engineering*, *90*(1), 119-123. http://doi.org/10.1016/j.jfoodeng.2008.06.010.

Sofo, A., Nicoletta Mininni, A., & Ricciuti, P. (2020). Comparing the effects of soil fauna on litter decomposition and organic matter turnover in sustainably and conventionally managed olive orchards. *Geoderma*, *372*, 114393. http://doi.org/10.1016/j.geoderma.2020.114393.

Soppelsa, S., Van Hemelrijck, W., Bylemans, D., & Andreotti, C. (2023). Essential oils and chitosan applications to protect apples against postharvest diseases and to extend shelf life. *Agronomy*, *13*(3), 822. http://doi.org/10.3390/agronomy13030822.

Sorze, A., Valentini, F., Smolar, J., Logar, J., Pegoretti, A., & Dorigato, A. (2023). Effect of different cellulose fillers on the properties of xanthan-based composites for soil conditioning applications. *Materials*, *16*(23), 7285. http://doi.org/10.3390/ma16237285. PMid:38068029.

Steffens, J., Preci, D., Nunes, M. B., Fernandes, I. A., Seguenka, B., Valduga, E., & Steffens, C. (2020). Hidrólise de soro de leite ovino difiltrado pela enzima corolase h-ph e avaliação da geração de peptídeos bioativos. *Revista Tecnológica*, *29*(1), 168-183. http://doi.org/10.4025/revtecnol.v29i1.51138.

Swaminathan, J., Van Koten, C., Henderson, H. V., Jackson, T. A., & Wilson, M. J. (2016). Formulations for delivering *Trichoderma atroviridae* spores as seed coatings, effects of temperature and relative humidity on storage stability. *Journal of Applied Microbiology*, *120*(2), 425-431. http://doi.org/10.1111/jam.13006. PMid:26600429.

Trivunović, Z., Mitrović, I., Puškaš, V., Bajić, B., Miljić, U., & Dodić, J. (2022). Utilization of wastewaters from red wine technology for xanthan production in laboratory bioreactor. *Journal of Food Processing and Preservation*, *46*(10). http://doi.org/10.1111/jfpp.15849.

Trivunović, Z., Zahović, I., Vlajkov, V., Grahovac, M., Grahovac, J., & Dodić, J. (2024). Xanthan production using wastewaters from rose wine Industry: Screening of *Xanthomonas euvesicatoria* Isolates. *Periodica Polytechnica. Chemical Engineering*, *68*(3), 428-436. http://doi.org/10.3311/PPch.23907.

United Nations. (2022). *World population prospects 2022: Summary of results*. New York.

Vandenberghe, L. P. S., Valladares-Diestra, K. K., Bittencourt, G. A., Zevallos Torres, L. A., Vieira, S., Karp, S. G., Sydney, E. B., Carvalho, J. C., Thomaz Soccol, V., & Soccol, C. R. (2022). Beyond sugar and ethanol: The future of sugarcane biorefineries in Brazil. *Renewable & Sustainable Energy Reviews*, *167*, 112721. http://doi.org/10.1016/j.rser.2022.112721.

Vandermeulen, G. W. M., Boarino, A., & Klok, H. (2022). Biodegradation of water-soluble and water-dispersible polymers for agricultural, consumer, and industrial applications: Challenges and opportunities for sustainable materials solutions. *Journal of Polymer Science*, *60*(12), 1797-1813. http://doi.org/10.1002/pol.20210922.

Veshapidze, S., Otinashvili, R., Gvarutsidze, A., Abuselidze, G., & Zoidze, G. (2022). Modern technologies to overcome the challenges of globalization. *Entrepreneurship*, *10*(2), 22-32. http://doi.org/10.37708/ep.swu.v10i2.2.

Vijayalakshmi, V., Sathish, S., & Umarani, R. (2024). Effect of Xanthan gum seed coating on seed germination and seedling vigour of finger millet (*Eleusine coracana* L.). *Environment Conservation Journal*, *25*(1), 206-210. http://doi.org/10.36953/ECJ.24342669.

Wani, S. M., Mir, S. A., Khanday, F. A., & Masoodi, F. A. (2021). Advances in pullulan production from agro-based wastes by *Aureobasidium pullulans* and its applications. *Innovative Food Science & Emerging Technologies*, *74*, 102846. http://doi.org/10.1016/j.ifset.2021.102846.

Willis Chan, D. S., Prosser, R. S., Rodríguez-Gil, J. L., & Raine, N. E. (2019). Assessment of risk to hoary squash bees (*Peponapis pruinosa*) and other ground-nesting bees from systemic insecticides in agricultural soil. *Scientific Reports*, *9*(1), 11870. http://doi.org/10.1038/s41598-019-47805-1. PMid:31413274.

Xie, P. (2015). Study of international anticancer research trends via co-word and document cocitation visualization analysis. *Scientometrics*, *105*(1), 611-622. http://doi.org/10.1007/s11192-015-1689-0.

Zhang, S., Bao, Z., Wu, Y., Wang, Y., Liu, R., Gao, Y., Zhao, X., Zhang, C., & Du, F. (2023). Enhancing the stability and effectivity of multiple pesticide formulation mixtures by adding an eco-friendly adjuvant. *ACS Sustainable Chemistry & Engineering*, *11*(42), 15385-15396. http://doi.org/10.1021/acssuschemeng.3c04446.

Zhang, P., Pan, T., Ma, L., Liu, B., Tian, S., & Chen, X. (2024). Enhancing stability and odor control of water-based foam for pesticide site restoration using xanthan gum. *Process Safety and Environmental Protection*, *185*, 660-669. http://doi.org/10.1016/j.psep.2024.03.038.