

Microbial Biosurfactant Production: A Systematic Review

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Abstract: Surfactants are compounds with surface-active properties that play a key role in industrial processes involving substance dispersion, detergency, emulsification, and solubilization. Derived from petroleum, they are not biodegradable and have a high degree of toxicity, but they are the most widely used in the oil and gas, cosmetics, cleaning products, pharmaceutical, and agricultural pesticide industries due to their low production cost. Microbial biosurfactants reduce surface tension and are presented as substitutes for conventional surfactants, being attractive due to their biodegradability, low toxicity, and high tolerance to extreme pH and temperature conditions. Although promising, the costs associated with the production of these compounds prevent them from competing with synthetic surfactants. The objective of this study was to present a systematic review, highlighting the growth of scientific research on the topic in recent decades, covering the period between 2005 and 2025. The Web of Science, Scopus, and CAPES Periodicals databases were chosen for document collection due to their academic rigor, generating 129 results. Duplicate works were detected and reorganized into a total of 101 results to avoid redundancy and ensure consistency in the analyses. Documents without open access or unrelated to the topic were not analyzed beyond the year of publication. The methodology was effective, and the results allowed for the creation of figures representing the number of publications per year, the advantages and disadvantages of biosurfactants, and the main countries of publication. Thus, this study addressed the global need to find sustainable and integrated solutions that address environmental, social, organizational, and governmental issues. It also highlighted the need to encourage scientific research aimed at developing new technologies based on the concepts of multidisciplinary, green chemistry, sustainable development goals, and the circular economy.

Keywords: Microbial biosurfactants. Bioremediation. Production cost. Sustainability.

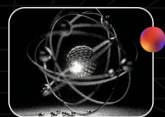
1. Introduction

Surfactants are amphiphilic compounds. This means they have a polar portion (hydrophilic head) and a nonpolar portion (hydrophobic tail). The polar portion interacts with water, and the nonpolar portion tends to interact with oily substances, such as grease, petroleum and its derivatives [1].

The main characteristic associated with these molecules is precisely the ability to reduce the surface tension between water/oil or oil/water, but the emulsifying, dispersing, detergent and fungicidal properties contribute to consolidating these compounds as high value-added products

in the most diverse industrial sectors, from the production of cosmetics, cleaning and personal hygiene products to the development of efficient pesticides, oil recovery agents and additives for the treatment of oily waste [2].

Conventional surfactants are derived from petroleum; therefore, they are neither biodegradable nor sustainable, but they are the most widely used in industries in general despite their toxicity, due to their easy accessibility and low production cost [3]. In recent decades, the scientific community has been striving to find a



sustainable and economically viable alternative to replace these compounds [4].

This context, coupled with growing concerns about environmental pollution, is driving scientific focus toward discovering more environmentally friendly production methods. Thus, the production of microbial surfactants is emerging as a biotechnological strategy that is generating interest. Biosurfactants, in turn, are surfactant molecules with the above-mentioned structure and properties, but originating from microorganisms, a renewable source [5].

The main classes of biosurfactants are glycolipids, lipopeptides and lipoproteins, fatty acids, neutral lipids and phospholipids, polymeric surfactants, and particulate surfactants. The main obstacle to the industrial production of these green surfactants is the cost of raw materials [6]. BASF, Evonik, Stepan, Jeneil Biosurfactant, AGAE Technologies, TensioGreen, Saraya, UNILEVER and Paradigm Biomedical are examples of companies operating in the global biosurfactant market, which generated around US\$ 2.54 billion in 2020, with an expected reach of up to US\$ 3.56 billion in 2026 [7-8].

Bioremediation aims to mitigate environmental impacts caused by human activities, such as oil spills, and with the help of biosurfactants, it produces satisfactory and highly relevant results. Therefore, studies related to both the production

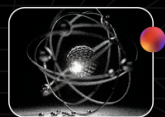
of these compounds, and the reduction of raw material costs are important and contribute to achieving sustainable development goals [9-10].

This article aims to provide a broad overview of microbial surfactant production over the past twenty years, including the challenges of industrial scale-up and future trends.

2. Methodology

The methodology adopted to produce this article was a systematic review. The databases chosen for document collection were Web of Science, Scopus and CAPES Periodicals because they provide not only results but also significant analysis tools. The search began with the selection of related keywords. The Boolean operators "AND" and "OR" were used to further target the data collection. The combination of keywords and Boolean operators was: "microbial biosurfactant" AND ("bioremediation" OR "sustainability" OR "industrial production" OR "treatment" OR "economic viability" OR "cost").

The above combination was entered into the Web of Science and CAPES Periodicals databases under the "All Fields" option. In the Scopus database, it was allocated to the "Article Title, Abstract, Keywords" category. A time filter was used, covering the period between 2005 and 2025, and the search was limited to articles, both review and non-review, in the "open access" category. The results obtained



through the data platforms were then compared to detect and remove duplicates that could alter the discussion of the results. Articles whose titles or abstracts were unrelated to the topic were also excluded, and the results of the analyses conducted using this methodology are presented in Table 1 below.

Table 1. Search methodology

Database	Results	Duplicates	Total
Web of Science	23	19	101
Scopus	33		
CAPEs Periodicals	73		

Source: Own, 2025.

A systematic review was chosen because it provides a comprehensive assessment of the current literature, highlighting existing gaps in published work and proposing directions for future studies based on identified market trends. Future perspectives were based on globalization, the diffusion of technology, and communication in general.

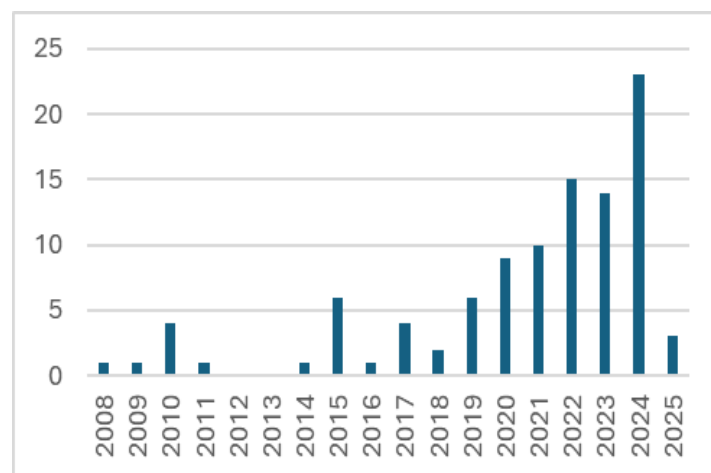
The COVID-19 pandemic was used as a historical milestone for analyzing the results, as it marked a time of great global concern for both human health and the environment, the indiscriminate use of natural resources, and the

dependence on substances from non-renewable sources, such as fossil fuels. Multidisciplinarity was also considered, assessing the need to integrate knowledge sciences to leverage society's arrival to a less consumerist, more sustainable, and meaningful lifestyle, through meeting the sustainable development goals.

3. Results and Discussion

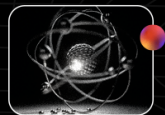
From the 101 final documents obtained, two figures were constructed. Figure 1 below demonstrates the number of publications made over the period studied.

Figure 1. Number of Publications by year on Microbial Biosurfactants



Source: Own, 2025.

Figure 1 shows a significant increase in publications on the production of microbial biosurfactants over the last decade. Based on the results obtained, no papers were published before 2008. In 2020, despite the COVID-19



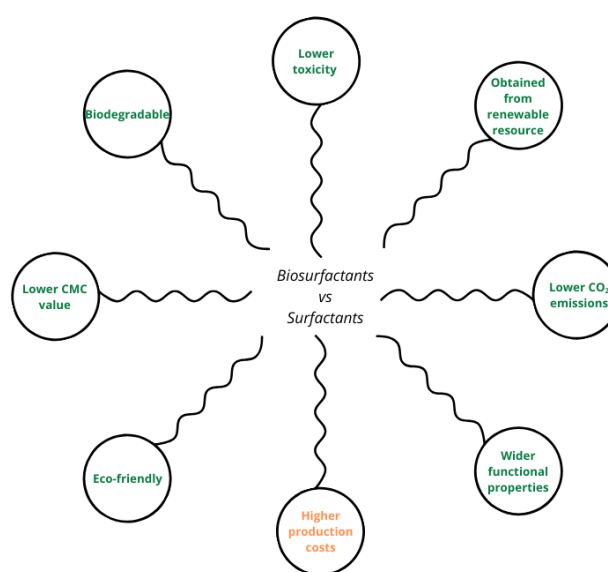
pandemic, publication rates remained unchanged and continued to grow. A plausible explanation is the increase in environmental concerns and current consumption habits. The integration of fields such as chemistry, biotechnology, microbiology, and toxicological sciences is suggested to accelerate discoveries with significant global impact [11-12]. The year 2024 stands out, with the highest number of publications on the topic in the analyzed period, and the maturation of biotechnological tools and strategies may have contributed to both the awakening of interest among various industrial sectors and the dissemination of scientific production.

Over the years, several techniques for producing lower cost biosurfactants have been studied and are still under development. The interest in producing these amphipathic compounds is because they come from renewable sources, have low toxicity, high biodegradability, and tolerance to extreme pH and temperature conditions without loss of surfactant activity [8].

The global dependence on synthetic surfactants of petroleum origin was highlighted during the COVID-19 pandemic, which saw an increase in the consumption of products with cleaning, detergency, and emulsification properties. Conversely, environmental recovery has also been observed in several locations around the globe, simply by reducing human intervention. In this scenario, biosurfactants present an

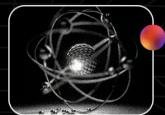
alternative to conventional surfactants, in addition to being bioremediation agents with high potential [13]. Figure 2 below illustrates the main advantages and disadvantages regarding the production of these biocompounds.

Figure 2. Advantages (green letters) and Disadvantages (orange letters) between Biosurfactants and Surfactants.



Source: Adapted from [14].

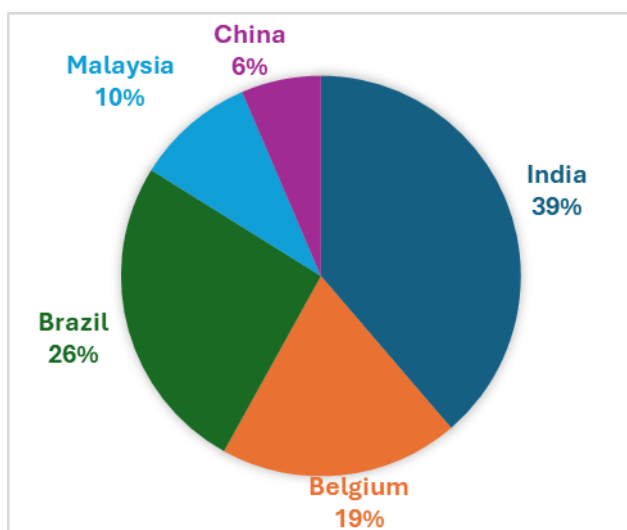
As illustrated in Figure 2 above, biosurfactants have several advantages over synthetic surfactants, such as low CMC (Critical Micelle Concentration), biodegradability, low toxicity, availability from renewable sources, low CO₂ emissions during the degradation process of contaminants, as well as having broad functional properties and being environmentally friendly [14]. However, the raw material costs for producing microbial biosurfactants remain a barrier to their large-scale production and



subsequent competitive commercialization. Although precise data on operational costs are lacking, technological advances over the last decade have enabled the discovery of the production of these compounds from various alternative substrates, primarily those derived from agroindustrial waste [15].

Regarding global reach, Figure 3 below shows the main countries publishing on the topic and their respective percentages.

Figure 3. Leading Countries in Scientific Production on Microbial Biosurfactants



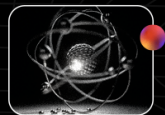
Source: Own, 2025.

India, Belgium, Brazil, Malaysia, and China have distinguished themselves in the production of scientific knowledge on microbial biosurfactants. The strong influence of agribusiness and the consequent high and varied volumes of waste from agroindustrial processes confer high production potential for these bioproducts in these countries [13].

These countries, like most developing countries, face environmental and social problems as they develop industrially. Thus, microbial biosurfactants have been used in the treatment of oily effluents [16], degradation of petroleum hydrocarbons [17], industrial production of cosmetics [18] and formulation of drugs indicated for the treatment of cancer [19], a fact that demonstrates the broad range of applications for solving various global problems.

The industrial production of biosurfactants depends on several factors, ranging from society's consumption habits to business decisions. To competitively introduce microbial bioproducts to the market, studies reveal that customized production tailored to each application is a possible path forward [20], but it is necessary to develop technologies that increase bioproduct yield [13] or discover promising compounds that allow their use at lower concentrations to offset operational costs [20].

The costs of producing sophorolipids range from €2 to €5/kg. The production of rhamnolipids costs US\$20/kg, considering a volume of 20 m³, and US\$5/kg, if produced on a larger scale, of 100 m³ [21]. The use of bioreactors in the production of microbial biosurfactants provided a yield of 40.5 g/L, with an approximate cost between US\$0.14 – 0.15/L and US\$0.02/g [22]. In contrast, the average cost of producing synthetic chemical surfactants is much lower,



ranging from US\$1–3/kg [23], a fact that may justify the difficulty of inserting microbial compounds into the biosurfactant market in a competitive manner, as well as the resistance of organizations to migrate to a sustainable product.

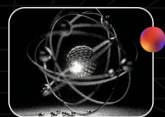
Overall, the results showed a significant increase in scientific production on the topic, where techniques were presented with the aim of increasing process efficiency and yield and reducing energy consumption [24], based on the use of alternative substrates from food industry byproducts [25]. They also demonstrated the existence of challenges, where biorefinery associated with the concepts of circular bioeconomy can be applied, as it uses underexploited biomass to obtain value-added bioproducts, thus reducing raw material consumption and, consequently, operating costs [26].

The growing demand for agricultural chemicals, detergents in general, and the search for green, more sustainable, and bio-based solutions, in addition to stricter environmental regulations on the use of synthetic surfactants, have driven the expansion of the global biosurfactant market. Despite restrictions related to production costs and information gaps linked to low toxicity, biotechnological advances aimed at cost-effectiveness are trends that seek to overcome the challenges of large-scale production [14].

The compilation of microbial biosurfactant production techniques, their various applications, and optimizations contribute to achieving a wide range of Sustainable Development Goals. Goal 8 stands out for promoting economic growth in areas with significant agro-industrial waste; Goal 9 for biologically-derived innovation in the surfactant industry; Goals 11 and 12 for changing consumption habits that lead to greater sustainability; Goals 13, 14, and 15 for demonstrating that the use of waste as raw materials in more sustainable processes protects the climate and life on land and in water; and Goal 17 for highlighting the need for partnerships between organizations, government, academia, and the knowledge sciences.

4. Conclusion

The rise in global concern for the environment, coupled with the emergence of concepts related to green chemistry and the circular economy, is stimulating scientific discoveries in a wide range of fields. It's true that national regulations can influence organizational decisions, but global issues require the constant promotion of theoretical and technical knowledge, which is fundamental to the development of multidisciplinary strategies and greener production methods.



Companies operating in the global biosurfactant market have invested in partnerships to advance the development of strategies that enable increased yield, reduced production costs, and the cautious insertion of bioproducts into the competitive market, either individually or alongside a portfolio of conventional products already commercialized and well-received by consumers. This behavior aligns with future trends, as they indicate that changing consumer habits will drive the search for more natural, sustainable, and environmentally friendly products, leading companies to adapt to meet these demands.

However, the methodology used was sufficient to achieve the proposed objective and to draw attention to the fact that the incentive directed towards scientific research must continue, as this is responsible for disseminating knowledge that serves as a basis for supporting and justifying significant changes in the organizational, social and governmental spheres.

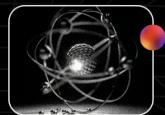
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