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MARKET ANALYSIS OF MICROBIAL SURFACTANTS

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Aim. The purpose of the study was to analyze the global biosurfactant market.

Methods. A bibliometric analysis of scientific publications from databases such as Scopus, Web of Science, DOAJ, and PubMed was conducted to collect information about the microbial surfactant market. A SWOT analysis was conducted to assess the strengths and weaknesses of the biosurfactant market, as well as its opportunities and threats.

Results. It has been shown that the global biosurfactant market reached USD 4.44 billion in 2023 according to various estimates of industry experts. At the same time, its annual growth is predicted on average 5.4–9.1% by 2031. The leader in the global biosurfactant market is Europe with a share of 35%, due to the widespread use of biosurfactants in the composition of detergents, both for industrial and personal use.

Conclusions. The prospects for the biosurfactants market are closely tied to advancements in biomedicine, which will expand their commercial use, as well as efforts to optimize production processes and reduce costs.

Key words: biosurfactants, market study, market segmentation, glycolipids, lipopeptides.

Biosurfactants, or biogenic surfactants, are natural amphiphilic compounds that are synthesized as secondary metabolites by bacteria, yeasts, and fungi and are characterized by surface activity. These compounds have a number of advantages over synthetic surfactants, including low toxicity, high biodegradability, environmental compatibility, and specific activity at extreme temperatures, pH, and, as a result, have higher stability than synthetic surfactants [1]. Given these properties, biosurfactants are widely used as potential substitutes for some products in the pharmaceutical, medical, and cosmetic industries, in the development of detergent formulations, and also for bioremediation of contaminated soils. However, large-scale production and mass application of microbial surfactants are limited by their relatively low yields and associated high production costs.

The lack of standardized methods combined with limited yields of target biosynthesis products has slowed down the commercialization process of biosurfactants [2]. This problem can be partially solved by optimizing the production of microbial surfactants, primarily such key production parameters as pH of the environment, fermentation temperature, aeration and the composition of nutrient media. The main strategies that can increase the efficiency of the biosynthesis of target products and, accordingly, reduce the cost of production include the following: searching for accessible and cheap sources of carbon and nitrogen, selecting nutrient medium components, and

using highly effective genetically modified strains of microorganisms.

This strategy fully fits into the rapidly developing concept of bioeconomy in the world developed countries. The term bioeconomy can also be understood as an economy closely related to the production and processing of biological resources, as well as to the large-scale integration of bioengineering and biotechnology [3]. Therefore, the main goal of the bioeconomy is to ensure sustainable development by reducing dependence on non-renewable resources, reducing the impact on the environment and creating economic benefits.

The economic potential and environmental attractiveness of biosurfactants make them promising substances for replacing synthetic surfactants, and their production is fully consistent with the principles of sustainable development.

Therefore, we analyzed the global market for microbial biogenic surfactants and the possibilities of their industrial application.

The article includes information on the global biogenic surfactant market from open sources, including scientific articles and analytical reports.

Biosurfactant market trends

According to the available data, in 2022, the biosurfactant market size was estimated at USD 3.7 billion with great potential for growth. It is expected to grow at a compound annual growth rate (CAGR) of 8.2% from 2023 to 2031 and reach USD 7.5 billion by the end of 2031 [4].

A similar study reported that bioactive surfactants market size has grown significantly in the recent years. It is expected to grow from USD 4.44 billion in 2023 to USD 4.85 billion in 2024, at a CAGR of 9.2%. The market size is projected to reach USD 6.87 billion in 2028, at a CAGR of 9.1% [5].

Another independent study predicts that the global biosurfactant market will grow from USD 4.65 billion in 2024 to USD 6.71 billion by 2032, at a CAGR of 5.4% over the forecast period [6].

The actual growth of the biosurfactant market is primarily due to their increased use in the pharmaceutical industry, increased demand for cosmetics, increased environmental issues [1, 2], and the need to switch to environmentally friendly solutions in developed countries. According to industry experts, the capacity of the biologically active surfactants market will continue its upward trend in the next few years [6].

The growth of the biosurfactant market in the forecast periods is obviously related to the intensification of scientific research activities, the growing trend towards the transition to clean and renewable energy, and the increase in demand from the agricultural sector [5]. These data indicate significant interest and investment in the biosurfactant manufacturing sector, highlighting the biosurfactant importance in the context of the bioeconomy. An important bioeconomy tool for assessing the strengths and weaknesses of a product, its capabilities and threats is SWOT analysis.

Accordingly, we conducted a SWOT analysis of the biosurfactant market (Table 1).

Market segmentation

Synthetic surfactants are currently used worldwide, as can be seen from Fig. 1. In particular, in the petrochemical industry, a large number of synthetic surfactants are used as agents for cleaning, processing and transporting petroleum products. As can be seen from the diagram, biosurfactants account for only 4% of the total volume (Fig. 1).

Various manufacturers may be interested in the production of biosurfactants:

1. Detergent and industrial cleaning product manufacturers: manufacturers are interested in using biogenic surfactants primarily because of their environmental friendliness, biodegradability and multifunctionality.

2. Petrochemical equipment operators: the use of biosurfactants in biocidal preparations helps to prevent biocorrosion.

3. Pharmaceutical companies: are interested in using biosurfactants to create targeted drug delivery systems, vaccine adjuvants, antimicrobial and antioxidant agents, as well as nanoemulsions and innovative coatings.

4. Cosmetic manufacturers: manufacturers use biosurfactants to create a variety of cosmetic products, including shampoos and hair conditioners.

5. Research organizations: universities, research institutes and other scientific institutions can conduct research to create drugs for various purposes, including medicine, innovative cosmetics, as well as agriculture as biocides and growth stimulants or innovative coatings.

Therefore, it is evident that there are currently stakeholders keen on acquiring and utilizing biosurfactants.

Table 1

SWOT analysis of the biosurfactants market

Strengths	**Weaknesses:**
Environmental appeal. Biosurfactants are environmentally friendly, biodegradable and have low toxicity compared to their synthetic counterparts, which primarily appeals to consumers who are concerned about the environment [1]. *Great potential for application.* Biosurfactants are widely used in detergent, petroleum, pharmaceutical and agricultural industries, providing promising market growth opportunities [7, 8]. *Rapid technological advances.* Scientific research, development and innovation in the field of biotechnology are improving the production methods of biosurfactants, increasing their efficiency and reducing costs [9].	*High production cost.* The production of biosurfactants requires significant investment, including expensive equipment and highly skilled labor, which, as a result, leads to a higher cost of biosurfactants compared to their synthetic analogues [10]. *Limitation of mass production.* Current methods for synthesizing biosurfactants have relatively low productivity, which limits their speed to market and increases their cost [11]. *Strict regulatory requirements.* The production and use of biosurfactants are subject to strict regulatory requirements, which require significant time and financial costs to comply with [6]. *Resistance from established companies.* Major producers of synthetic surfactants are unwilling to shift to biosurfactants, as they prefer to stick with their established production processes and business models, making it difficult for the industry to adopt these more sustainable alternatives [6].
Opportunities	**Threats**
Growing demand for organic products. More and more consumers and companies prefer organic products, which can stimulate an increase in demand [4]. *Development of the new markets.* The development of new markets, especially in developing countries and new industries, contributes to the market growth [6]. *Cooperation and strategic alliances.* The cooperation of biosurfactant companies and strategic alliances can help overcome weaknesses and accelerate the development of the industry [4–6].	*High competition from synthetic analogues.* Synthetic surfactants are usually cheaper and more accessible than biosurfactants, which creates significant competition in the market [10]. *Low consumer awareness:* Lack of information on the part of consumers about the benefits of biosurfactants slows down the growth of the biosurfactant market [4]. *Economic instability.* Changes in the market can adversely affect investments in the industry [10].

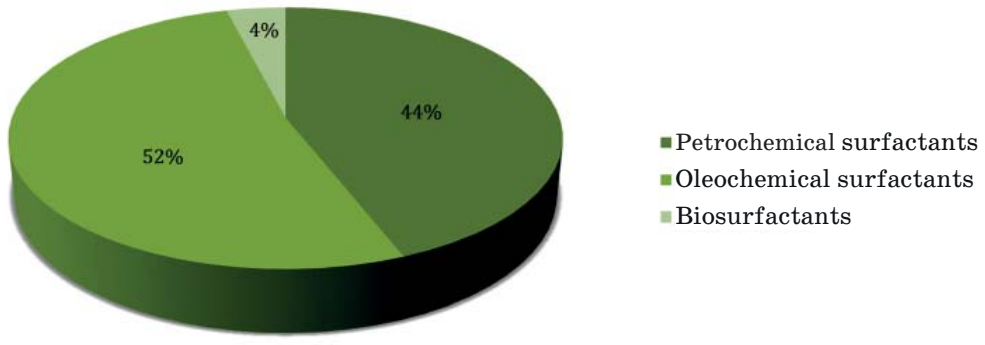

Fig. 1. **Segmentation of the surfactant market [12]**

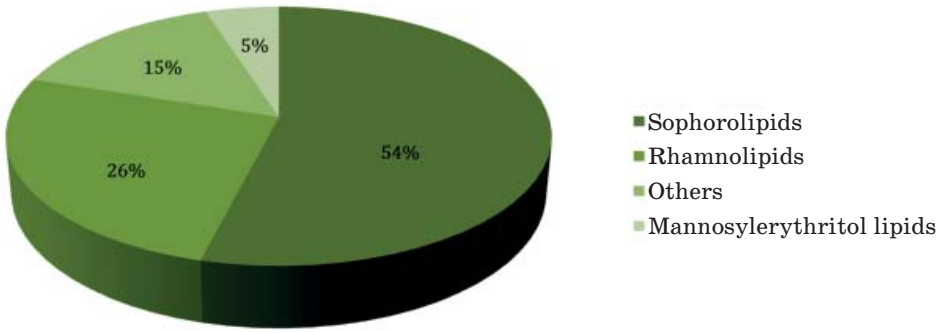

Fig. 2. **Segmentation of the biogenic surfactant market [12]**

All biosurfactants can be divided into two large groups by molecular weight: low molecular weight and high molecular weight. Low molecular weight biosurfactants include lipopeptides, glycolipids, fatty acids, while high molecular weight biosurfactants include polymers and solid particles [2]. Lipopeptides and glycolipids are the most promising types of biogenic surfactants for the pharmaceutical, therapeutic and biotechnological industries. Fig. 2 presents the segmentation of the biosurfactants market by their types.

Analysis of the available data today showed (Fig. 2) that 80% of all biosurfactants currently used are glycolipids. The most famous glycolipids are rhamnolipids and sophorolipids.

Sophorolipids are produced by yeast, they consist of the dimeric sophorose carbohydrate linked to a long-chain hydroxylated fatty acid by means of a glycosidic bond [13]. As can be seen from the presented diagram, the share of sophorolipids in the total amount of biosurfactants is 54%. Rhamnolipids, which are mainly synthesized by the opportunistic bacterium *Pseudomonas aeruginosa* on diverse substrates [14], hold a market share of 26%.

Sophorolipids have low toxicity and high biocompatibility, which makes them particularly attractive for use in the cosmetic, pharmaceutical, and food industries [15]. They show antibacterial, antiviral and antifungal activity, due to which they are widely used in medicine. In addition, sophorolipids are completely biodegradable, which makes them environmentally safe and reduces the risk of environmental pollution. Their stability under different temperature and pH conditions allows them to be used in a wide range of industrial processes [15].

Rhamnolipids, on the other hand, have slightly different advantages and applications. They are known for their ability to effectively destroy biofilms, making them useful in the industrial equipment cleaning and bioremediation of contaminated environments [2]. Rhamnolipids are also used in oil production to improve oil recovery due to their ability to reduce the interfacial tension between water and oil [16]. However, toxicity and lower biocompatibility compared to sophorolipids limit their use in some industries, particularly those where with high human safety requirements and environmental concerns.

According to industry experts, the segment of lipopeptides will be the fastest growing in the future [6]. As the research shows, their potential in environmental restoration is extremely high. Lipopeptides are considered a promising alternative to conventional surfactants due to their biodegradability, low toxicity, and ability to exhibit antimicrobial activity [17].

Geographical segmentation of the biosurfactant market

An important factor affecting the growth of the biosurfactant market is the growing consumer demand for bio-based products, which is associated with an increase in consumer income. Manufacturers are constantly updating their product range to meet the growing demands of end users [18]. It is clear that this, in turn, leads to an increase in the consumption of biosurfactants.

In 2021, Europe became the leader in the global biosurfactant market, holding a dominant share of approximately 35% (Fig. 3) [18]. This significant share is due to the high consumption of biosurfactants in this region, mainly due to the growing demand from the use of detergents.

According to the International Association for Soaps, Detergents and Maintenance

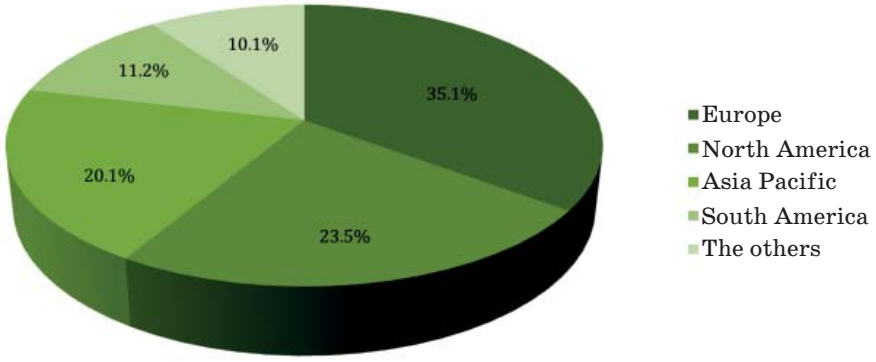

Fig. 3. **Geographical segmentation of the biosurfactant market [18]**

Products (A.I.S.E), the European household cleaning industry was estimated at USD 37 billion in 2020 [18]. This figure indicates a significant growth of 7.3% compared to the previous year, demonstrating the positive dynamics of the industry. At the same time, the industrial detergents sector in Europe also experienced significant growth, reaching USD 10.1 billion. This represents an impressive growth of 22.22% compared to 2019 figures, further highlighting the sustainable growth of the detergent industry in the region [18].

In the EU, the production of detergents is regulated by Regulation (European Commission) No. 648/2004 of the European Parliament and of the Council of March 31, 2004 on Detergents [19] to ensure the free movement of surfactants and detergents on the EU market. This document contains safety requirements for human health and the environment. Its main features include provisions on complete biodegradability, specific information on ingredients and dosage on labels, as well as restrictions on the content of toxic compounds [20].

In the United States, the approval and use of biosurfactants in food products are regulated by the United States Department of Agriculture and require proper labeling or classification as "Generally Recognized as Safe". Biosurfactants, such as those derived from *Candida utilis*, are included in the Code of Federal Regulations under Title 21 (21CFR-172.590), as recognized by the federal Department of Health and Human Services and the Food and Drug Administration. This regulatory framework ensures that biosurfactants meet safety standards for human health, enabling their controlled use in various food-related applications [21].

In China, the regulation of chemical substances, including biosurfactants, is overseen by the Ministry of Ecology and Environment (MEE) under China Regulations on the Environmental Management of New Chemical Substances as per MEE Order No. 12. This regulation mandates that manufacturers or importers register new chemical substances prior to their market introduction, with the type of registration (regular, simplified, or record) based on the volume of production or import. Biosurfactants produced in quantities greater than one ton annually must undergo registration, which includes providing risk assessments for human health and environmental impacts. Additionally, registrants need to submit data on the substance's persistence, bioaccumulation, and toxicity [22].

Regulatory requirements for biosurfactants in developed countries are designed to ensure the safety of human health and the environment, though they are implemented in different ways. These regulations set standards for the ecological safety and biodegradability of biosurfactants, ensuring they meet environmental protection criteria.

As mentioned above, recent studies confirm that biosurfactants can be more effective than synthetic surfactants [1, 2]. A comparative study by Jimoh et al. [23] demonstrated that a lipopeptide biosurfactant isolated from *Paenibacillus sp.* D9, showed more than 60% effectiveness in removing coffee and tomato sauce stains compared to commercial surfactants. Also, the biosurfactant obtained from *Pseudomonas aeruginosa* ATCC 10145 ensured the removal of almost 100% of special fuel oil B1, as well as the dispersion of 98% of automotive grease stains on fabric [24].

The global cosmetics industry is gradually shifting towards innovative ingredients that have fewer side effects and are also more effective. Accordingly, the industry is

benefiting from the growing demand for such products, and consumers are becoming more aware of the capabilities of these products.

A study by Rincon-Fontan et al. [25] showed the stabilization of vitamin C by introducing a biosurfactant extract, derived from the corn wet-milling process, into an aqueous solution of L-ascorbic acid. Vitamin C is widely used in the cosmetics industry, playing an important role in collagen production and skin protection. Box-Benken design showed how various concentrations of vitamin C and biosurfactant, along with storage time, affected vitamin C degradation. Biosurfactant significantly inhibited degradation, reducing it by up to 58% after 14 days compared to solutions without the biosurfactant.

On the other hand, biosurfactants are often used to create biocidal preparations for agriculture and petrochemistry [7, 8]. For example, the effectiveness using glycolipid as an environmentally friendly biocide in corrosion of carbon steel, widely used in many sectors of the gas and oil industry, has been shown [26]. It is known that microbial corrosion accounts for 30–40% of the total volume of corrosion problems in the oil and gas industry [26].

Another promising direction of using biosurfactants is the creation of innovative coatings, mainly for medical textiles. A study by Firdose et al. [27] showed the protective role of a rhamnolipid-based coating against the formation of biofilms by pathogens such as *Enterococcus faecium* and *Acinetobacter baumannii*. Thus, at a concentration of 31.2 μg/ml, rhamnolipids reduced the concentration of *Enterococcus faecium* cells on the surface by 91%, while to reduce *Acinetobacter baumannii* cells by 76%, the concentration of rhamnolipids was much higher and amounted to 250 μg/ml [27].

Accordingly, information on the biosurfactant-based product market is provided in Table 2.

Another segment related to the development of antimicrobial drugs based on biosurfactants is considered one of the most promising today [2]. The synergistic effect of biogenic surfactants and antibiotics was demonstrated by Shusterman et al. [28].

It was shown that rhamnolipids in combination with antibiotics increased the zones of inhibition against *E. coli* for four out of six antibiotics tested (ampicillin, chloramphenicol, erythromycin, kanamycin and tetracycline). When testing against *Bacillus megaterium*, the authors [28] observed an increase in the zone of inhibition for all six tested antibiotics. In a study by Amirinejad et al. [29], it was shown that a glycolipid synthesized by *Shewanella algae* exhibits antimicrobial properties both alone and when used together with ciprofloxacin and gentamicin, and when used simultaneously with gentamicin or ciprofloxacin, 99% efficiency in disrupting biofilms was achieved.

Today, the biosurfactant market is consolidated and its considerable capacity is occupied by five key players. As can be seen from Table 2, the leaders of the biosurfactant market are Evonik Industries AG, BASF SE, Ecover, Jeneil and Givaudan [4]. As mentioned above, the largest share of the biosurfactant market in 2024 is Europe, mainly Germany, UK, France, and Italy [6]. This is due to both the developed chemical, pharmaceutical and oil and gas industries, as well as the increased public awareness of the principles of sustainable development [5].

Another reason for such growth is the development of innovative products, as there is competition between manufacturers to maintain consumer interest [18]. However, market analysts believe that by 2029, the highest growth rates of the biosurfactant market will be observed in the Asia Pacific region, which is associated with both an increase in the population and their standard of living [30].

Conclusions

Marketing research indicates that the global biosurfactant market is experiencing steady annual growth, with promising prospects for further expansion due to the unique characteristics of these compounds and the development of innovative products. However, biogenic surface-active substances currently represent only a tiny segment of the overall surfactant market, comprising just 4%. Among all biosurfactants, sophorolipids and rhamnolipids are the most frequently utilized, holding market shares of 54% and 26%, respectively. The primary applications of biosurfactants include the production of detergents, cosmetics, and pharmaceuticals, as well as their use in petrochemistry and agriculture. Advances in biotechnology are enhancing production efficiency, reducing costs, and improving market viability.

However, significant challenges persist, notably high production costs and mass

Table 2

Biosurfactant-based products market [6]

Aspect	Description
Product type	Glycolipids
	Phospholipids
	Lipopeptides
	Polymeric biosurfactants
	Other products
Use	Detergents, including those for industrial use
	Cosmetic products
	Agro-preparations
	Food industry
	Petrochemistry
	Textiles (innovative coatings)
	Others
Supply chains	Supermarkets/Hypermarkets
	Online shopping
	Pharmacies
	Specialized cosmetics stores
Main market players	Evonic Industries AG (USA)
	BASF SE (Germany)
	Ecover (Germany)
	Jeneil (USA)
	Givaudan (Switzerland)
	GlycoSurf LLC (USA)
	Holiferm (UK)
	Stepan Company (USA)
	Tensiogreen (USA)
	Biotensidon GmbH (Germany)
	Saraya Co. Ltd (Japan)
	TeeGene Biotech (UK)
	WHEATOLEO (France)

production limitations. Strict regulatory requirements and resistance from established synthetic surfactant producers also hinder widespread adoption. Despite these challenges, the increasing demand for organic products and opportunities in emerging markets present strong growth potential.

The major threats include:

- Competition from cheaper synthetic alternatives.
- Low consumer awareness of biosurfactants.
- Potential economic instability that could impact investment in this sector.

Author Contributions

Y.Y.B. and H.V.V. developed the concept of the review, performed the literature review and collected relevant sources, drafted the manuscript, and revised and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest

Authors declare that there is no conflict of interest.

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АНАЛІЗ РИНКУ МІКРОБНИХ СУРФАКТАНТІВ

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Мета. Аналіз світового ринку біогенних поверхнево активних речовин (біосурфактантів).

Методи. Бібліометричний аналіз наукових статей та аналітичних матеріалів таких баз даних, як *Scopus*, *Web of Science*, *DOAJ*, and *PubMed*. Для оцінювання сильних та слабких сторін глобального ринку біосурфактантів, його можливостей та загроз використано SWOT-аналіз.

Результати. Показано, що світовий ринок біоПАР за різними оцінками експертів галузі у 2023 році досяг 4,44 млрд доларів США. При цьому прогнозується його щорічне зростання в середньому 5,4–9,1% до 2031 року. Лідером на світовому ринку біосурфактантів є Європа з часткою 35%, завдяки широкому використанню біоПАР у складі мийних засобів, як для промислового, так і особистого користування.

Висновки. Перспективи ринку біосурфактантів тісно пов'язані з дослідженнями в галузі біомедицини, що дасть змогу розширити їх комерційне використання, а також у напрямку оптимізації їх виробництва для зниження собівартості продукції.

Ключові слова: біосурфактанти, маркетингові дослідження, сегментація ринку, гліколіпіди, ліпопептиди.