Scientific Bulletin. Series F. Biotechnologies, Vol. XXVIII, No. 1, 2024
ISSN 2285-1364, CD-ROM ISSN 2285-5521, ISSN Online 2285-1372, ISSN-L 2285-1364

CLASSIFICATION AND INDUSTRIAL APPLICATIONS OF BIOSURFACTANTS – MINIREVIEW

Georgiana-Gabriela IORDACHE, Narcisa-Elena BABEANU

University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Mărăști Blvd., Bucharest, Romania

Corresponding author email: iordachegeorgianagabriela@gmail.com

Abstract

A well-developed industrial sector based on biotechnology will significantly reduce dependence on chemical resources, contributing to climate change objectives and leading to a greener and more environmentally friendly growth. The key lies in developing new technologies for the sustainable transformation of renewable natural resources into bio-based products and biofuels. Bioeconomy involves the production of renewable biological resources and their conversion into food, feed, and bio-based products through innovative and efficient technologies provided by industrial biotechnology. This paper presents a general classification of biosurfactants used in industrial applications. The term "surfactant" is derived from "surface-active agent." Biosurfactants have become increasingly significant across various fields owing to their diverse properties, including enhanced biodegradability and reduced toxicity. They are categorized into high and low molecular weight molecules. Biosurfactants find applications in industries such as cosmetics, food processing, pharmaceuticals, and environmental bioremediation. While numerous surfactants are already in use in various industries, it's essential to develop indigenous technologies for the production of biosurfactants from local micro-organism. This would ensure their suitability for application in specific environments.

Key words: *bioremediation, biosurfactants, emulsifiers, industry, microorganisms.*

INTRODUCTION

Biosurfactants enhance the surface area of hydrophobic substrates that are insoluble in water, which organisms utilize for their growth and function effectively in processes such as biodegradation, bioremediation, and biocontrol processes.

Microorganisms that utilize hydrocarbons produce a surface-active agent known as biosurfactant, which accelerates these processes. Various methods exist to test the biosurfactant potential of bacterial isolates, including hemolytic activity, drop collapse test, oil spreading test, emulsification index test, blue agar plate test, CTAB agar plate method, and hydrocarbon overlay agar method. This article discusses the classification, properties, methods, and significance of biosurfactants (Amaral et al., 2009).

Shete et al. (2006) charted the patents related to biosurfactants and bioemulsifiers, revealing a significant number of patents in industries such as petroleum (33%), cosmetics (15%), antimicrobial agents and medicine (12%), and bioremediation (11%). Notably, sophorolipids (24%), surfactin (13%), and rhamnolipids (12%) represent a substantial portion of these patents.

The physiological role of biosurfactant production in microorganisms includes antimicrobial activity and facilitating the availability of substrates for cell absorption under adverse environmental conditions. Biosurfactants are classified based on molecular weight and chemical composition (Maneerat, 2005). They offer advantages such as biodegradability, reduced toxicity and enhanced surface and interface activity, yet challenges include limitations in production scalability and patent rights. Factors influencing biosurfactant production encompass the carbon source, nitrogen source, C:N ratio, temperature, aeration and pH. Biosurfactants find applications in agriculture, industry, medicine, and the petroleum sector.

Surfactants, the active ingredients in soaps and detergents, concentrate at air-water interfaces and are commonly used to separate oily matters from specific environments by increasing the water solubility of non-aqueous liquids and reducing surface/interfacial tension at air-water and oil-water interfaces.

The main classes of biosurfactants include glycolipids, phospholipids, polymeric biosurfactants, and lipopeptides (surfactin). Glycolipids, such as rhamnolipids, sophorolipids, and trehalolipids, are well-known, while surfactants, widely used in various applications, are often chemically synthesized, posing potential environmental and toxicological risks. With advancements in biotechnology, there is increasing interest in environmentally friendly processes for producing biosurfactants from microorganisms (Cohen & Exerowa, 2007).

Classification of Biosurfactants

Biosurfactants are classified based on their molecular weight and chemical composition.

Classification based on Molecular Weight

Biosurfactants with low molecular weight, typically glycolipids or lipopeptides, reduce surface and interfacial tension at air/water interfaces. Examples include rhamnolipids, trehalolipids, and sophorolipids, which consist of acylated disaccharides with long-chain fatty acids or hydroxylated fatty acids. Often referred to as bioemulsifiers, biosurfactants with high molecular weight are more efficient in stabilizing oil-in-water emulsions and exhibit extended substrate specificity. They contain long-chain fatty acids or fatty acid derivatives in their hydrophobic moiety and can include carbohydrates, amino acids, phosphate, or cyclic peptides in their hydrophilic portion (Tahzibi et al., 2004).

Classification based on Chemical Structure

Glycolipids are carbohydrates, such as glucose, mannose, galactose, and rhamnose, combined with long-chain aliphatic acids or hydroxy aliphatic acids through ether or ester groups. Rhamnolipids, trehalolipids, and sophorolipids are prominent examples, with other glycolipids including cellobiolipids (Monteiro et al., 2007).

Rhamnolipids are composed of rhamnose molecules linked to one or two molecules of β-hydroxydecanoic acid. The glycosidic linkage involves the OH group of one of the hydroxydecanoic acids with the reducing end of the rhamnose disaccharide; the OH group of the other hydroxydecanoic is involved in ester formation (Monteiro et al., 2007).

Trehalolipids. Trehalose is a non-reducing disaccharide in which the two glucose units are linked by an α,α-1,1-glycosidic bond. It is the basic component of cell wall glycolipids in mycobacteria and corynebacteria. Several trehalose lipid structures are found.

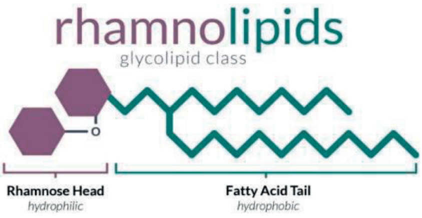

Figure 1. Chemical formula for Rhamnolipids

Sophorolipids. Many yeast species, such as *Torulopsis bombicola*, *T. petrophilum* (Cooper & Paddock, 1983), and *T. apicola*, mainly produce sophorolipids. Sophorolipids are dimeric sophorose carbohydrates linked to long-chain hydroxylated fatty acids, with a mixture containing at least six to nine different hydrophobic sophorosides. While sophorolipids are capable of reducing surface and interfacial tension, they are not highly effective as emulsifying agents (Cooper & Paddock, 1984).

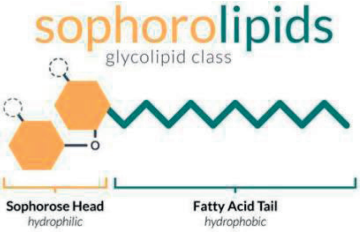

Figure 2. Chemical formula for Sophorolipids

Lipopeptides and Lipoproteins. Bacteria like *Bacillus brevis* and *Bacillus polymyxa* produce numerous cyclic lipopeptides, including decapeptide antibiotics (e.g., gramicidin) and lipopeptide antibiotics (e.g., polymyxin), which exhibit remarkable surface-active properties. These compounds consist of a lipid attached to a polypeptide chain (Desai & Banat, 1997; Muthusamy et al., 2008).

Fatty Acids, Phospholipids, and Neutral Lipids. Certain bacteria and yeasts produce significant amounts of fatty acids and phospholipid-like surfactants when grown on n-alkane substrates. These surfactants, resulting from microbial oxidations, include straight-chain acids and complex fatty acids containing hydroxyl and alkyl branch groups, such as corynomuolic acids (Rahman & Gakpe, 2008).

Phospholipids are major constituents of microbial membranes. When hydrocarbon-degrading bacteria or yeasts grow on alkane substrates, the levels of phospholipids in their membranes increase significantly. For instance, when the bacteria *Acinetobacter sp.* HO1-N grows on hexadecane substrate, it primarily produces phosphatidylethanolamine (Muthusamy et al., 2008).

Polymeric Microbial Surfactants. Many biosurfactants are polymeric heteropolysaccharides containing proteins. Prominent examples include emulsan, liposan, manoprotein, and protein-polysaccharide complexes (Desai & Banat, 1997).

Particular biosurfactants. Certain bacteria produce extracellular membrane vesicles that facilitate the partitioning of hydrocarbons and the formation of microemulsions. These microemulsions play a crucial role in the absorption of alkanes by microbial cells, such as those produced by *Acinetobacter* sp. (Desai & Banat, 1997).

Properties of biosurfactants:

- Reduction of water surface tension;
- Excellent capacity for micelle critical concentration (CMC) formation;
- Low lethality;
- Good compatibility and digestibility.

Methods for Evaluating Biosurfactant Efficiency

Various methods are employed to assess the efficiency of biosurfactants, including the hemolysis test, oil spreading test, drop collapse method, emulsification index, hydrocarbon overlay agar method, and blue agar method (Amalesh et al., 2012).

Hemolytic activity. In this test, the isolate is streaked onto a blood agar plate and then incubated at 37°C for 48-72 hours. After the incubation period, the presence of a halo zone around the indicated colonies indicates a positive result. This halo zone is categorized as alpha, beta, or gamma hemolysis. Alpha-hemolysis manifests as a greenish zone around the inoculum, beta-hemolysis presents as a clear white zone around the inoculated colony, and gamma-hemolysis occurs when there is no change around the streaked colony.

Oil spreading test. Two layers are formed on an empty Petri dish: water as the first layer and hydrocarbons as the second layer. The cell-free extract of the 24-hour isolate is added to the surface of the Petri dish. A clear zone around the culture indicates a positive result, and the diameter of this clear zone is measured. A water drop serves as a control (Langer et al., 2006).

Drop collapse test. This qualitative test assesses biosurfactant activity. The isolated strains are placed on a hydrocarbon surface, and the collapse of suspension drops without cells indicates a positive result. A water drop serves as a control (Langer et al., 2006).

Emulsification index test. This is a quantitative process where 2 ml of hydrocarbon is mixed with 2 ml of a 48-hour grown culture suspension in test tubes. The mixture is then vortexed for 2 minutes and allowed to stand for 24 hours. After incubation, the emulsification index is calculated according to standard methodologies (Langer et al., 2006).

Blue agar plate method or CTAB agar plate method detects extracellular glycolipid production. A CTAB agar plate containing methylene blue (5 mg/mL) and cetyltrimethylammonium bromide (CTAB) (0.2 mg/mL) is prepared. The 24-hour bacterial isolate is inoculated in spots on the plate and then incubated for 24 to 48 hours. The formation of a dark blue color indicates extracellular glycolipid production (Langer et al., 2006).

Hydrocarbon overlay agar method. In this method, an LB agar plate covered with hydrocarbons is inoculated with a 24-hour culture. The plate is then incubated at 37°C for 48 to 72 hours. After inoculation, growth is observed on the LB plate, and a colony surrounded by emulsified halos is considered positive for biosurfactant production (Kitamato et al., 2002).

Importance of biosurfactants for microbial cells. Biosurfactant production provides a selective advantage to slow-growing microorganisms over fast-growing ones. These compounds are secreted extracellularly or attached to cell surfaces, primarily on water-immiscible substrates, and play a crucial role in increasing the availability of nutrient substrates. Additionally, biosurfactants exhibit antimicrobial activity, enabling microorganisms to increase their cellular biomass (Kitamato et al., 2002).

An organism produces different types of biosurfactants with extensive applications in the petroleum field, as described in Table 1.

Table 1. Microorganisms involved in bioremediation (Silva et al., 2014)

Type of biosurfactant*	Application	Microorganism
Glucolipids and trehalose lipids	Operations for cleaning oil stains	*Rhodococcus erythropolis* 3C-9
Trehalose tetra ester	Bioremediation in petroleum-contaminated environments	*Micrococcus luteus* BN56
Lipopeptide	Bioremediation of marine oil pollution Environmental applications	*Rhodococcus* sp. TW53 *Bacillus subtilis* BS5 *Nocardiopsis alba* *zotobacter chroococcum*
Rhamnolipid	Bioremediation in petroleum-contaminated environments Bioremediation of marine oil pollution Environmental applications Bioremediation of marine and soil environments	*Pseudomonas aeruginosa* S2 *Pseudomonas aeruginosa* BS20 *Pseudoxanthomonas* sp. PNK-04 *Pseudomonas alcaligenes* *Pseudomonas cepacia* CCT6659 *Pseudomonas cepacia* CCT665
Glycolipids	Bioremediation applications Bioremediation of marine and soil environments	*R. wratislaviensis* BN38 *Pseudozyma hubeiensis* *Nocardiopsis lucentensis* MSA04
Sophorolipid	Environmental applications Bioremediation of marine environments	*Candida bombicola* *Candida lipolytica* UCP0988

**The table presented outlines different types of biosurfactants, their applications, and the microorganisms involved in bioremediation according to a study by Silva et al. from 2014.*

Bioremediation of soil environments

Biodegradation by soil microorganisms. Soil contains various microbial communities that play key roles in breaking down organic pollutants. Bacteria, fungi and other microorganisms produce enzymes that degrade complex chemicals into simpler, less harmful compounds (Kitamato et al., 2002).

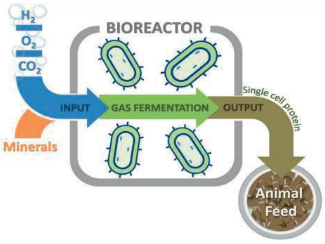

Figure 3. The stages of gas fermentation

Phytoremediation in soil: Similar to marine phytoremediation, plants can be used to extract pollutants from soil or water. Plant roots absorb contaminants, which are then either stored in the plant tissues or broken down into less toxic forms (Konishi et al., 2007; Csutak et al., 2017).

Bioaugmentation. This involves introducing specific microorganisms into contaminated soil to enhance biodegradation processes. Selected strains of bacteria or fungi may be added to the soil to accelerate the breakdown of pollutants (Konishi et al., 2007).

These methods represent different approaches to bioremediation, each with its advantages and limitations. By harnessing the natural abilities of microorganisms and plants, bioremediation offers a sustainable and environmentally friendly solution to pollution problems in marine and soil environments

Bioremediation, in general, represents a sustainable and efficient approach in the fight against pollution, contributing to the regeneration and conservation of marine and terrestrial ecosystems. It is important to consider the local characteristics of the environment and the species involved before implementing specific bioremediation techniques. Microbial biosurfactants are compounds produced by microorganisms such as bacteria, fungi, or algae, and they possess surfactant properties. Surfactants are substances that enhance the water's ability to disperse and interact with other substances, such as oils and fats (Konishi et al., 2007).

Microbial biosurfactants have several key characteristics (Mukherjee et al., 2006):

- **Microbial origin**: they are produced by microorganisms such as bacteria (e.g., *Pseudomonas, Bacillus),* fungi (such as *Candida, Aspergillus*), or algae.
- **Chemical diversity**: there is a variety of chemical structures found in microbial biosurfactants, including glycolipids, lipoproteins, polysaccharides, peptides and phospholipids.
- **Surfactant properties**: these compounds possess the capability to decrease the surface tension of water and promote the dispersion of fatty substances in water or vice versa.
- **Role in bioremediation**: microbial biosurfactants are applied in various fields, especially in bioremediation, due to their ability to facilitate the breakdown and

removal of hydrophobic compounds, such as hydrocarbons, from soil or water.

- **Synthesis in diverse conditions**: a great advantage of microbial biosurfactants is their ability to be synthesised in various environments, including extreme conditions such as high or low temperatures and in the presence of high salt concentrations.
- **Biotechnological potential**: due to their distinctive characteristics, microbial biosurfactants are valuable compounds for biotechnology, but can also be used in other industries such as oil and gas, agriculture, food processing and bioremediation.
- **Favorable ecological effects**: the use of microbial biosurfactants in bioremediation processes offers numerous environmental benefits, because they can increase the bioavailability of contaminants and facilitate the activity of microorganisms implicated in their degradation. The use of microbial biosurfactants in bioremediation technologies is an environmentally friendly and sustainable approach to treating and removing pollutants from various environments.

The Relevance of Biosurfactants in Other Fields

Global production of biosurfactants has grown significantly, with an estimated annual growth rate of around 3 to 4%. The specific applications of surfactants are categorized based on their importance within their respective fields.

In **agriculture**, compounds with surface activity are used to hydrophilize heavy soils to maintain their nutrient retention capacity.

Agricultural productivity is a serious concern for all developing countries in meeting the ever-increasing needs of the human population. There is a need for the use of ecological compounds to achieve productive agriculture, and globally, on average, 35% of agricultural yield is lost due to pre-harvest pests. Today, conventional chemical pesticides used in agriculture are still under pressure to be phased out due to their harmful effects on the ecosystem, and resistance of bacteria and fungi also poses a significant barrier to their use (Mukherjee et al., 2006).

Recently, biosurfactants have become one of the promising biopesticides. Biopesticides have gained attention in managing fungi, pests and insects, and have been presented as potential alternatives to chemical pesticides. Scientific reports have mentioned the use of microbial biosurfactants in controlling diseases caused by fungi, in combating harmful insects. Lipopeptide and rhamnolipid biosurfactants have low toxicity to the ecosystem and are highly biodegradable, representing promising surface-active compounds that can be used as biopesticides. So far, rhamnolipid biosurfactants have been successfully studied and commercialised in the field of biopesticides. Growing environmental concerns about pesticides and agrochemicals are a real boost for the use of environmentally friendly chemicals in the agrochemical industry, where biosurfactants may be the best alternative. This section examines lipopeptide and rhamnolipid biosurfactants as biopesticides and promising alternatives to chemical pesticides (Mukherjee et al., 2006).

Biosurfactants hold considerable potential in **medicine** due to their unique properties and characteristics. Here are some potential applications of biosurfactants in the medical field (Sullivan, 1998):

- Biosurfactants can enhance wound healing by promoting cell migration, proliferation and angiogenesis. They can also aid in the removal of debris and promote tissue regeneration.
- Biosurfactants can be utilized to formulate drug delivery systems such as liposomes, micelles and nanoparticles. These systems can improve the solubility, stability and bioavailability of drugs, leading to enhanced therapeutic efficacy and reduced side effects.
- Some biosurfactants exhibit antimicrobial properties and can be used to develop antimicrobial formulations for treating infections caused by bacteria, fungi and viruses. They can disrupt microbial cell membranes, inhibit biofilm formation and enhance the activity of conventional antimicrobial agents.
- Biosurfactants have been shown to possess anti-inflammatory properties and can modulate inflammatory responses. They can be used to develop new therapeutics to treat inflammatory conditions such as arthritis, dermatitis, and inflammatory bowel disease.
- Biosurfactants can be incorporated into scaffolds and matrices used in tissue

engineering applications. They can improve the mechanical properties, biocompatibility and cell adhesion of tissue-engineered constructs, facilitating tissue regeneration and repair.

Biosurfactants have diverse applications in medicine and hold great promise for the development of new therapeutic strategies and medical devices. Continued research and innovation in this field are essential to fully appreciate the potential of biosurfactants in improving human health and well-being.

Biosurfactants have a wide range of applications in various industries due to their unique properties and environmental benefits. There are several significant **industrial applications** where biosurfactants play an important role, like (Tabatabaee et al., 2005):

- *Oil and gas.* Biosurfactants are used in enhanced oil recovery (EOR) processes to improve the efficiency of oil extraction from reservoirs. They can reduce interfacial tension between oil and water, alter the wettability of reservoir rocks and mobilize trapped oil, leading to increased oil production.
- *Agriculture.* Biosurfactants can be used as adjuvants in agricultural formulations to enhance the efficacy of pesticides, herbicides and fertilizers. They can improve the spreading, wetting and penetration of agrochemicals, resulting in better crop protection and increased yields.
- *Food and beverage.* Biosurfactants are used in food processing and manufacturing to emulsify, stabilize foam food products. They can improve the texture, appearance and shelf-life of food products, as well as reduce the use of synthetic additives and preservatives.
- *Cosmetics and personal care.* Biosurfactants are used in cosmetics and personal care products such as shampoos, soaps, and skin creams. They can act as gentle cleansers, moisturizers and foaming agents, providing mild and sustainable alternatives to synthetic surfactants.
- *Pharmaceuticals.* Biosurfactants have potential applications in pharmaceutical formulations as drug delivery systems, emulsifiers and stabilizers. They can improve the solubility, stability and bioavailability of drugs, leading to enhanced therapeutic efficacy and reduced side effects.
- *Environmental remediation.* Biosurfactants are used in bioremediation processes to degrade and remove pollutants from soil, water, and air. They can enhance the bioavailability of contaminants, stimulate microbial activity and promote the degradation of hydrocarbons, heavy metals and other pollutants.

Biosurfactants offer sustainable and eco-friendly solutions to various industrial challenges and have the potential to replace conventional surfactants derived from petrochemicals. Continued research and development in this field are essential to reveal the full potential of biosurfactants in industry and to promote sustainable development.

Biosurfactants are gaining more and more attention in the *food industry* due to their potential applications and benefits. The following describes the ways in which biosurfactants are explored in the food industry.

- *Emulsification and stabilization*: they can act as emulsifiers, helping to stabilize oil and water emulsions in food products such as salad dressings, sauces, and mayonnaise. They improve the texture, appearance and shelf-life of these products by preventing phase separation and maintaining a homogeneous mixture (Tabatabaee et al., 2005).
- *Foaming and whipping:* they can enhance the foaming and whipping properties of food products such as whipped cream, meringues and mousses. Biosurfactants increase the volume and stability of foam structures, resulting in lighter textures and improved mouthfeel (Tabatabaee et al., 2005).
- *Fat reduction*: they can be used to reduce the amount of fat or oil in food formulations without compromising sensory attributes such as taste and texture. By forming stable emulsions and reducing the surface tension of water, biosurfactants enable the dispersion of fat droplets throughout the food matrix, resulting in lower fat content and healthier food options.
- *Antimicrobial properties*: some biosurfactants exhibit antimicrobial properties and can be used to inhibit the growth of pathogenic bacteria and fungi in food products. They can

be incorporated into food packaging materials or applied directly to food surfaces to extend shelf-life and improve food safety.

- *Clean label ingredients*: they derived from natural sources offer clean label alternatives to synthetic emulsifiers and stabilizers commonly used in processed foods. Consumers are increasingly seeking clean label products with minimal additives and biosurfactants provide a sustainable and eco-friendly option for food manufacturers (Rodrigues et al., 2006).
- *Encapsulation and delivery of bioactive compounds*: they can be used to encapsulate and deliver bioactive compounds such as vitamins, antioxidants and flavors in food products. They improve the solubility, stability and bioavailability of these compounds, enhancing their functionality and nutritional value (Rodrigues et al., 2006).

Overall, biosurfactants offer versatile and sustainable solutions for improving the quality, safety and nutritional value of food products. Continued research and innovation in this field are essential to unlock the full potential of biosurfactants in the food industry and meet the evolving needs and preferences of consumers.

Biosurfactants play a significant role in the food industry due to their biocompatible, biodegradable and non-toxic nature, offering a range of beneficial properties. They function as emulsifiers, foaming agents, wetting agents, solubilizers, adhesive agents and antimicrobial agents, making them versatile additives (Cameotra & Makkar, 2004).

In food applications, emulsions play a crucial role, where biosurfactants contribute to their stability and texture. Emulsifiers are particularly valuable in low-fat products, enhancing their creaminess and texture (Ron & Rosenberg, 2002). Polymeric surfactants form stable emulsions, preventing coalescence, which is advantageous for cosmetics and food formulations.

Biosurfactants also serve as food stabilizers, aiding in consistency control in bakery and ice cream products. They act as fat stabilizers and anti-spattering agents during cooking with oils and fats (Kosaric, 1992). In food processing, rhamnolipid surfactants enhance the texture and shelf life of starch-containing products, influencing the rheological properties and stability of dough. Additionally, surfactants help control fat globule agglomeration, stabilize aerated systems and improve the texture of fat-based products.

Moreover, L-Rhamnose, derived from hydrolyzing rhamnolipid surfactants produced by *P. aeruginosa*, has industrial applications as a precursor to high-quality flavor components like Furaneol .

Biosurfactants are increasingly recognized as valuable food additives due to their multifunctional properties, including emulsifying, anti-adherent and antimicrobial activities. In food processing, where the aim is not only to ensure safety but also to maintain taste, appearance and aroma, additives play a crucial role in enhancing the final product's quality and appeal.

Emulsifiers are vital components in food manufacturing, facilitating the mixing of immiscible phases by reducing surface tension at their interface. While traditional emulsifiers like lecithin derived from soy and egg, and synthetic emulsifiers, have long been used, the growing demand for natural or organic ingredients in functional foods presents an opportunity for new alternatives. Biosurfactants, due to their natural origin, environmentally friendly nature and unique properties, hold promise as efficient emulsifiers in the food industry. Their ability to reduce toxicity and meet consumer preferences for natural ingredients further strengthens their potential market.

Moreover, biosurfactants exhibit antimicrobial properties against various microorganisms, including bacteria, yeasts, fungi, algae and viruses (Nitschke & Costa, 2007). Lipopeptides, a well-known class of biosurfactants, demonstrate notable antimicrobial activity, with surfactin from *Bacillus subtilis* being a prime example (Das et al., 2009; Fernandes et al., 2007). This antimicrobial action extends to other lipopeptides produced by *Bacillus* species, such as fengycin, iturin, bacillomycin and myco-subtilin (Das et al., 2007).

Aside from their applications in the food industry, biosurfactants find utility in other sectors such as petroleum and pharmaceutical industries. In petroleum recovery processes, biosurfactants aid in the degradation of hydrocarbons, enhancing oil recovery by microorganisms and facilitating the cleaning of oil reservoirs and storage tanks (Perfumo et al., 2010).

Furthermore, biosurfactants demonstrate potential in pharmaceutical applications, including genetic manipulation techniques. Studies have shown that biosurfactant-based liposomes exhibit higher efficiency in genetic transfection compared to commercially available cationic liposomes, making them a promising tool in gene therapy and other biomedical applications (Gharaei-Fathabad, 2011; Kitamato et al., 2002). In the last decade, some techniques and methodologies have been developed for liposome-based gene transfection. Ueno et al. in 2007 examined liposome containing MEL-A for genetic transfection by introducing biosurfactants into this field.

Biosurfactants in Pollution Control

According to reported literature, biosurfactants have the ability to emulsify hydrocarbon-water mixtures (Zhang and Miller, 1992). In the current era, petroleum pollution accidents have become numerous and have caused social and ecological catastrophes (Burger, 1993; Burns et al., 1993), and in these cases, the emulsifying properties of biosurfactants make them potentially useful tools for controlling petroleum pollution, by enhancing hydrocarbon degradation in the environment (Atlas, 1993; Bertrand et al., 1994).

The Role of Biosurfactants in Bioremediation Process

Accelerating the natural process of biodegradation in contaminated environments by using microbial metabolism is known as bioremediation. Biosurfactants are involved in bioremediation by increasing the surface area of insoluble hydrophobic substrates in water.

Biosurfactants have a number of advantages, including: biodegradability, low toxicity, good digestibility and compatibility, good emulsifying properties and availability. Biosurfactants undergo easy degradation by microorganisms, promoting environmental sustainability. In contrast to certain chemically synthesized counterparts, they can be naturally decomposed.

Biosurfactants generally demonstrate minimal toxicity, rendering them safer for diverse applications compared to specific chemical surfactants that may pose environmental and health hazards.

Biosurfactants exhibit favorable compatibility and digestibility with other organisms, enhancing their suitability for application across various biological and ecological systems without causing harm.

They can be derived from inexpensive and readily accessible raw materials in substantial quantities, rendering biosurfactant production cost-effective and scalable.

Biosurfactants are good emulsifiers, facilitating more efficient dispersion and stabilization of immiscible substances (e.g., oil and water). This capability proves advantageous in numerous industrial processes.

Biosurfactants are environmentally acceptable because of their long-lasting properties. Their natural origin and eco-friendly attributes contribute to their embrace in green and sustainable practices.

These advantages emphasize the potential of biosurfactants as a more sustainable and environmentally friendly substitute for certain synthetic surfactants in a range of industrial, agricultural, and medical applications.

CONCLUSIONS

Creating new strategies and technologies is necessary to minimize the production cost of biosurfactants on a commercial scale and to make the production process economically competitive.

Leading scientists use approaches such as green chemistry and genetic engineering of microorganisms to improve the yield and quality of biosurfactant production. Pretreating renewable substrates makes it easy to grow organisms.

However, care must be taken not to lose the nutritional values of these substrates. Because both the quality and quantity of the product are mandatory to open wide industrial perspectives for microbial surfactants. There is huge potential for waste from food processing, animal fats, and dairy industry sectors that are still waiting to be explored.

In recent years, numerous biochemically derived compounds and their production methods have been patented, although only a handful have made it to commercialization.

The profitability of biosurfactant production hinges on various factors, including raw material expenses, the feasibility of an economical production process and the yield of the microorganism product. Consequently, cheaper substrates, including waste materials, can be utilized, alongside genetically modified strains and efficient bioprocessing techniques, to achieve cost-effective biosurfactant production.

In conclusion, the biosurfactant market is poised for growth as screening initiatives uncover new microbial strains harboring novel molecules with exceptional properties. Additionally, advancements in sourcing low-cost raw materials and refining strategies for scaling up processes promise to yield successful outcomes in the biosurfactant industry.

REFERENCES

Amalesh, S., Pinski, P., Anupam M., Chandrima, S., Asif, L., Das, M. (2012). Estimation of biosurfactants activity of Alkaline protease producing bacteria isolated from municipal solid waste. *Cent Europ, J of Exper Bio*, 1, 26-35.

Amaral, P., Colao, M., Coelho, M. A., Fontes, G., & Nele, M. (2009). Characterization of a bioemulsifier produced from glycerol and gloucose by Yarrowia lipolytica. *New Biotechnol*., 25, 138-138.

Atlas, R. M. (1993). Bacteria and bioremediation of marine oil spills. *Oceanus;(United States)*, *36*(2), 71-81.

Bertrand, J. C., Bonin, P., Goutx, M., Mille, G., & Gauthier, M. (1994). The potential application of biosurfactants in combatting hydrocarbon pollution in marine environments. *Research in Microbiology; (France)*, 145(1).

Burger, A. E. (1993). Estimating the mortality of seabirds following oil spills: effects of spill volume. *Marine pollution bulletin*, *26*(3), 140-143.

Burns, K. A., Garrity, S. D., & Levings, S. C. (1993). How many years until mangrove ecosystems recover from catastrophic oil spills? *Marine Pollution Bulletin*, *26*(5), 239-248.

Cameotra, S. S., & Makkar, R. S. (2004). Recent applications of biosurfactants as biological and immunological molecules. *Current opinion in microbiology*, *7*(3), 262-266.

Cohen, R. and Exerowa, D. (2007). Surface forces and properties of foam films from rhamnolipid biosurfactants. *Adv. Colloid Interfac.*, 134, 24-34.

Cooper, D. G., & Paddock, D. (1983). Torulopsis petrophilum and surface activity. *Applied and environmental microbiology*, *46*(6), 1426-1429.

Cooper, D. G., & Paddock, D. (1984). Production of a biosurfactant from Torulopsis bombicola. *Applied and environmental microbiology*, *47*(1), 173-176.

Csutak, O., Simon-Gruiţă, A., Corbu, V., Constantin, N., Pojoga, D., Vassu, T., & Duţă-Cornescu, G. (2017). Preliminary studies on yeast-plant systems with applications in phytoremediation. *Scientific Bulletin Series F. Biotechnologies*, *21*.

Das, P., Mukherjee, S., & Sen, R. (2009). Antiadhesive action of a marine microbial surfactant. *Colloids and Surfaces B: Biointerfaces*, *71*(2), 183-186.

Das, K. & Mukherjee, A. K., (2007). Comparison of lipopeptide biosurfactants production by *Bacillus subtilis* strains in submerged and solid state fermentation systems using a cheap carbon source: Some industrial applications of biosurfactants. *Process Biochem*., 42, 1191-1199.

Desai, J. D., & Banat, I. M. (1997). Microbial production of surfactants and their commercial potential. *Microbiology and Molecular biology reviews*, *61*(1), 47-64.

Fernandes, P. A. V., Arruda, I. R. D., Santos, A. F. A. B. D., Araújo, A. A. D., Maior, A. M. S., & Ximenes, E. A. (2007). Antimicrobial activity of surfactants produced by Bacillus subtilis R14 against multidrug-resistant bacteria. *Brazilian Journal of Microbiology*, 38, 704-709.

Gharaei-Fathabad, E. (2011). Biosurfactants in pharmaceutical industry (A Mini-Review). *Ame J Dr Discov and Dev.*, *1*(1), 58-69.

Kitamato, D., Isoda H. and Hara, T. N. (2002). Functions and potential applications of glycolipid biosurfactants-from energy-saving materials to gene delivery carriers. *J. Bio. Sci. Bio. Eng.,* 94, 187-201.

Konishi, M., Morita, T., Fukuoka, T., Imura, T., Kakugawa, K., and Kitamoto, D., (2007). Production of different types of mannosylerythritol lipids as biosurfactants by the newly isolated yeast strains belonging to the genus Pseudozyma. *Applied Microbiol. Biotechnol*., 75, 521-531.

Kosaric, N. (1992). Biosurfactants in industry. Pure *Applied Chem.,* 64, 1731-1737.

Langer, O., Palme, O., Wray, V., Wray, H., Tokuda & Lang, S. (2006). Production and modification of bioactive biosurfactants. *Process Biochem*., 41, 2138-2145.

Maneerat, S., (2005). Production of biosurfactants using substrates from renewable-resources. Songklanakarin *J. Sci. Technol.,* 27, 675-683.

Monteiro, S. A., Sassaki, G. L., L. Souza, M. J., Meira, M. & Araujo, J. M. (2007). Molecular and structural characterization of the biosurfactant produced by *Pseudomonas aeruginosa* DAUPE 614. *Chem. Phys. Lipids*, 147, 1-13.

Muthusamy, K., Gopalakrishnan, S., Ravi, T. K., & Sivachidambaram, P. (2008). Biosurfactants: properties, commercial production and application. *Current science*, 736-747.

Mukherjee, S., Das P. & Sen R., (2006). Towards commercial production of microbial surfactants. *Trends Biotechnol*., 24, 509-515.

Nitschke, M. & Costa S.G.V.A.O., (2007). Biosurfactants in food industry. *Trends Food Sci. Technol*., 18, 252-259.

Perfumo, A., Rancich, I., & Banat, I. M. (2010). Possibilities and challenges for biosurfactants use in petroleum industry. *Biosurfactants*, 135-145.

Rahman, P. K., & Gakpe, E. (2008). Production, characterisation and applications of biosurfactants-Review. *Biotechnology*. *7*(2), 360-370.

Rodrigues, L., Banat, I. M., Teixeira, J. & Oliveira, R. (2006). Biosurfactants: Potential applications in medicine. *J. Antimicrobial Chemotherapy*, 57, 609-618**.**

Ron, E. Z., & Rosenberg, E. (2002). Biosurfactants and oil bioremediation. *Current opinion in biotechnology*, *13*(3), 249-252.

Shete, A. W., Banat, D., Chopade, I., Balu (2006) Mapping of Patents on Bioemulsifiers and Biosurfactants: A Review; *Journal of scientific and industrial research.*

Silva, R. D. C. F., Almeida, D. G., Rufino, R. D., Luna, J. M., Santos, V. A., & Sarubbo, L. A. (2014). Applications of biosurfactants in the petroleum industry and the remediation of oil spills. *International journal of molecular sciences*, *15*(7), 12523-12542.

Sullivan, E. R., (1998). Molecular genetics of biosurfactant production. *Curr. Opin. Biotechnol., 9*(3), 263-269.

Tabatabaee, A., Mazaheri, M. A., Noohi, A. A. & Sajadian,V. A. (2005). Isolation of biosurfactant producing bacteria from oil reservoirs*. Iran. J. Environ. Health Sci. Eng*., *2*(1), 6-12.

Tahzibi, A., Kamal, F. & Assadi, M. M. (2004). Improved production of rhamnolipids by a *Pseudomonas aeruginosa* mutant. *Iran. Biomed. J.*, 8, 25-31.

Zhang, Y. I. M. I. N., & Miller, R. (1992). Enhanced octadecane dispersion and biodegradation by a Pseudomonas rhamnolipid surfactant (biosurfactant). *Applied and environmental microbiology*, *58*(10), 3276-3282.