Asian Journal of Chemistry; Vol. 36, No. 10 (2024), 2221-2230

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2024.32425

REVIEW

Recent Innovations in Biosurfactant Production: Exploring Biomedical and Environmental Applications

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Received: 30 July 2024; *Accepted*: 6 September 2024; *Published online*: 30 September 2024; AJC-21751

The unique characteristics and ecological friendly nature of biosurfactants, which are compounds with amphiphilic properties derived from biological sources, have garnered considerable interest. This review article explores into the fascinating characteristics of biosurfactants, with a particular emphasis on identifying and studying microorganisms that produce biosurfactants in unusual conditions, such as harsh ecosystems and agricultural wastes. Using innovative techniques, researchers investigated a wide variety of microbial strains for their ability to produce biosurfactants and evaluated the biosurfactants that were recovered. Furthermore, researchers also conducted assays on a laboratory scale to explore their possible uses in fields including bioremediation and increased oil recovery. The effectiveness of biosurfactants in combating environmental problems and fostering sustainability is emphasized in this investigation. Additionally, researchers considered cost-effective techniques while evaluating the economic viability of biosurfactant production. These findings provide insight into strategies to effectively incorporate biosurfactants into new technologies for a range of applications. This study highlights the potential of biosurfactants as eco-friendly alternatives in industrial processes and enhances the awareness of their sources of production. The purpose is to explore a more sustainable future by integrating biosurfactants into widespread biomedical devices while supporting further research and advancement in the pharmaceutical industry.

Keywords: Microbial surfactants, Wound healing, Drug delivery system, Biodegradation, Emulsification.

INTRODUCTION

Tensioactive compounds or surfactants, can be either naturally occurring or synthetic and have many uses; for instance, they are used in hydraulic fracturing to produce chemically improved oil, the drilling process, demulsification and other petroleum-related processes [1]. Biosurfactants are a type of biologically generated surface-active compound that have minimal toxicity, biodegradable properties and excellent precision that decrease surface and interaction tension owing to their hydrophilic and hydrophobic moieties. They are a class of microbial molecules developed through different fungi, yeasts and bacteria. Surfactants pollute the natural environment through effluents from agrochemical goods, commercial goods and even domestic processes [2].

Amphipathic particles generated by microbes were known as biosurfactants. The continued progress of the chemical reaction is dependent on those molecules, which resemble other types of metabolites in form. Organisms that are produced by biocide operators, detecting quorums, nutrient conveying systems or host-microbe interactions [3]. They improve the absorption and solubility in water of non-aqueous phase liquids and may decrease surface tension and tension between surfaces in oily substances, moreover, they cause foam to develop [4].

Surfactants are surface-active chemicals that help reduce tension on the surface and tension between surfaces at water-oil and air-water interfaces, among others. Microorganisms often use abundant and affordable substrates to produce biosurfactants. Their accessibility, biodegradable properties and excellent foaming power render them a good alternative to surfactants made from synthetic chemicals. Cosmetics, food and pharmaceuticals all benefit from biosurfactants because of their appealing qualities and efficacy [5].

Biosurfactants have many important uses in modern medicine, including antimicrobial therapies, pharmaceutical delivery systems and ecological sustainability *via* biological remediation and rehabilitation of soil. This review article provides an in-depth and current account of these developments, highlighting their vital applications in these fields. This analysis is unique because it examines new applications and focuses on state-of-the-art manufacturing methods that include nanotechnology to improve biosurfactant qualities. It also identifies areas for future study that might promote interaction and originality across disciplines, as well as answers to the problems of scalability and economic feasibility [6].

Biosurfactants: The biosurfactants that are most well-recognized as glycolipids and lipopeptides. They are anti-adhesive, show action against biofilms and are antibacterial across the board. Many fields that make use of them as surfactants, emulsifiers and antibacterial substances include the pharmaceutical, cosmetic and food sectors [7]. In addition to its applications in petroleum-based industries, bacterial biosurfactants find extensive application in personal hygiene and home products, such as antibacterial shampoos and pharmaceuticals. Biological remediation, bioemulsification and active administration of medicines are some applications for microbial enhanced oil recovery (MEOR) in the fields of ecological biotechnology, food production and healthcare [8].

Classification of biosurfactants

Based on molecular weight: A biosurfactant's molecular mass determines whether it is low- or high-molecular-weight. Glycolipids, lipopeptides and lipoproteins are the examples of tiny molecules that constitute low-molecular weight biosurfactants (Fig. 1). The topological action of these kinds of molecules is unusual and they are often more effective in lowering the tension on their surfaces than their high-molecular weight equivalents [9]. Complex carbohydrates, protein molecules and lipids are examples of biosurfactants with a large molecular weight, on the other hand. Their biological compatibility and flexibility render them useful in a wide range of ecological and biological applications and their distinctive properties contribute to their reduced surface movement [10].

Based on the chemical structure

Glycolipid: Among biosurfactants, glycolipids have received the most attention and use. The hydrophilic carbohydrates in glycolipids are linked to the lipophilic long-chain fatty acid chains or hydroxyl aliphatic acids *via* ester or ether bonds. The structural diversity of glycolipids lowers surface and interfacial tension. The sub-classification of glycolipids is further dependent on whether they are hydrophilic (carbohydrate group) or lipophilic (lipid group) [11].

Rhamnolipid: *Pseudomonas aeruginosa* is the most significant producer of rhamnolipids, biosurfactants with strong surface active characteristics. Biological remediation, increased recovery of oil and ecological remediation are enhanced by

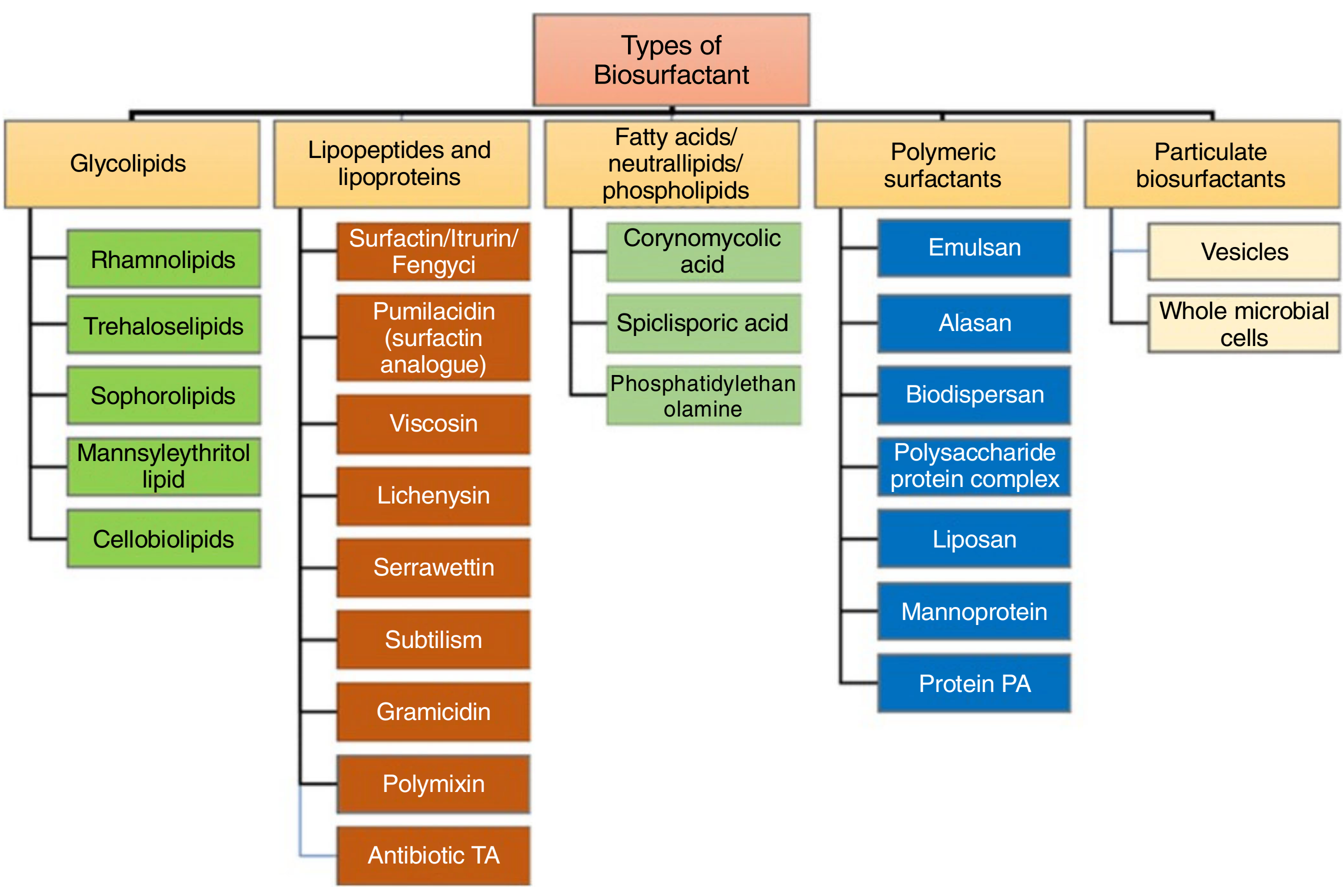

Fig. 1. Classification of biosurfactants

the remarkable emulsifying characteristics of these glycolipids. Recent studies have shown that they have antibacterial and anti-biofilm properties, which might have medicinal and pharmaceutical uses. The economic viability of naturally occurring substrates is also attracting attention because of developments in sustainable manufacturing processes (Fig. 2). Rhamnolipids are a potential biotechnology resource in many different sectors due to their multimodal characters [12].

Sophorolipid: Sophorolipids are versatile biosurfactants with great biodegradability and low levels of toxicity produced by yeast such as *Starmerella bombicola*. Because of their emulsification and antibacterial qualities, recent studies have shown their promise in a variety of uses including biological remediation, personal care products and drugs. Sophorolipids' attraction to green chemistry applications is increasing as sustainable manufacturing of them using renewable resources gains strength. Their ability to disturb biofilms also makes them a contender for medicinal applications. Sophorolipid manufacture and use are being further expanded by developments in genetic and metabolic engineering [13].

Trehalolipids: Trehalolipids, which are complex glycolipid biosurfactants, are produced by many actinomycetes, especially Mycobacterium species. These compounds exhibit strong surface activity, antibacterial properties and biological compatibility, which contribute to their ecological and biological applications. Recent studies have demonstrated the high efficacy of these substances in the remediation of soil and water, as well as their low toxicity and ability to break down naturally, which makes them suitable for use in drug delivery systems. Active research in the field of long-term trehalolipid synthesis from biotechnological developments using renewable substrates. Their adaptability and potentiality for industrial uses are enhanced by their capacity to produce stable emulsions and stop the development of biofilm [14].

Mannosyl erythritol lipid (MELs): Some yeasts, espically Candida species, produce biosurfactants called manosyl erythritol lipids (MELs), which are known for being effective emulsion builders with low toxicity. Recent studies have shown that these materials have great potential for environmental applications, such as water and soil remediation, due to their biodegradability and ibility to mobilize hydrophobic compounds. Additionally showing great antibacterial action are MELs, which might find use in the medicinal and pharmacological industries. The scalability and cost-effectiveness of MEL manufacturing are being impacted by improvements in substrate optimization and fermentation processes. MELs are appealing choices for long-term industrial applications due to their versatility and sustainability [15].

Lipopeptides

Surfactin: A powerful lipopeptide biosurfactant derived from *Bacillus subtilis*, with remarkable surface-active and antibacterial qualities, is surfactin. Its efficiency has been shown in many uses, including bioremediation, in which it helps hydrophobic contaminants be mobilized and degraded. Surfactin is a possibility for medicinal use including healing wounds and

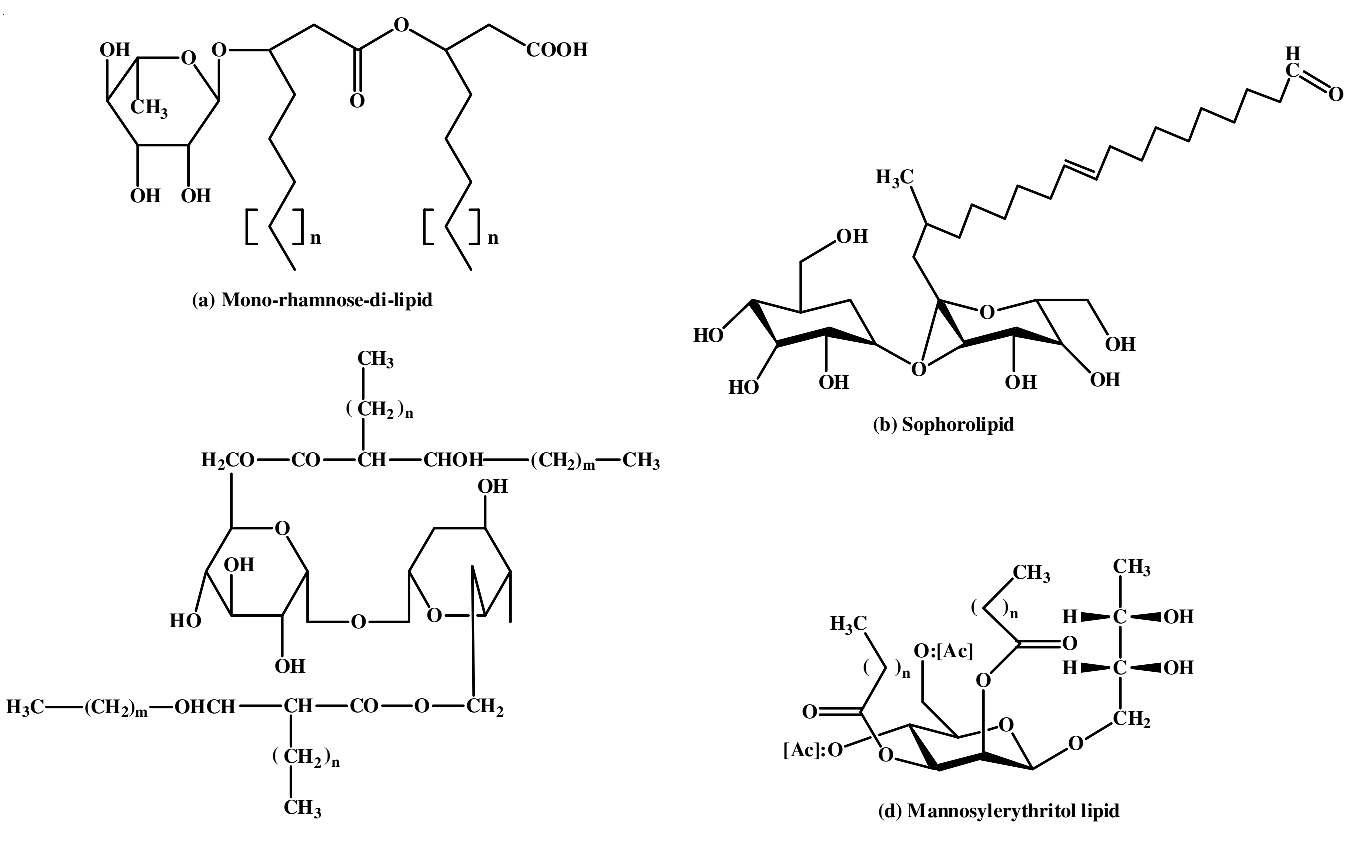

Fig. 2. Chemical structure of (a) mono-rhamnose-di-lipid, (b) trehalolipids, (c) irutin, (d) mannosylerythritol lipid

treatment of infections as it may disturb the biofilms of microbial organisms. Genetic engineering and fermentation condition optimization are the two examples of new manufacturing processes, which are increasing its adaptability and decreasing its expenses (Fig. 3). Environmental benefits and a host of other features make it ideal for use in a wide variety of industries [16].

Potent antibacterial and surface-active fengycins are cyclic lipopeptide biosurfactants produced by *Bacillus fengyoi*. Recent investigations have shown the high efficacy of these substances in combating hazardous microorganisms and inhibiting the formation of biofilms, which makes them valuable in both industrial and medicinal applications. Because fengycins emulsified hydrophobic contaminants, they additionally demonstrate potential for ecological bioremediation. Genetic engineering and fermenting methods have advanced to help fengycin manufacturing be more scalable and efficient. Their non-toxic nature and wide spectrum action allow them to distinguish themselves as a potential substitute for conventional synthetic surfactants [17].

Iturin: Iturin (~1.1 kDa) is a cyclic lipopeptide including a fatty acid chain ranging from C-14 to C-17 in addition to a seven amino acid peptide chain. These fall into iturin A, C, D and E widely synthesized and displaying notable antifungal effect, iturin A. Derived from Bacillus species, several cyclic

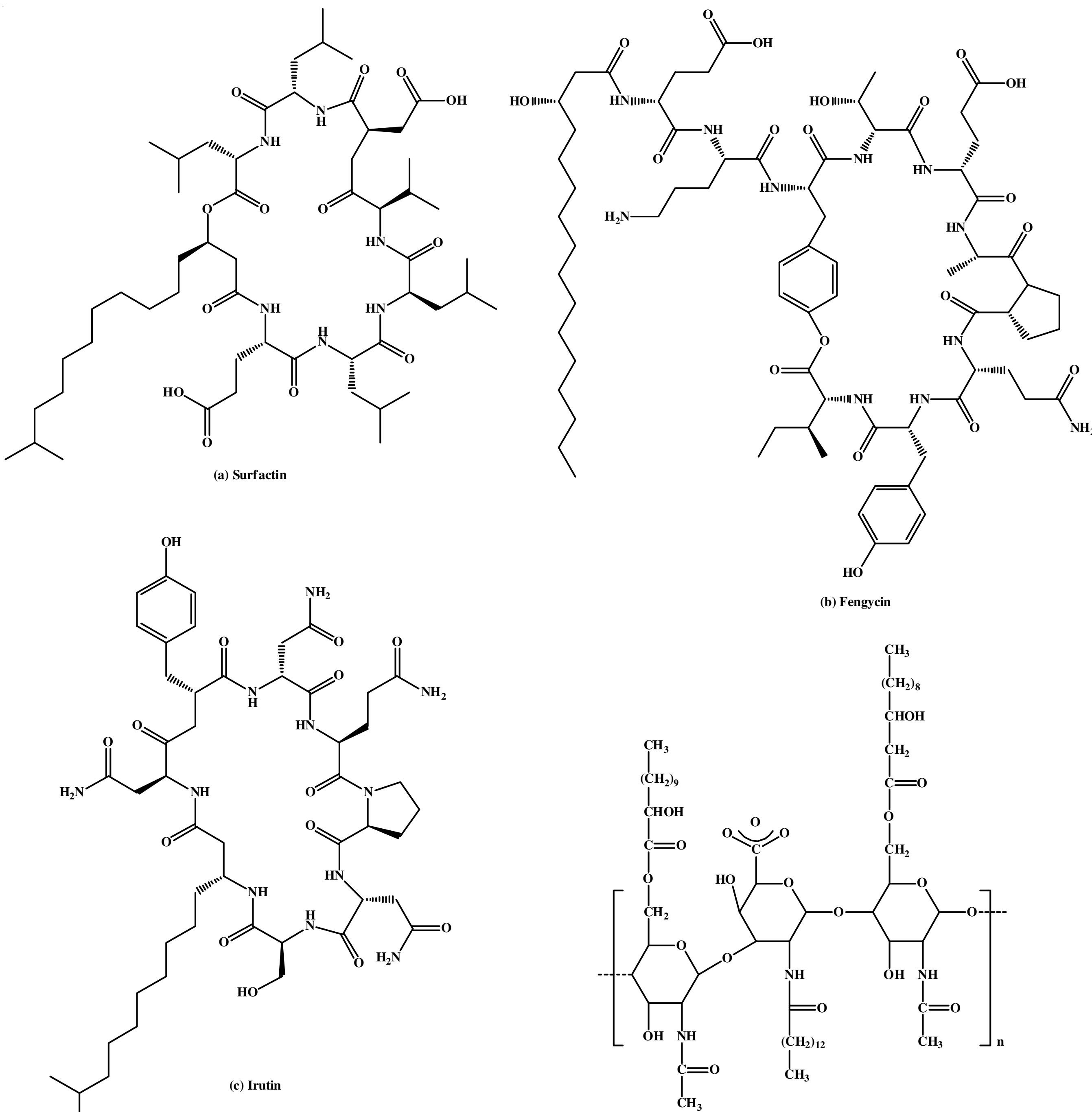

Fig. 3. Chemical structure of (a) surfactin, (b) fengycin, (c) irutin, (d) emulsan

lipopeptide biosurfactants with strong antibacterial and surface active characteristics are called iturins [18]. The use of antibiotics for medicinal and agricultural applications derives from studies showing their effectiveness in eradicating harmful bacteria and disturbing biofilms. By emulsiating and mobilizing hydrophobic contaminants, iturins also contribute significantly to bioremediation. Recent developments in genetic alterations and fermenting techniques are improving the affordability and output of iturin synthesis. Their sustainable character and multifarious use emphasize their possibilities as sustainable substitutes for traditional surfactants [19].

Polymeric compounds: Evident by their capacity to stabilize emulsions and efficiently lower surface tension, polymeric surfactants, include both synthetic and natural polymers. Recent studies show that by adding more stability and better functional characteristics, they help classic surfactants including rhamnolipids performance to be enhanced. Because of their adjustable qualities and great effectiveness, these surfactants provide benefits in uses ranging from industrial cleaning to drug delivery systems [20]. Advances in polymer chemistry are extending the spectrum of polymer surfactants, hence increasing their value in conjunction with rhamnolipids for improved ecological and biomedical applications. Their adaptability and performance improvements make them interesting parts in sophisticated surfactant compositions [21].

Particulate surfactants: Due to their huge surface area and altering capabilities, particulate surfactants such as those consisting of nanoparticles or microparticles offer expectional interface active qualities. Previous study [22] indicates that the stability and effectiveness of emulsions can be enhanced by combining particle surfactants with rhamnolipids, making them suitable for advanced applications such as pollution control and drugs delivery. Increased pollution removal and antibacterial activity follow from improved distribution and association of rhamnolipids with different substrates by these surfactants. Enhanced efficiency in both industrial and biomedical sectors depends on the improvements to the production and fictionalization of particulate surfactants extending their possible usage in combination with rhamnolipids. Their ability to interact together with rhamnolipids offers fascinating prospects for developing novel and effective surfactant complexes (Table-1) [23].

Neutral lipids, phospholipids and fatty acid

Phospholipid: Essential elements of cellular membranes, phospholipids are well-known for helping to stabilize the emulsion and improve the transport of bioactive molecules. Integrating phospholipids with rhamnolipids has been demonstrated to increase durability and enhance emulsifying characteristics, hence improving the performance of biosurfactant compositions. Application in drug delivery systems, the ecological restoration and industrial operations benefit from the relationship among phospholipids and rhamnolipids [24]. Furthermore, improving antibacterial and anti-biofilm capabilities is the interaction among these surfactants. Development in formulation methods is investigating the possibilities of phospholipid-rhamnolipid combinations for more flexible and efficient surfactant complexes [25].

Neutral lipid: Emulsions are stabilized and the dissolution of different substances is improved in substantial quantities by neutral lipids like sterols and triglycerides. Several studies suggest that the effectiveness and stability of biosurfactant compositions are significantly enhanced by combining neutral fatty acids with rhamnolipids. Its uses include increased extraction of oils, bioremediation and drug administration, this blend improves the emulsification and dispersion properties of rhamnolipids, hence increasing their efficacy [26]. Improved regulation of the development of biofilm and the development of bacteria is also facilitated by the interaction of neutral lipids with rhamnolipids. Highly flexible and effective surfactant systems have found their path due to better knowledge of these chemical reactions [27].

TABLE-1
TYPES OF BIOSURFACTANTS AND THEIR PRODUCING ORGANISMS

Biosurfactant	Types	Microorganism	Ref.
Glycolipid	Soporolipid	*Rhodotorula babjevae YS3*	[28]
		Candida albicans	[29]
		C. bombicola	[30]
	Trehalose	*Rhodococcus fascians*	[31]
	Mannosylerythritol lipid	*Pseudozyma aphidis*	[32]
	Rhamnolipid	*Pseudomonas stutzeri*	[32]
		P. aeruginosa	[33]
		P. aeruginosa	[34]
Lipopeptides	Surfactin	*Bacillus subtilis*	[35]
	Fengycin	*Bacillus subtilis*	[36]
	Iturin A	*B. amyloliquefaciens*	[37]
Polymeric compounds	Liposan	*C. lipolytica* *Acinetobacter RAG-1*	[38]
	Emulsan	*A.calcoaceticus*	[39]
Particulate compounds	Vesicles and fimbriae	*Acinetobacter* sp. *HO1-N*	[40]
Phospholipids and fatty acids	Corynomycolic acid	*Corynebacterium lepus*	[41]
	Spiculisporic acid	*Penicillium spiculisporum*	[41]
	Phosphatidylethanolamine	*Rhodococcus erythropolis* *Acinetobacter*	[41]

Sources of biosurfactants: Plants, animals and bacteria among other sources produce biosurfactants. Though sometimes restricted by yield and extraction complexity, plant-based biosurfactants such as glycosides and saponins provide environmentally beneficial alternatives. Efficient but challenging for sustainability and ethical sourcing are animal derived biosurfactants including lecithins and bile acids [25]. Especially for rhamnolipids, bacteria such as *Pseudomonas aeruginosa*, yeast and fungus offer an affordable and adaptable means of manufacturing a variety of biosurfactants. Recent studies concentrate on optimizing microbial fermentation techniques and investigating renewable fuels to improve industrial effectiveness and sustainability all around [6].

Plant-based biosurfactants

Saponins: Plant-derived glycosides with surfactant characteristics and possible health advantages define saponins. Recent studies show that they are important in producing stable foams and emulsions, which help in food, cosmetics and medicines among other uses. Saponins are widely employed in several therapeutic applications due to their significant antibacterial and anticancer properties [42]. The increased productivity and production rates for saponin manufacture are resulting from developments in both extraction and purification processes. Their natural source and many uses help saponins to be interesting substitutes for manufactured surfactants and stabilizers [43].

Microbe-based biosurfactants: Due to their significant surface active qualities, microbe-based biosurfactants produced by bacteria, yeast and fungi have numerous applications. Studies on maximizing the synthesis of these biosurfactants from microbial sources like *Pseudomonas aeruginosa* for rhamnolipids, *Bacillus subtilis* for surfactin and many yeasts for sophorolipids have concentrated on certain biosurfactants are valued for their low toxicity, biodegradability, possibility for environmental cleanup, improved oil recovery and medicinal uses (Table-2). The cost-effectiveness and productivity of bacterial biosurfactant production are being enhanced by advancements in metabolic engineering and fermentation technologies. Microbe-based biosurfactants show promise as a substitute for conventional chemical surfactants because of their longevity and multifarious uses [44].

Genes involved in the production of microbial biosurfactants: The structure and quantity of these molecules are substantially influenced by genes that regulate the synthesis of microbial biosurfactants. While *sfp* in *Bacillus subtilis* is vital for surfactin synthesis, significant genes that include *rhlA* and *rhlB* in *Pseudomonas aeruginosa* are in charge of rhamnolipid biosynthesis. Characterizing and modifying these genes to improve biosurfactant generation *via* genetic engineering and metabolic optimization has been the emphasis of recent studies. Knowing the groups of genes and networks of regulation involved will assist biosurfactant production to be more flexible and efficient. Increasingly concentrated and effective biosurfactant manufacturing techniques are made possible by developments in synthetic biology and genetics. The *srf*A operon, consisting of four ORFs (*srf*AA, *srf*AB, *srf*AC and *srf*AD), synthesizes amino acid moieties of surfactin. The *sfp* gene synthesizes phosphopantetheinyl transferase, which activates surfactin through post-translational modification [2].

Application of biosurfactant

Petroleum industry: In petroleum sector, biosurfactants find great use mainly in bioremediation and oil recovery (EOR). Microbes synthesize these molecules that may boost hydrocarbon mobilization and solubilization, hence facilitating reservoir residual oil extraction. Compared to conventional surfactants, biosurfactants such as rhamnolipids and sophorolipids increase the effectiveness of oil absorption and lower the negative environmental effects, according to studies. Furthermore, by improving the breakdown of hydrocarbon by local populations of microbes, biosurfactants help to bioremediate oil spills. Developments in the manufacturing and use of biosurfactants are boosting their popularity in petroleum industries for improved sustainability as well as extraction of oil and preservation of the environment [55].

Cosmetics: Biosurfactants are becoming increasingly popular in the cosmetics industry because of their natural origin, ability to break down naturally and low level of toxicity. These microbial surfactants, such as sophorolipids and rhamnolipids, are used in formulations for skincare and haircare products for their emulsifying, foaming and moisturizing properties. Research highlights that biosurfactants can enhance the stability and performance of cosmetic products while minimizing skin irritation compared to synthetic surfactants. Additionally, their antimicrobial properties contribute to the preservation of cosmetic formulations. The trend towards sustainable and eco-friendly ingredients is driving increased research and application of biosurfactants in cosmetics [23].

Biosurfactant in nanotechnology: Although biosurfactants can stabilize nanoparticles and enable sustainable synthesis

TABLE-2
BIOSURFACTANT-PRODUCING MICROORGANISMS WITH THEIR BIOLOGICAL ACTIVITY

Biosurfactant	Microorganism	Activity	Ref.
BioEG	*Lactobacillus paracasei*	Induces cell cycle arrest at G1 phase	[45]
Iturin	*Bacillus* sp.	Leads the apoptosis induction and inhibits tumor growth	[46]
Sophorolipids	*Starmerella bombicola*	Interferes with cell migration and intracellular ROS increase	[47]
Rakicidins	*Micromonospora*	Interferes with the invasiveness	[48]
Surfactin	*B. circulans*	Selective anti-proliferative activity	[49]
Cyclic lipopeptide	*Bacillus natto*	Inhibits cell growth by inducing apoptosis	[50]
Glycolipoprotein	*Acinetobacter* M6	Decreases cell viability and induces cell cycle arrest at G1 phase	[51]
Somocystinamide	*Lyngbya majuscula*	Induces apoptosis	[52]
Serrawettin W2	*Serratia surfactantfaciens*	Selective cancer cell lines growth suppression	[53]
Viscosin	*Pseudomonas libanensis*	Inhibits migration of metastatic cells	[54]

techniques, they are being more and more used in nanotechnology. By efficiently lowering the surface tension, these natural surfactants rhamnolipids and sophorolipids help to produce and stabilize nanoparticles with well-calibrated dimensions and forms. Studies show that biosurfactants improve the biological compatibility and distribution of nanoparticles, therefore qualifying them for potential use in biomedical fields like imaging and drug delivery. Moreover, in the field of nanotechnology, their very low toxicity and ability to disintegrate naturally make them advantageous compared to the conventional surfactants. Utilizing biosurfactants in the synthesis of nanoparticles aligns with the principles of ecological chemistry and contributes to the progress of ecological nanotechnology [56].

Biosurfactants as drug delivery agents: Because of their biological compatibility, biodegradable properties and capacity to produce stable micelles and vesicles, biosurfactants provide potential therapeutic agents. By encapsulating hydrophobic medicines, these naturally occurring surfactants such as surfactin and rhamnolipid increased their solubility and bioavailability. Studies show that biosurfactant-based delivery systems for drugs may provide selective and regulated drug release, hence enhancing therapeutic effectiveness and lowering adverse effects. Their natural antibacterial qualities may also be very helpful in combating illnesses. Constant research and advancement in this sector are motivated by the possibility of biosurfactants to enhance the delivery of drugs effectiveness [57].

Biosurfactants as antimicrobial agents: The significant antibacterial action of biosurfactants renders them important in many biological and environmental applications. Many harmful microbes, including bacteria, fungi and viruses, have been demonstrated to be inhibited by compounds like surfactin, rhamnolipids and sophorolipids. Studies show that biosurfactants break microbial cell membranes, causing cell death and lysis. Their efficiency against biofilms increases their possibilities for both commercial and medicinal use significantly. The low toxicology of biosurfactants appeal as eco-friendly antibacterial agents promote an abundance of researches on their processes and applications [58].

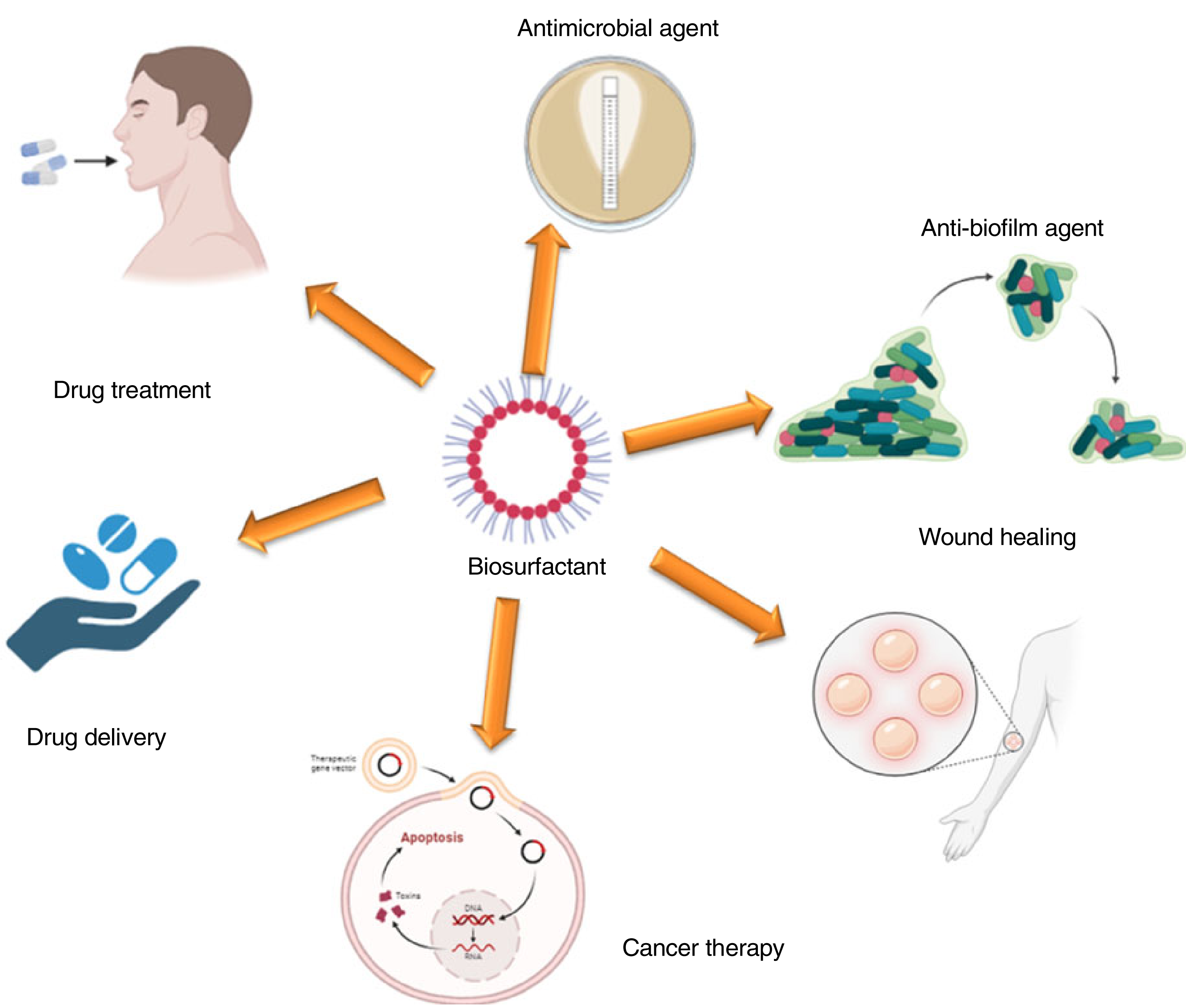

Fig. 4. Illustration of biosurfactants' therapeutic applications, including drug treatment and delivery, antimicrobial and anti-biofilm activities, wound healing and cancer therapy

Applications of surfactin in pharmaceutical industry: A potent biosurfactant produced by *Bacillus subtilis*, surfactin has interesting uses in the pharmaceutical industry. Studies reveal that surfactin increases drug dissolution and bioavailability therefore improving its effectiveness in administering hydrophobic drugs. Its antibacterial qualities also help to avoid contamination of drug formulations. Drug delivery strategies utilize the capacity of surfactin to produce stable emulsions and micelles, hence improving controlled and precise release. Its low toxicity and biocompatibility also make it a viable choice to produce safer and more powerful pharmaceuticals [2].

Wound healing applications: Surfactin is a biosurfactant with great promise for use in wound healing produced by *Bacillus subtilis*. Surfactin promotes the cell migration and proliferation, thus enhances tissue regeneration, which accelerates up the healing process. It reduces complications by preventing infection at the site of wound because of its antibacterial properties. Surfactin also helps a protective layer to develop over wounds, therefore enhancing the results of healing (Fig. 4). Due to its biocompatibility and low toxicity, surfactin is being considered as a potential alternative for advanced wound healing [47].

Bioremediation of marine oil spills and petroleum contamination: Through improving the microbial breakdown of hydrocarbons, biosurfactants are essential for the bioremediation processes of marine spills of oil and hydrocarbon pollution. Rhamnolipids and sophorolipids are among these microbial surfactants that boost the bioavailability of hydrophobic toxins, facilitating their accessibility to breaking down organisms (Fig. 5). By breaking down oil into tiny droplets and encouraging microbial activity, research shows that biosurfactants may greatly speed the cleaning process. Their sustainable characteristic also lessens the ecological effect than that of conventional dispersing agents. Technologies in the biosurfactant production and applications are boosting their adoption as viable options for mitigating maritime oil spills and petroleum pollution [59].

Dairy industry: In dairy sector, biosurfactants might find use, especially for their emulsification and antibacterial characteristics. Through the utilization of these naturally occurring substances such as surfactin and rhamnolipids, deterioration and infectious microbes may be inhibited, therefore improving the safety and shelf life of dairy products. Studies show that biosurfactants may also help dairy emulsions including those in yogurt and cheese have better stability and texture. Their suitability for many dairy industries is derived from their capacity to lower the surface tension and produce stable emulsions. The dairy sector is exploring and using biosurfactants in response to the move towards natural and sustainable components [60].

Leather industry: Biosurfactants are receiving more and more investigation for use in the leather sector because of their eco-friendly and strong characteristics. Using these microbial surfactants such as rhamnolipids and sophorolipids one may

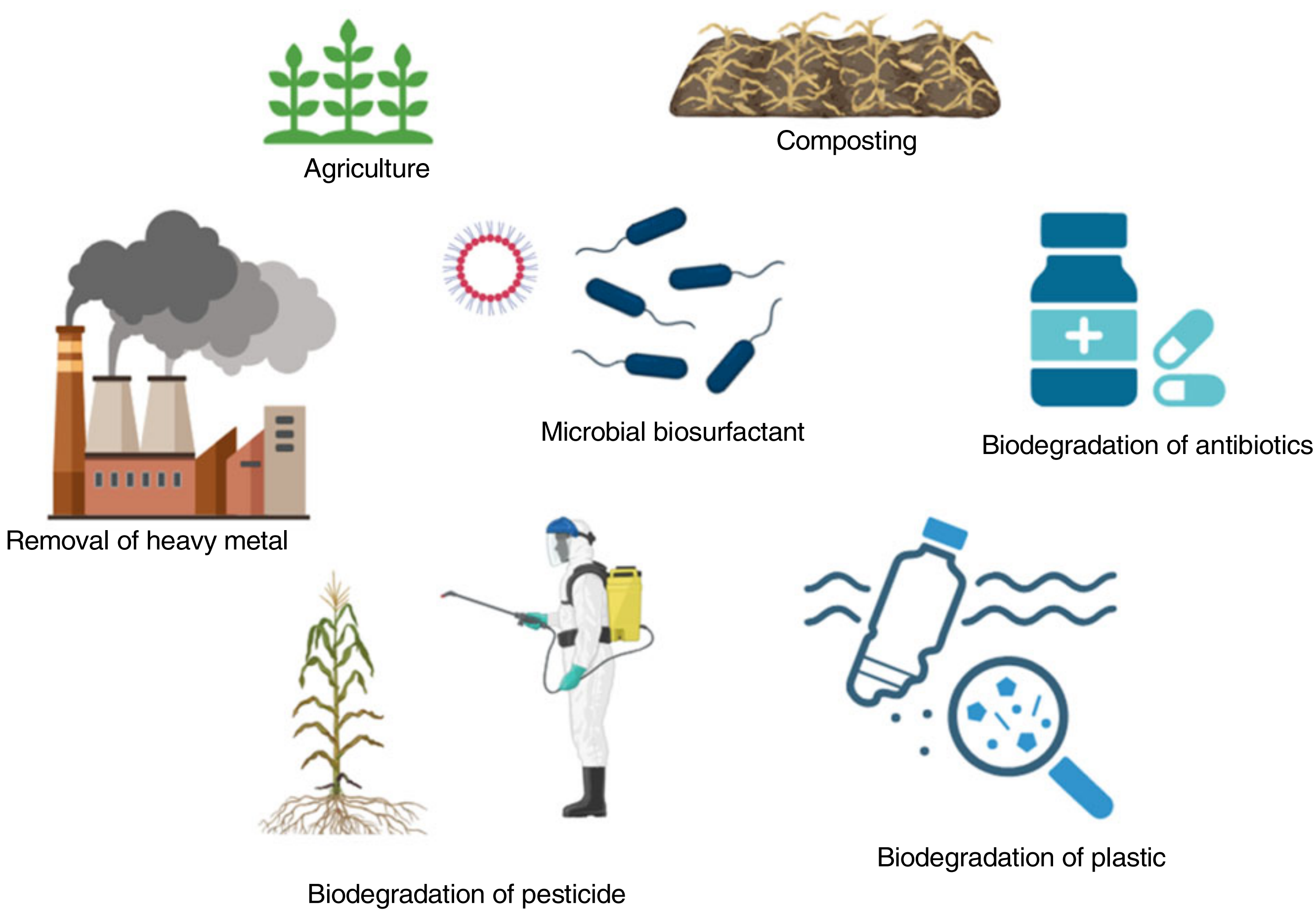

Fig. 5. Applications of microbial biosurfactants, including their roles in agriculture, composting, heavy metal removal, antibiotics biodegradation, pesticide biodegradation and plastic biodegradation

effectively extract fats and oils from animal hides during the degreassing process. Studies show that by providing a sustainable substitute for traditional synthetic surfactants, biosurfactants help to lower ecological damage and contamination. Utilizing enhanced absorption and therapeutic agent dispersion, they can significantly the appearance of the leather. The use of biosurfactants in leather processing reflects the trend of the sector to increasingly ecologically sound and sustainable production techniques [60].

Food industries: The natural and beneficial qualities of biosurfactants have enabled them to acquire popularity in the food sector. Food products include these microbial surfactants, rhamnolipids and sophorolipids, as emulsifiers, stabilizers and antibacterial agents. Studies show that biosurfactants could improve the shelf life and texture of many foods, including baked items, sauces and dairy products. Their antibacterial qualities help control infections and spoiling agents, therefore enhancing food safety. Biosurfactants are being used in the manufacture and preservation of food under the increasing need for renewable and sustainable food additives [51].

Biosurfactants as anti-adhesive agents: Biosurfactants are increasingly valuable as anti-adhesive agents due to their ability to inhibit the growth of microbes and biofilms. Research indicates that surfactin and rhamnolipids, which are two types of biosurfactants, have the potential to disrupt the adhesion of fungi and bacteria to surfaces. As a result, they can effectively reduce the formation of biofilm on industrial machinery and medical devices. Their surface-active characteristics disrupt bacterial adhesion processes, therefore improving cleanliness and lowering contamination. Biosurfactants are biocompatible and biodegradable, making them suitable for use in a wide variety of settings, such as food processing and healthcare. A growing interest in environmentally friendly alternatives has encouraged research into biosurfactants as potential natural and effective anti-adhesive agents [60-63].

Conclusion

In conclusion, recent developments in the biosurfactant synthesis have greatly increased their potential uses in biomedical and ecological sectors. Improved production, effectiveness and affordability of biosurfactant generation are the results of developments in microbial fermentation methods and genetic engineering. These advances have rendered it possible to use biosurfactants in many fields, including green detergents and biological remediation of contaminants like oil spills. Biosurfactants are under investigation in medical applications for their functions as anti-adhesive agents, wound healing and drug delivery mechanisms. Biosurfactants are having a revolutionary impact in combating against environmental problems and for medical solution development, owing to the convergence of sustainable production practices with an increasing range of applications.

ACKNOWLEDGEMENTS

The authors thank Vivekanandha College of Arts and Sciences for Women, Tiruchengode, India for their kind support and help.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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