



## Biosurfactants: Moving Towards Healthcare Applications

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### Abstract

Biosurfactants, fascinating molecules originating from microbial sources, have captivated researchers' imaginations for their escalating potential across a spectrum of healthcare applications. This comprehensive review explores the multifaceted world of biosurfactants, elucidating their diverse nature and exceptional physicochemical properties, propelling them toward becoming game-changers in healthcare. It represents a captivating array of compounds, boasting structural diversity encompassing glycolipids, lipopeptides, fatty acids, phospholipids, and more. These microbial marvels, formed at the intersection of hydrophilicity and hydrophobicity, offer adaptability and utility that extend across various applications. They wield the power to reduce surface and interfacial tension, making them adept at emulsifying immiscible substances. Biosurfactants serve as formidable antimicrobial agents combating drug-resistant bacteria and emerging viral threats. In the realm of wound care and tissue regeneration, biosurfactants shine. They promote wound healing and tissue repair through enhanced cell migration and regeneration opening new vistas for healthcare professionals. Biosurfactants have found their place in pharmaceutical formulations, elevating drug solubility and stability. These molecules significantly improve drug delivery systems, potentially amplifying their therapeutic efficacy. In cosmetics and personal care products, biosurfactants contribute to their emulsifying prowess, enhancing product texture and quality. They are also making their mark in the food industry, improving the solubility of bioactive compounds, and expanding the horizons of functional food additives. Biosurfactants are integral to diagnostic assays, offering improved stability and sensitivity. While biosurfactants hold immense promise, challenges include sustainability and environmental considerations. However, the burgeoning field of biosurfactants in healthcare beckons further research and development.

**Keywords:** Biosurfactants; Physicochemical properties Healthcare applications; Diagnostic assays; Pharmaceutical formulations

### Introduction

In the ever-evolving realm of healthcare, where the boundaries of medical science and technology are ceaselessly pushed, the quest for innovative solutions to complex healthcare challenges is an enduring endeavour. For accurate disease diagnosis, quick delivery of life-saving drugs, faster wound healing, and the growth of damaged tissues, healthcare needs new methods that can meet strict standards for safety and effectiveness, as well as those that are long-lasting and compatible with living things (Flessa & Huebner, 2021; Herrmann & Schlegel, 2022). In this dynamic landscape, the enigmatic world of biosurfactants emerges as a promising and versatile player. These extraordinary

molecules, characterized by their amphiphilic nature, are a product of the microbial world. While they have their origins in microbial survival strategies, biosurfactants have transcended their humble beginnings to become vital agents with the potential to reshape the future of healthcare (Ceresa *et al.*, 2023).

Biosurfactants, owing to their remarkable chemical diversity and unique physicochemical properties, possess an innate ability to interact at the interfaces of different phases. They can lower the interfacial tension between substances that do not mix, which makes emulsification, dispersion, and the creation of stable colloidal systems easier (Zhen *et al.*, 2023). Such extraordinary surface-active properties make biosurfactants invaluable in various healthcare applications, from wound healing to pharmaceutical formulations and cosmetic enhancement to functional food production (Dias *et al.*, 2023).

As researchers continue to unravel the multifaceted potential of biosurfactants, their role in healthcare expands (Dias *et al.*, 2023). Biosurfactants are powerful antibacterial agents that fight drug-resistant bacteria and new viral threats. Biosurfactants are highly effective in the field of wound treatment and tissue regeneration. Through improved cell migration and regeneration, they aid in wound healing and tissue repair, providing new opportunities for medical practitioners. Pharmaceutical formulations now include biosurfactants, which improve the stability and solubility of drugs. These compounds significantly improve the drug delivery methods, which could improve the therapeutic efficacy of the drugs. Biosurfactants help emulsify cosmetics and personal care products, improving the texture and quality of the final product (Haddaji *et al.*, 2023). Along with changing the solubility of bioactive substances and broadening the applications of functional food additives, they are also leaving their mark on the food business. Diagnostic assays require biosurfactants because they provide increased sensitivity and stability. Although biosurfactants have great potential, environmental concerns, and sustainability pose difficulties (Ceresa *et al.*, 2023).

In this review, we embark on a comprehensive journey through the world of biosurfactants in healthcare. We explore their microbial origins, discover their physicochemical properties, and uncover their diverse applications. We show how biosurfactants are changing the way healthcare is done by showing their amazing abilities in areas like antibacterial properties, wound healing, pharmaceutical innovation, cosmetic enhancement, functional food enhancement, diagnostic and biomedical uses, and more.

## **Biosurfactants**

### *Nature and Diversity*

Biosurfactants represent an intriguing and multifaceted class of molecules that have captivated researchers and industries due to their remarkable versatility. This section explores the nature and diversity inherent to biosurfactants, unveiling their distinctive attributes and broad applicability. According to Begum *et al.* (2023), biosurfactants are amphiphilic, which means they can stick to both hydrophobic and hydrophilic surfaces. This unique property empowers them to interact at the interfaces of various phases, enabling crucial functions such as reducing surface tension and facilitating emulsification. Biosurfactants exhibit substantial diversity, encompassing various types and classes. These include glycolipids, lipopeptides, fatty acids, phospholipids, and more (Karnwal *et al.*, 2023). Each type boasts distinct chemical structures and properties, contributing to various industry applications. Furthermore, the microbial world serves as the cradle of biosurfactants, where microorganisms synthesize these molecules as part of their survival strategies (Khanna *et al.*, 2023). Understanding their microbial origin and the intricate pathways governing their production is fundamental to harnessing the full potential of biosurfactants across diverse fields, from healthcare to biotechnology and beyond.

### *Definition and Amphiphilic Nature*

Microorganisms produce surface-active molecules, which are the basis of biosurfactants. These molecules exhibit a unique characteristic, amphiphilicity, essential to their function. This amphiphilic

nature arises from their dual affinity for hydrophilic (water-attracting) and hydrophobic (water-repelling) environments. This property allows them to effectively interact with interfaces between immiscible substances, such as the interface between water and oil (Ceresa *et al.*, 2023).

### **Types and Classes of Biosurfactants**

Biosurfactants come in various types and classes, each with distinct structures and properties (Banat *et al.*, 2016).

**Table 1.** The most notable classes of biosurfactants

Glycolipids	Glycolipids are biosurfactants composed of carbohydrates linked to long-chain aliphatic acids. Examples include rhamnolipids, sophorolipids, trehalolipids, mannosyl erythritol, cellobiose lipids, lamins, and exorphins. These glycolipids are pivotal in reducing surface tension and facilitating emulsification.
Lipopeptides and Lipoproteins	Lipopeptides, such as gramicidin, and lipoproteins, like polymyxins, are essential biosurfactants known for their antimicrobial properties. They often comprise both hydrophilic and hydrophobic segments, enabling them to interact with lipid bilayers and disrupt microbial cell membranes.
Fatty Acids, Phospholipids, and Neutral Lipids	Some microorganisms produce biosurfactants such as fatty acids, phospholipids, and neutral lipids. These biosurfactants can play roles in solubilizing hydrophobic compounds and stabilizing emulsions.
Polymeric Biosurfactants	This class includes biosurfactants like Emulsan (a glycolipid), liposan, mannoprotein, and other polysaccharide-protein complexes. Their high molecular weight characterizes them and serve as effective emulsifiers
Particulate Biosurfactants	These unique biosurfactants form microemulsions and are particularly significant in enhancing the uptake of hydrophobic compounds by microbial cells. They are vital for processes like alkane uptake.

### *Microbial Origin and Production*

Microorganisms like bacteria, yeasts, and fungi are primarily responsible for producing biosurfactants (Banat *et al.*, 2010). These microorganisms synthesize biosurfactants at their cell surfaces (cell-bound) and excrete them into their surrounding environment (extracellular). The production of biosurfactants by microorganisms can be influenced by various factors such as the type of microorganism, growth conditions, and nutrient availability (Santos *et al.*, 2016). Understanding the nature and diversity of biosurfactants lays the foundation for exploring their myriad applications, including their significant roles in healthcare, biotechnology, environmental remediation, and beyond.

### *Physicochemical Properties of Biosurfactants*

Biosurfactants, with their unique physicochemical properties, are at the heart of their diverse applications. This section will delve into these properties, focusing on their surface-active nature, ability to reduce surface and interfacial tension, and remarkable emulsifying capabilities (Santos *et al.*, 2016).

### *Surface-Active Properties*

Biosurfactants are renowned for their surface-active properties, a fundamental characteristic that sets them apart. These properties result from their amphiphilic nature – the simultaneous presence of hydrophobic (water-repelling) and hydrophilic (water-attracting) moieties within their molecular structure. This amphiphilicity enables biosurfactants to interact effectively at interfaces between two immiscible substances, such as the interface between water and oil or between water and air. At these points, biosurfactant molecules arrange themselves to lower the surface or interfacial tension, which makes it easier for the substances to interact with each other (Bjerk *et al.*, 2021).

*Reducing Surface Tension*

One of the primary roles of biosurfactants is the reduction of surface tension. Surface tension is the force that acts at the interface of a liquid and tends to minimize the area of the interface. In the case of water, it is the force that enables water droplets to form spherical shapes (Ron, & Rosenberg, 2001). Biosurfactants reduce surface tension by selectively accumulating at the liquid-air or liquid-liquid interface. Their hydrophilic heads align with the aqueous phase, while their hydrophobic tails extend into the non-aqueous phase. This orientation effectively weakens the cohesive forces within the liquid, reducing the tendency of the liquid to minimize its surface area. As a result, surface tension decreases, facilitating processes like emulsification and foaming (Santos et al., 2016).

*Reducing Interfacial Tension*

Interfacial tension occurs at the boundary between two immiscible liquids, such as oil and water. Biosurfactants can also reduce this tension by acting at the interface between these immiscible phases (Satpute et al., 2010). They achieve this by adsorbing at the liquid-liquid interface and disrupting the attractive forces between the different phases. This reduction in interfacial tension promotes the formation of stable emulsions, where tiny droplets of one liquid are dispersed in the other. This property is invaluable in industries like food, cosmetics, and pharmaceuticals, where stable emulsions are crucial (Eras-Muñoz et al., 2022).

*Emulsifying Capabilities*

Biosurfactants' emulsifying capabilities testify to their remarkable utility (Akbari et al., 2018). Emulsions are systems where one immiscible liquid is finely dispersed in another. Biosurfactants are great at emulsifying because they have an amphiphilic structure and can lower surface and interfacial tensions. They can create and stabilize emulsions by reducing the interfacial tension between immiscible liquids, preventing droplets from coalescing, and separating. This emulsifying prowess is particularly valuable in various applications, including the formulation of pharmaceuticals, cosmetics, and food products. Biosurfactants contribute to improved product stability, texture, and bioavailability, enhancing these products' overall quality and performance. Understanding these physicochemical properties of biosurfactants is pivotal in harnessing their potential across diverse applications, including healthcare, biotechnology, environmental remediation, and more. Their ability to manipulate interfacial properties makes them indispensable in industries striving for innovative solutions in managing and utilizing complex liquid systems (Peele et al., 2016).

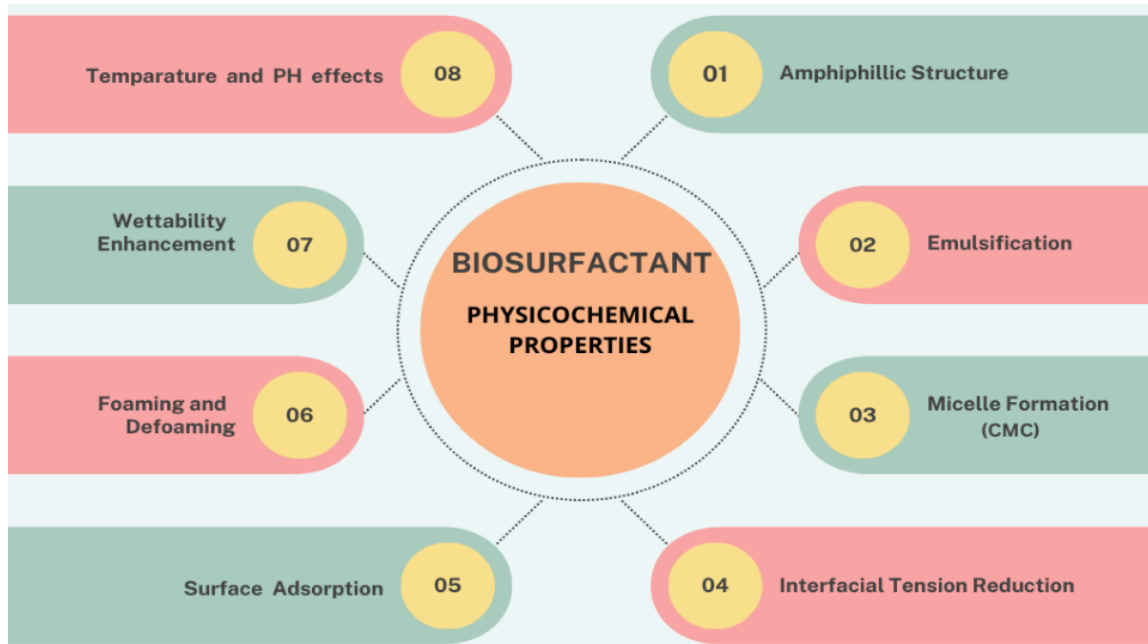


Figure 1. Physicochemical properties of biosurfactants

### Biosurfactants in Healthcare Applications

In this section, we will delve into the remarkable role of biosurfactants in healthcare applications, with a specific focus on their antibacterial properties and potential applications in wound care and infection control.

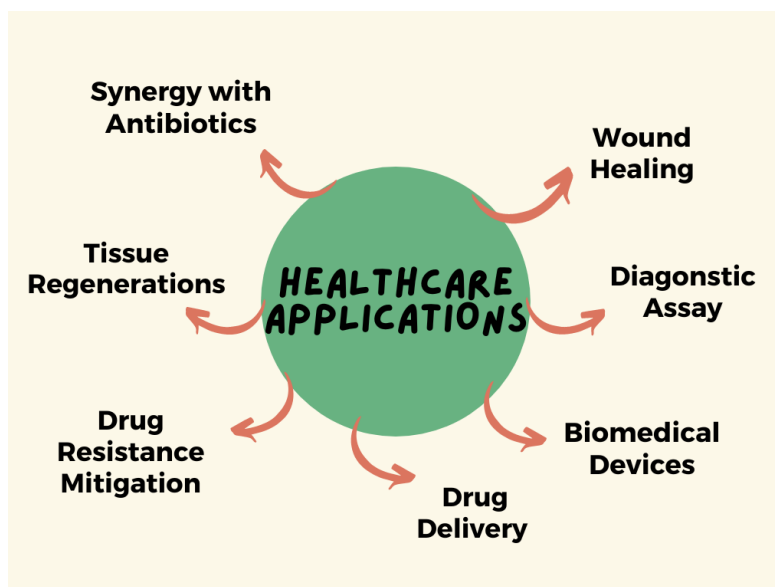


Figure 2. Healthcare Applications

#### Antibacterial Properties

Biosurfactants have exhibited robust antibacterial properties, showcasing their potential as novel antimicrobial agents. Research has unveiled their effectiveness against various bacteria (Santos *et al.*, 2016), including Gram-positive and Gram-negative strains. Several studies have explored the antibacterial effects of different biosurfactants, shedding light on how biosurfactants combat bacterial pathogens. For instance, glycolipids such as rhamnolipids have demonstrated significant antibacterial activity against pathogens like *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Surfactin and iturin are two lipopeptide biosurfactants that have shown promise in stopping the growth of bacteria. This means that they could be used as antimicrobials. The mechanisms underlying biosurfactants' antibacterial effects are multifaceted. They can disrupt bacterial cell membranes, leading to leakage of cellular contents and cell death. Additionally, biosurfactants may interfere with essential bacterial processes, such as biofilm formation, surface adherence, and nutrient uptake, ultimately inhibiting bacterial growth and survival (Ndlovu *et al.*, 2017)

#### Applications in Wound Care

The antibacterial properties of biosurfactants hold great promise in healthcare, particularly in wound care. Biosurfactants hold remarkable potential to expedite and enhance the wound healing process, primarily through their ability to prevent and treat infections within wounds. In wound care, especially for chronic wounds or severe burns, the presence of bacterial infections can be a significant impediment to the natural healing cascade. Biosurfactants offer a multifaceted approach to addressing this challenge (Ceresa *et al.*, 2023). First and foremost, biosurfactants act as powerful antimicrobial agents. They disrupt bacterial cell membranes and inhibit microbial growth, thus reducing the risk of infection in the wound site. By creating a microenvironment inhospitable to pathogens, biosurfactants effectively bolster the body's innate immune responses, allowing for unimpeded tissue repair. Moreover, biosurfactants' unique emulsifying capabilities enable them to remove debris, dead cells, and contaminants from the wound, promoting a cleaner and healthier healing environment. Their biocompatible nature ensures minimal tissue irritation, making them ideal candidates for wound care applications. In essence, biosurfactants offer a multifaceted approach to wound healing by preventing and treating infections, facilitating wound cleansing, and ultimately

creating an optimal milieu for the body's natural regenerative processes to flourish (Ohadi *et al.*, 2023).

#### *Infection Control*

In healthcare environments where infection control is paramount, biosurfactants have emerged as valuable allies in the battle against microbial threats. Their unique properties make them ideal candidates for incorporation into disinfectants and antiseptic formulations (Hashim *et al.*, 2022). Biosurfactants, with their amphiphilic nature, can remarkably disrupt bacterial cell membranes and inhibit biofilm formation. This dual-action approach enhances the efficacy of disinfectants and serves as a deterrent against developing resilient microbial communities on surfaces. The significance of biosurfactants in infection control cannot be overstated, particularly in healthcare-associated settings where patients are vulnerable to nosocomial infections. Biosurfactant-infused products can help lower the risk of infections by making disinfection more effective. This keeps patients safe and lowers the burden of healthcare-associated illnesses (Ceresa *et al.*, 2023; Karnwal *et al.*, 2023). Using biosurfactants in infection control strategies is a proactive way to keep the healthcare environment clean and germ-free, which leads to better patient outcomes and more efficient healthcare delivery overall (Ceresa *et al.*, 2023; Karnwal *et al.*, 2023).

#### *Antifungal Properties*

This subsection will delve into the captivating realm of biosurfactants' antifungal properties, summarizing research findings and exploring their potential applications in combatting fungi. Research has unveiled the potent antifungal properties of biosurfactants, rendering them promising candidates in the battle against fungal infections (Santos *et al.*, 2016; Sen *et al.*, 2010). These infections can be particularly challenging to treat, and the emergence of drug-resistant fungal strains has necessitated novel therapeutic approaches. Numerous studies have investigated the antifungal effects of various biosurfactants. Glycolipids like rhamnolipids have demonstrated efficacy against pathogenic fungi such as *Candida albicans*, *Aspergillus fumigatus*, and *Cryptococcus neoformans*. Lipopeptides, including surfactin, exhibit antifungal activity against various fungal species (Karnwal *et al.*, 2023). The mechanisms underlying biosurfactants' antifungal properties are multifaceted (Santos *et al.*, 2016). They can disrupt fungal cell membranes, causing membrane permeabilization and cell death. Additionally, biosurfactants may interfere with fungal biofilm formation, a key virulence factor in many fungal infections. By disrupting biofilms, biosurfactants render fungal cells more susceptible to conventional antifungal agents.

#### *Antiviral Properties*

Biosurfactants are emerging as formidable guardians against viral threats, expanding their repertoire to include antiviral properties. In an era of new and formidable viral pathogens, the quest for effective antiviral strategies has never been more critical. Biosurfactants, with their multifaceted mechanisms of action, are gaining attention as potential allies in the battle against viral infections (Subramaniam *et al.*, 2020). Their antiviral properties are particularly intriguing. Biosurfactants can disrupt viral envelopes and interfere with the integrity of viral particles, rendering them less infective. This interference can prevent viral attachment to host cells, thereby inhibiting the initiation of infection. Such capabilities hold promise for combating a wide range of viral pathogens, including known and emerging threats. In a world where viral outbreaks can have far-reaching consequences, biosurfactants offer hope in the ongoing quest for effective antiviral interventions (Subramaniam *et al.*, 2020). Their versatility and biocompatibility make them valuable candidates for developing novel antiviral formulations, potentially reshaping the landscape of viral disease management and prevention (Bjerk *et al.*, 2010). Studies have explored the antiviral effects of biosurfactants against a range of viruses, including enveloped and non-enveloped viruses. For example, some biosurfactants have exhibited activity against enveloped viruses like influenza virus and herpes simplex virus. Additionally, they have shown potential for inhibiting non-enveloped viruses such as adenovirus and norovirus. The mechanisms by which biosurfactants exert antiviral effects are still being elucidated. They may disrupt viral envelopes, rendering the viruses non-infectious. Biosurfactants could also

interfere with viral entry into host cells or disrupt viral particles, inhibiting their infection ability (Sarangi *et al.*, 2022; Raza *et al.*, 2023).

### **Other Applications of Biosurfactants**

#### *Biotechnology*

Biosurfactants can be used to develop antifungal and antiviral coatings for surfaces in healthcare settings, reducing the risk of nosocomial infections (Zhang *et al.*, 2021). Additionally, they may be integrated into antiviral drug delivery systems, enhancing the efficacy of antiviral medications.

#### *Enhanced Drug Delivery Systems*

Biosurfactants may also be integrated into antiviral drug delivery systems, potentially improving the efficacy of antiviral medications. Their ability to enhance drug solubility and bioavailability makes them valuable components in drug delivery formulations (Abbot *et al.*, 2022).

#### *Wound Healing and Tissue Regeneration*

Biosurfactants have emerged as compelling players in tissue regeneration, potentially revolutionizing these critical aspects of healthcare. With support from relevant studies, this section examines the mechanisms by which biosurfactants promote tissue regeneration and wound healing. One of their key contributions lies in their ability to maintain a moist environment at the wound site, which is essential for optimal wound healing. This moisture balance facilitates cellular migration, angiogenesis (formation of new blood vessels), and the deposition of extracellular matrix components necessary for tissue repair (Kumari *et al.*, 2020). Studies have shown that when applied to wounds, biosurfactants can enhance wound contraction and re-epithelialization. For instance, research has demonstrated that certain biosurfactants can accelerate the migration of keratinocytes, the cells responsible for re-establishing the epidermal barrier. This enhanced cell migration results in quicker wound closure, reducing the risk of infection and improving overall wound healing (Subramaniam *et al.*, 2020).

#### *Stimulating Regenerative Processes*

Biosurfactants hold promise in stimulating tissue regeneration, particularly for chronic wounds or instances where natural healing processes are compromised. Their properties can influence cellular behaviour, promoting tissue formation and remodelling. Recent studies have shown that biosurfactants can influence the behaviour of fibroblasts, the cells responsible for producing collagen and extracellular matrix components crucial for tissue structure and strength. According to Ceresa *et al.* (2023), biosurfactants help improve tissue quality during the regenerative process by encouraging the growth of fibroblasts and the production of collagen. Additionally, these molecules have been found to modulate the expression of growth factors and cytokines, orchestrating a favourable environment for tissue regeneration. Multiple investigations have provided evidence of biosurfactants' impact on wound healing and tissue regeneration. These studies often involve *in vitro* cell culture models, as well as animal models, to evaluate the effects of biosurfactant application on wound closure rates, cellular migration, collagen deposition, and total tissue structure (Karnwal *et al.*, 2023).

#### *Applications in Pharmaceutical Formulations*

Biosurfactants have earned a significant place in pharmaceutical formulations, where their unique properties enhance drug solubility, stability, and delivery. In this subsection, we will elucidate how biosurfactants contribute to these crucial aspects of pharmaceutical development.

#### *Biosurfactants as Solubility Enhancers*

Many drugs, especially those with poor aqueous solubility, face challenges in effective delivery within the body. Biosurfactants offer a solution by improving drug solubility. They do this by solubilizing the drugs, which means they can surround hydrophobic drug molecules with a hydrophobic core and show the hydrophilic heads to the water around them. This solubilization process drastically increases the drug's apparent solubility in water (Bhadoriya *et al.*, 2013).

### *Enhanced Drug Stability*

Biosurfactants also contribute to drug stability, particularly for compounds prone to degradation or precipitation. By forming protective micellar structures around the drug molecules, biosurfactants shield them from environmental factors such as light, heat, and oxidation, which can lead to drug degradation. This protective effect extends the shelf-life and effectiveness of pharmaceutical formulations (Adejumo *et al.*, 2021).

### *Biosurfactants as Drug Carriers*

Biosurfactants serve as versatile drug carriers in various drug delivery systems. Their amphiphilic nature enables them to self-assemble into micelles, vesicles, or other structures when dispersed in an aqueous environment. These structures can encapsulate hydrophobic drugs in their core, providing a stable and biocompatible means of drug delivery (Thakur *et al.*, 2020).

### *Enhanced Bioavailability*

The use of biosurfactants in drug delivery systems enhances the bioavailability of drugs. By improving solubility and stability, they increase the concentration of the drug in the bloodstream after administration, leading to improved therapeutic outcomes. This is particularly crucial for drugs with low bioavailability, which may require large doses to achieve the desired effect (Kaczorek *et al.*, 2018).

### *Biosurfactants in Emulsions*

Emulsions are widely used in pharmaceutical formulations, and biosurfactants are pivotal in their stability. By lowering the interfacial tension between phases that can't mix (like oil and water), biosurfactants keep emulsions well-mixed and don't separate over time (Santos *et al.*, 2016). This is vital for oral and parenteral formulations, such as emulsion-based drug delivery systems.

### *Biosurfactants in Nanoparticles*

Biosurfactants are also utilized in the formulation of nanoparticles for drug delivery. They can stabilize nanoparticles, preventing aggregation and maintaining a consistent particle size distribution. This is crucial for drug-controlled release and their targeted delivery to specific tissues or cells (Nitschke & Marangon., 2022).

### *Applications in Cosmetic and Personal Care Products*

Biosurfactants have found a significant niche in the cosmetic and personal care product industry, where their unique properties offer distinct advantages. This subsection will explore how biosurfactants are incorporated into cosmetic and personal care items, emphasizing their emulsification and product texture benefits (Adu *et al.*, 2020).

### *Biosurfactants as Formulation Enhancers*

Cosmetic and personal care products often require blending ingredients that would naturally separate, such as oil and water. Biosurfactants come into play as formulation enhancers, ensuring the stability and functionality of these products (Bjerk *et al.*, 2021).

### *Efficient Emulsification*

Biosurfactants excel at reducing the interfacial tension between immiscible components, which is crucial in emulsification. They can create and stabilize emulsions, ensuring that oil-in-water or water-in-oil mixtures remain uniform and do not separate over time (Bjerk *et al.*, 2021).

### *Improved Product Texture*

Using biosurfactants in emulsions contributes to the overall texture and feel of cosmetic and personal care products. They help achieve the desired consistency, whether a lotion, moisturizer, or shampoo (Bjerk *et al.*, 2021).

### *Enhanced Sensory Experience*

Biosurfactants can enhance the sensory experience of using cosmetic and personal care products. They contribute to a pleasant texture, making the product feel more luxurious and enjoyable (Bjerk et al., 2021; Adu et al., 2020).

### *Improved Spreadability*

Biosurfactants improve the spreadability of products, allowing them to be applied more evenly and with ease. This is particularly important for creams and lotions that are meant to be applied to large areas of skin (Bjerk et al., 2021; Adu et al., 2020).

### *Biosurfactants in Shampoos*

In shampoos, biosurfactants help in the even distribution of cleansing agents and conditioners, ensuring effective cleaning and conditioning of hair. They also improve the lathering properties, providing a satisfying foaming experience (Rincón-Fontán et al., 2020).

### *Biosurfactants in Skin Care Products*

In skin care products like creams and lotions, biosurfactants contribute to a smooth and non-greasy texture. They facilitate the even distribution of active ingredients, enhancing their efficacy (Adu et al., 2020).

### *Sustainability and Biocompatibility*

Biosurfactants are particularly attractive in the cosmetic and personal care industry due to their sustainability and biocompatibility. They are often derived from renewable and biodegradable resources, making them more environmentally friendly than synthetic alternatives. Additionally, their biocompatibility ensures they are well-tolerated by the skin and pose minimal risk of skin irritation or allergic reactions (Adu et al., 2020; Rincón-Fontán et al., 2020).

## **Applications of Biosurfactants in the Food Industry**

### *Functional Food Additives*

Biosurfactants have made their mark in the food industry, serving as valuable functional food additives. This subsection explores their role in this industry, highlighting how biosurfactants enhance food product quality and contribute to the efficient delivery of bioactive compounds. In the food industry, biosurfactants are versatile additives with multifaceted functions. Their unique properties make them valuable tools for improving the quality and functionality of various food products (Ribeiro et al., 2020).

### **Enhancing Food Product Quality**

#### *Emulsification and Stabilization*

Biosurfactants excel at emulsification, which is crucial for various food products, including salad dressings, sauces, and dairy products. They facilitate the uniform distribution of oil and water phases, resulting in desirable textures and mouthfeel. They also stabilize foams in meringues and mousses. Additionally, biosurfactants stabilize these emulsions, preventing phase separation and enhancing product shelf life (Ribeiro et al., 2020).

#### *Foaming and Texture Enhancement*

Biosurfactants form and stabilize foams in meringues, whipped creams, and mousses. This enhances the texture and appearance of these products, providing a pleasing sensory experience to consumers (Sharma D et al., 2023).

#### *Biosurfactants as Delivery Vehicles*

Biosurfactants also play a pivotal role in efficiently delivering bioactive compounds in functional foods. Biosurfactants make it easier for bioactive ingredients that don't dissolve in water to be absorbed by

cells by encasing them in their micellar structures. This is particularly important for enhancing the health benefits of functional foods (Sharma D et al., 2023).

#### *Biosurfactants in Dairy Products*

In the dairy industry, biosurfactants improve the texture and stability of products like ice creams, yogurts, and cheese. They aid in the dispersion of fat globules, contributing to a creamy and smooth mouthfeel (Sharma et al., 2023).

#### *Biosurfactants in Baked Goods*

Biosurfactants enhance dough handling properties in baked goods, resulting in softer and more palatable products. They also form a desirable crust in bread and pastries (Ribeiro et al., 2020).

#### *Sustainability and Clean Label*

Biosurfactants align with the growing consumer demand for sustainable and clean-label food products. They are often derived from natural sources, making them suitable for clean-label formulations. Their environmentally friendly profile and biodegradability appeal to consumers looking for sustainable food options (Ribeiro et al., 2020; Sharma, 2020)

### **Applications of Biosurfactants in Diagnostic Assays and Devices**

#### *Diagnostic and Biomedical Applications*

Biosurfactants have found a niche in diagnostic assays and medical devices, significantly improving diagnostics and enhancing biocompatibility. This subsection explores their use in these critical applications (De Giani et al., 2021).

#### *Biosurfactants as Stabilizing Agents*

In diagnostic assays, biosurfactants are stabilizing agents for various reagents and components. They help maintain the integrity and activity of antibodies, antigens, enzymes, and other biomolecules in these assays. This is crucial for the accuracy and reliability of diagnostic tests (Ceresa et al., 2023).

#### *Enhanced Sensitivity in Diagnostics*

Biosurfactants can enhance the sensitivity of diagnostic assays. By lowering background noise and nonspecific binding, they raise the signal-to-noise ratio, which lets lower concentrations of target analytes be found. This is particularly important in assays aimed at early disease detection (De Giani et al., 2021). Biocompatibility and reduced interference biosurfactants also contribute to the biocompatibility of diagnostic devices. They keep matrix effects from getting in the way of the assay's performance by reducing the impact of biological components like lipids and proteins (Ceresa et al., 2023).

#### *Biosurfactants in Medical Coatings*

Biosurfactants are making significant strides in medical devices, particularly in developing advanced coatings. These coatings, infused with biosurfactants, exhibit exceptional properties that enhance the performance and safety of various medical instruments and implants. Biosurfactants act as stabilizing agents, preventing microbial adhesion and biofilm formation on the surfaces of medical devices. This reduces the risk of device-related infections, extends the lifespan of implants, and ensures their long-term functionality. Biosurfactants are also great for medical coatings because they are biocompatible, which means they don't cause bad reactions or tissue inflammation when they come into contact with the body (Ceresa et al., 2023; De Giani et al., 2021).

#### *Reduction of Biofouling*

Biosurfactants have emerged as formidable allies in the relentless battle against biofouling, a persistent issue in various industries, including healthcare and marine engineering. Because they are amphiphilic, these compounds naturally stop microorganisms and organic matter from sticking to surfaces. This makes them very good at preventing biofouling. By reducing the adhesion of bacteria,

algae, and other fouling organisms, biosurfactants play a crucial role in maintaining the efficiency and longevity of equipment and structures. Because they are biocompatible and eco-friendly, they are even more appealing as long-term solutions for controlling biofouling. This helps the environment and meets the need for effective fouling prevention methods (Ceresa *et al.*, 2023; De Giani *et al.*, 2021).

### **Contributions to Improving Biocompatibility**

#### *Enhanced Tissue Integration*

Biosurfactant-coated medical implants have been shown to promote tissue integration. The biocompatible nature of biosurfactants reduces inflammation and encourages the formation of a protective layer of tissue around the implant, improving its long-term performance.

#### *Reduced Inflammation*

Biosurfactants contribute to reducing inflammation associated with medical devices. This is especially important for devices like catheters and prosthetics, where chronic inflammation can lead to complications (De Giani *et al.*, 2021).

### **Challenges in Biosurfactants' Healthcare Applications**

The incorporation of biosurfactants into healthcare applications faces several significant challenges. First, there is a pressing need for standardization and regulatory frameworks to ensure biosurfactant-containing products' consistent quality, safety, and efficacy. Variability in production processes and product purity can pose risks in healthcare settings, necessitating robust quality control measures and adherence to regulatory guidelines. Scalability remains a persistent challenge, as cost-effective large-scale biosurfactant production methods are essential to making them economically viable for healthcare applications. Also, biosurfactants are usually biocompatible, but there are concerns about possible allergenic or immunogenic effects that need to be fully investigated. This means that full biocompatibility studies are needed to make sure that they are safe to use in medical devices, wound care, and other healthcare settings. Finally, biosurfactants must be optimized for specific healthcare applications, with tailored characteristics (such as hydrophilicity, stability, and emulsification capacity) to meet the precise requirements of wound healing, drug delivery, diagnostics, and other therapeutic areas (Herrmann & Schlegel, 2022; De Giani *et al.*, 2021).

### **Future Directions for Biosurfactants in Healthcare**

Despite these challenges, the future of biosurfactants in healthcare holds promise and potential. Combining biosurfactants with other materials in new and improved ways is an important area of research that could lead to better drug delivery systems, wound dressings, and diagnostic tests. Personalized healthcare solutions represent another exciting frontier, where biosurfactant-based treatments can be tailored to individual patient's needs, potentially revolutionizing how we approach healthcare. Looking into how biosurfactants and other therapeutic compounds, like antimicrobials or growth factors, can work together could lead to powerful new ways to treat wounds, stop infections, and help tissues grow back. Biomedical approaches are based on natural biological processes and allow us to create biosurfactants that work like certain cellular interactions. This could lead to very effective therapies for difficult healthcare situations. Additionally, the industry's growing commitment to sustainability and eco-friendliness opens doors for research into biosurfactant production from renewable resources using environmentally conscious methods. Rigorous clinical translation efforts, driven by collaborations between researchers, clinicians, and industry partners, are essential to validate the efficacy and safety of biosurfactant-based healthcare interventions and ensure their successful integration into mainstream healthcare practices (Dias & Nitschke 2023; De Giani *et al.*, 2021; Perfumo *et al.*, 2010).

### **Conclusion**

In conclusion, there have been significant advancements and promising horizons along the path of biosurfactants from their microbial origins to various healthcare applications. This review has

underscored the amphiphilic nature of biosurfactants, their diverse classes (including glycolipids, lipopeptides, and others), and their microbial origin and production. It has illuminated their physicochemical properties, such as surface tension reduction and emulsification capabilities, which underpin their pivotal role in healthcare. In conclusion, there have been significant advancements and promising horizons along the path of biosurfactants from their microbial origins to various healthcare applications. Biosurfactants have proven their mettle in wound healing and tissue regeneration by facilitating cellular migration, angiogenesis, and extracellular matrix deposition. Their contributions to pharmaceutical formulations, through improved drug solubility, stability, and delivery systems, offer promise for developing novel therapies. This versatility extends to personalized healthcare solutions, combination therapies, and biomimetic approaches that can redefine healthcare practices. Nonetheless, the integration of biosurfactants into healthcare is challenging. Standardization, scalability, biocompatibility, and optimization for specific applications remain critical hurdles. Future directions for biosurfactants in healthcare include advanced formulations, personalized medicine, combination therapies, biomimetic approaches, sustainable production, and rigorous clinical translation. Despite these challenges and prospects, biosurfactants have immense potential to revolutionize healthcare. Addressing research gaps and exploring novel avenues will be pivotal in fully harnessing the therapeutic power of biosurfactants and ushering in a new era of healthcare innovation and sustainability. As science and technology advance, the healthcare community can anticipate exciting breakthroughs fueled by these remarkable molecules, promising improved patient outcomes and a more sustainable healthcare landscape.

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### Conflict of Interest:

The authors declare no conflict of interest.

### Abbreviation:

NAPLs - Non Aqueous Phase Liquids, GLs – Glycolipids, LPS – Lipopeptides, FLs – Flavolipids, MRSA - Methicillin-Resistant *Staphylococcus Aureus*, HAI - Healthcare-Associated Infections, HIV - Human Immunodeficiency Virus, HSV - Herpes Simplex Virus, CMC - Critical Micelle Concentration, FDA - Food and Drug Administration, ECM - Extracellular Matrix, ATP - Adenosine Triphosphate, HPLC - High-Performance Liquid Chromatography, TEM - Transmission Electron Microscopy, SEM - Scanning Electron Microscopy, MRI - Magnetic Resonance Imaging, CT - Computed Tomography, PEO - Polyethylene Oxide, PEG - Polyethylene Glycol, ICU - Intensive Care Unit, PCR - Polymerase Chain Reaction, MIC - Minimum Inhibitory Concentration, MRSA - Methicillin-Resistant *Staphylococcus aureus*, ROS - Reactive Oxygen Species, NP - Nanoparticle

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