



MICROBIAL BIOSURFACTANTS: CLASSIFICATION, PRODUCTION, AND EMERGING INDUSTRIAL APPLICATIONS

Gadakh Pravin V.*

Department of Microbiology, Arts, Science and Commerce College, Badnapur Dist. Jalna

*Corresponding Author

ABSTRACT

Biosurfactants are produced by microorganisms and synthesized mainly by bacteria, fungi and yeast. They are amphiphilic in nature, hence able to reduce surface and interfacial tension. They are eco-friendly, biodegradable, low-toxic and environmentally compatible; due to these properties, biosurfactants gained significant attention as a strong alternative to chemically derived surfactants. In the present work, a special emphasis is given on classification, microbial sources, production substrate and major industrial applications of biosurfactant. Broadly, they are categorized into low molecular weight molecules like glycolipid and lipopeptides and high molecular weight molecules like polymeric surfactants. Various bacteria, yeast and fungi like *Pseudomonas*, *Bacillus*, *Acinetobacter*, *Lactococcus*, *Candida*, and *Penicillium* were reported to produce different types of biosurfactants using agro-industrial waste as cost-effective substrates. These biomolecules have a wide application in various industries, including the oil industry, food processing, agriculture, detergents, pharmaceuticals, health care, and the cosmetics industry. Despite these applications, challenges related to large-scale production and purification cost, biosurfactants represent a promising sustainable alternative to synthetic surfactants in future industrial and biomedical applications.

KEYWORDS : Biosurfactants, amphiphilic molecules, lipopeptides, agro-industrial waste)

INTRODUCTION:

Recently, the affection for biologically synthesized surfactant is increasing rapidly, as they have multiple benefits and advantages over chemically derived surfactants. Biosurfactants are microbially produced compounds that exhibit surface activity. Various chemicals were used for the synthesis of chemical surfactants; their residues remain persistently in the environment, which acts as an additional source of contamination when used for the treatment of contaminated sites. Use of biosurfactant will help in improving the economy and reducing the unwanted contamination (Bharadwaj et al., 2013). The global market for chemical surfactants is expected to expand at a compound annual growth rate (CAGR) of 5.3% between 2020 and 2027 (Dixit et al., 2020). In comparison, the biosurfactants market is expected to grow at a slightly higher CAGR of over 5.5% from 2020 to 2026. Within this segment, rhamnolipids are expected to see notable growth, with their market value potentially exceeding USD 145 million (Ahuja and Singh, 2020).

These biosurfactants are amphiphilic molecules consisting of hydrophobic and hydrophilic domains. Due to their amphiphilic nature, biosurfactants can partition at interfaces between different fluid phases, such as oil/water or water/air. Biosurfactants were first discovered as extracellular amphiphilic compounds of fermentation bacteria (Kitamoto et al., 2001). Initially, they were considered interesting because they could increase the solubility of insoluble or poorly soluble hydrocarbons. However, the more and more popular trend of using renewable resources in industry (especially in food and pharmaceutical industries) has led to relentless interest in gaining and applying natural surfactants, mainly biosurfactants (Nitschke and Costa, 2007). Nowadays, biosurfactants are produced using co- and by-products of various technologies as carbon sources for microorganisms (molasses, glycerol, whey, frying oil, animal fat, soap stock, and starch-rich wastes, e.g., potato wastes) (Maneerat, 2005). In the present study, focus is given on types and properties of biosurfactants and their application in different industries, including agriculture, oil and food, health care, hygiene, pharmaceutical and detergent industry.

Advantages of biosurfactant: There are several advantages of biosurfactant over chemically synthesised surfactants:

- i) Biodegradability
- ii) Low toxicity
- iii) Cheap raw material
- iv) Biocompatibility and digestibility
- v) Efficient in different environmental conditions
- vi) Specificity in action
- vii) Use in environmental control/ bioremediation

Structural classification of surfactant:

Biosurfactants are classified mainly on the basis of their chemical structure and origin. The hydrophilic head is usually an amino acid, a peptide, a mono-, di-, or polysaccharide. The hydrophobic tail is usually saturated, unsaturated, linear, branched or hydroxylated fatty

acid. The four major groups of biosurfactants are anionic, cationic, nonionic, and zwitterionic based on their polarity. The majority of compounds include sulfonates, alkyl benzene, alkyl phenol ethoxylate, synthetic fatty alcohols and their derivatives, which are petrochemical industry by-products

Anionic surfactants: The polar or hydrophilic head is generally used for classification purposes. The presence of a negative charge on the head end of surfactant is considered an anionic surfactant. The best example of anionic surfactants is soaps (Passos et al., 2023). The common major groups present in anionic surfactants are sulfonic acid, alcohol sulfates, alkylbenzene sulfonates, phosphoric acid esters, and carboxylic acid salts. Generally used for industry, laundry detergents and washing liquids (Chou-Yi Hsu et al., 2025)

Cationic surfactant: when the hydrophilic head is positively charged are called a cationic surfactant. Cationic surfactants are produced by reacting alkyl halides with fatty acids and are effective in acidic environments for reducing surface tension. However, they become ineffective when used with antacids such as quaternary ammonium salts. Generally used together with nonionic surfactant in products like fabric softeners, antistatic additives, etc. (Chou-Yi Hsu et al., 2025).

Nonionic surfactant: Nonionic surfactants do not ionize means that they do not form any charge. They have a wide range of chemical properties and are valued for their low foaming, strong oil-removal ability, and effective wetting. Widely used in the textile industry, they include alcohols, ethoxylated acids and amines, amine oxides, and polyoxymethylene derivatives. Their properties can be tailored by adjusting the balance of hydrophilic and hydrophobic groups (Passos et al., 2023). Generally used in cosmetic products like moisturisers and food.

Zwitterionic surfactant: Zwitterionic, or amphoteric, surfactants contain both cationic and anionic centres. Though less common than other surfactant types, they are mild and therefore widely used in personal care and household cleaning products. They may contain two distinct functional groups with different properties (Hanan et al., 2023).

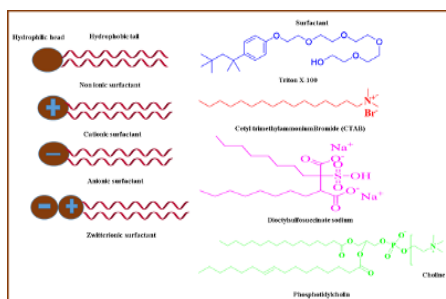


Fig. 1: The structure of different groups of surfactants

Classification of biosurfactants:

Biosurfactants are classified on the basis of their biological and chemical properties and the diversity of microbial origin. Biosurfactants can be categorised into two groups based on their molecular mass: low molecular weight and high molecular weight. Biosurfactants are also classified on the basis of chemical structure.

- **Low Molecular Weight Biosurfactant:** This type of biosurfactant is amphipathic in nature and was more effective in reducing surface tension. Most of the reported low molecular weight biosurfactants belong to the classes glycolipid, phospholipid and lipopeptide. These molecules possess both a hydrophobic tail and a hydrophilic head, which helps them work as wetting agents, emulsifiers, and dispersants, making them helpful in applications in pharmaceuticals, food and agriculture industries (Zhao et al., 2016).
- **High Molecular Weight Biosurfactant:** This type of biosurfactant is more effective in specially for stabilizing oil water emulsion, due to its high molecular weight hence also called as bioemulsifiers. Most of these are complex mixtures containing heteropolysaccharides, lipoproteins, lipopolysaccharides and proteins (Eduardo et al., 2011).

Classification of Biosurfactants Based on Chemical Structure:

Glycolipid: One of the major groups of biosurfactants formed as a result of glycosidic linkage with a carbohydrate group. All living creatures contain glycolipids in their cell membrane. These structures play a crucial role in the recognition of cells and in maintaining membrane stability. Their high yields and the feasibility of using renewable resources in their manufacturing make them highly suitable for commercial-scale production and application (Sharma et al., 2023). Membrane-bound carbohydrates are possessed by all eukaryotic cells that extend outward from the phospholipid bilayer into the surrounding extracellular environment. These molecules within the bilayer facilitate the identification of specific substances and contribute to both membrane integrity and the attachment of cells to tissues. The major groups of glycolipids, glyceroglycolipids and sphingolipids, are produced when a glycerol group is attached to a lipid component (Rheima et al., 2024). Sphorolipids, trehaloselipids and rhamnolipids are well-studied groups of glycolipids, of which rhamnolipids are produced by *Pseudomonas aeruginosa* are reported previously by most researchers.

Lipopeptides: Another type of biosurfactant produced by soil bacteria and parasites during the process of digestion is lipopeptides. Various configurations of the formation of the peptide bond of short-chain amino acids with lipids were reported. Lipopeptides are also a major group of biosurfactants produced and highly sensitive to microbial activity, reported earlier by various researchers (Mirani et al., 2024). The structure consists of fatty acids having 12-18 C-atoms attached to 4-12 amino acids containing peptide chains. A well-known cyclic lipopeptide includes amphicin, surfactin, iturin, fengycin, lichenicin, viscosin and petitsovan (Rheima et al., 2024). Lipopeptides are reported to have strong antibacterial, antifungal and anticancer properties along with medicinal and cosmetic applications. Apart from these strong reductions in surface tension of water up to 40 mN/m were reported (Mirani et al., 2024).

Phospholipids: hydrophilic head and hydrophobic tail are found in phospholipids arranged in a bilayer configuration. Phospholipids are present in the cell membrane of every living organism. Structurally, phospholipids are composed of two fatty acids, one phosphate molecule and one glycerol molecule (Chou-Yi Hsu et al., 2025). Desai and Banat (1997) reported a bacterial species of *Acinetobacter* and *Thiobacillus thiooxidans*, a strong producer of phospholipid-type biosurfactant. Phosphatidic acid, phosphatidylglycerol and phosphatidylinositol are the most reported types of phospholipids.

Fatty Acid: Fatty acid metabolism generates a substantial amount of ATP, making these molecules an important source of energy. Glucose or fatty acids are utilised by many cell types for energy. They vary in length; some contain only four carbon atoms, whereas other like caprylic acid, originated from natural fats and oils, may contain either eight or more carbon atoms. Fatty acids serve as fundamental components for the production of oils, surfactants and detergents. They are also widely used as emulsifying agents, moisturisers, nutrient modifiers and antifoaming additives (Sharma et al., 2023).

Polymeric Biosurfactant: These biosurfactants are also called as high molecular weight biosurfactants, mostly composed of different biopolymers like proteins, lipoproteins, polysaccharides and lipopolysaccharides. Strong tensile strength and high viscosity are the major characteristics of polymeric biosurfactants. Polymeric biosurfactants are commonly produced by *Acinetobacter calcoaceticus*, *A. radioresistens*, *C. lipolytica* and *C. tropicalis*, respectively. The well-known examples of polymeric biosurfactants are Emulsan, Alasan, Liposan and Lipomanan (Sharma et al., 2023). The property of emulsifying substances lowers the surface tension between liquids and solids, making them potentially applicable to include petroleum, cosmetics, food processing and the agriculture industry. Another key benefit of polymeric biosurfactants is biodegradability, and generally less harmful than conventional synthetic surfactants. Their eco-friendly nature makes them valuable, especially in bioremediation, where they can help break down pollutants and support the restoration of contaminated sites (Simoes et al., 2024).

Microorganisms Producing Biosurfactants: Since the discovery of biosurfactant-producing microorganisms, various biosurfactant-producing bacteria, fungi, and yeasts have been reported by researchers. These microorganisms have been reported from various countries and sites, including petroleum-contaminated sites, oil reservoirs, soil, and the marine environment. Despite these sites, various substrates were used for the production of biosurfactant. Table no. 1 shows representative data of different types of biosurfactants and producing organisms.

Table 1: Types of biosurfactants and producing microorganisms

Type of biosurfactant	Biosurfactant name	Name of producing organism	Type of organism
Glycolipids	Rhamnolipid	<i>Pseudomonas aeruginosa</i>	Bacteria
	Trehalolipid	<i>Rhodococcus</i> species	Bacteria
	Sphorolipids	<i>Metschnikowia churdharensis</i> <i>Torulopsis bombicola</i> ,	Yeast
	Mannosyl erythritolipid	<i>Candida Antarctica</i>	Yeast
	Xylolipid	<i>Lactococcus lactis</i>	Bacteria
	Cellobio lipids	<i>Ustilago maydis</i>	Fungi
	Flocculosin	<i>Pseudozyma flocculosa</i>	Fungi
	Glucolipid	<i>Burkholderia cenocepacia</i>	Bacteria
	Monoacylglycerol	<i>Candida ishiwadae</i>	Yeast
Lipopeptides and lipoproteins	Surfactin	<i>Bacillus subtilis</i>	Bacteria
	Arthofactin	<i>Arthrobacter</i> sp.	Bacteria
	Iturin	<i>Bacillus subtilis</i>	Bacteria
	Fengycin	<i>Bacillus subtilis</i>	Bacteria
	Lichenysin	<i>Bacillus licheniformis</i>	Bacteria
	Pumilacidin	<i>Bacillus pumilus</i>	Bacteria
	Serrawattin	<i>Serratia marcescens</i>	Bacteria
	Viscosin	<i>Pseudomonas fluorescens</i>	Bacteria
Fatty acids, Phospholipids and Neutral lipids	Fatty acids	<i>Corynebacterium lupus</i>	Bacteria
	Spiculiporic acid	<i>Penicillium spiculiporum</i>	Fungi
	Oleic acid	<i>Issatchenkia orientalis</i>	Yeast
	Neutral lipids	<i>Nocardia erythropolis</i>	Bacteria
	Phospholipids	<i>Acidithiobacillus thiooxidans</i>	Bacteria
Polymeric Bio-surfactants	Emulsan	<i>Acinetobacter calcoaceticus</i>	Bacteria
	Liposan	<i>Candida lipolytica</i>	Yeast
	Alasan	<i>Acinetobacter radioresistens</i>	Bacteria
	Biodispersan	<i>Acinetobacter calcoaceticus</i>	Bacteria
	Carbohydrate-protein-lipid	<i>Pseudomonas fluorescens</i>	Bacteria
Particulate Bio-surfactant	Vesicles and fimbriae	<i>Acinetobacter calcoaceticus</i>	Bacteria

Substrate used for biosurfactant production:

Since the last decade, demand for biosurfactant increasing day by day as a strong biodegradable alternative to chemically synthesised surfactants. The main constraint in the large-scale production of biosurfactants is production cost and downstream processes. The restless efforts of different scientists and contributors have reported various low cost substrate which can be utilised by the microorganisms as substrate for the production of biosurfactant; a waste from agro industrial residue, industrial and oil waste, carbohydrates and dairy waste are used and studied extensively. Among these, the substrate agro-industrial waste was found to be the most helpful and profitable and aids an additional benefit in effective management of waste (Rene et al., 2020).

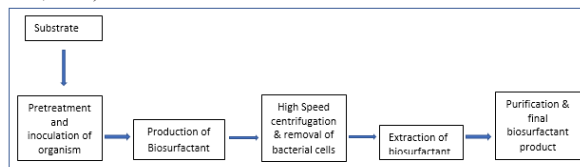


Fig. 2: Graphical representation of the process of biosurfactant production

Agro-industrial waste, such as cassava waste, date molasses, orange peel, corn steep liquor, and sugarcane bagasse, is used for the production of biosurfactant. Fruit peels of apple, banana, orange, and carrots have also been reported to be used as a substrate for biosurfactant production. After the extraction of juice from fruits, their peels act as waste in the environment. Use of cashew apple juice for biosurfactant production was reported by Rocha et al. (2007). Banana and carrot peels were also used as a substrate for biosurfactant production. Starch-rich waste from rice, wheat, cassava, soyabean flour and rice straw were also used as substrate for biosurfactant production. Waste olive oil and sunflower oil have been used as a substrate for biosurfactant production as they are rich in monoglycerides, diglycerides and triglycerides (Varjani et al., 2020). Apart from these, waste from dairy industries in the form of whey was also used as a substrate, as it is rich in lactose (Daverey et al., 2011). Molasses from sugar cane industries are rich in vitamins and other substances, which were also used as a substrate for biosurfactant production (Martins and Martins, 2018).

Application of biosurfactants

In recent years, biosurfactants have attained the interest of researchers as a special status of a chemical in demand, as a potential application including enhanced oil recovery, lubricant in crude oil drilling, surfactant-aided bioremediation of water-insoluble pollutants, and in the health care and food processing industries (Banat et al., 2010). Apart from these, biosurfactants are also used in other developing fields, like in cosmetic and soap formulations, foods and dermal as well as transdermal drug delivery systems, as reflected in Japanese patent literature. Traditional use of biosurfactant in the cleaning of hydrocarbon-contaminated sites is also reported. Maier and Soberon (2000), reported 100 g/L production of Rhamnolipid from *Pseudomonas* species using cheap renewable substrate and organic waste, which becomes a strong competitor to chemically derived surfactant. Below are some of the latest applications of biosurfactants in different field are discussed:

Oil industry:

When it comes to the oil industry, as we all know oil industry is one of the biggest industry worlds wide, which affect/support the economy of different countries. Extraction of oil from the reservoir, cleaning of oil reservoir, transferring oil from sludge and extraction of oil from sludge are the most crucial stages in the oil extraction process, and all these steps need the help of biosurfactant or surfactant (Farhadian et al., 2008). Keeping the oil reservoir protected for a longer time is one of the challenges for countries that have an oil reservoir. During the primary and secondary recovery process, about 75% oil is left in the reservoir. Different physical and chemical methods are used to increase oil recovery (Sen, 2010). The microbial approach is used to maximise the amount of oil output from the reservoir, in which microbial culture of interest is injected into the well with food. In these anaerobic environments, microbes alter the properties of oil, made them more fluid and decreasing the surface tension between oil and water and leads to creating a porous environment ultimately increase the oil recovery. Rhamnolipids are the most effective in this, as reported by Sharma et al., (2023). Crude oil storage tanks need to be

cleaned on a regular basis, as sludge settles at the bottom of the storage tank. Removal of these compounds is carried out by hot water vapour or by solvent. This method is time-consuming and has a health risk. Use rhamnolipid, surfactin and emulsan for cleaning and removal of these compounds, found helpful in this regard. Despite this, during the transportation of crude oil from the extraction site to the ports and refineries, paraffin and asphaltene present in oil form a deposit in the inner walls of the pipeline. Use of high molecular weight biosurfactants was found to improve oil mobility by forming a stable oil-water emulsion (Chou-Yi Hsu et al., 2025).

Food Industry:

By considering the strong potential alternative to chemical surfactants, biologically synthesised products like bioemulsifiers and biosurfactant getting attention nowadays. In the food industry, many products are prepared by mixing different types of formulation. These formulations need to remain stable for a longer life. To increase the taste of products and smooth texture formation, emulsifiers are used in this process. Emulsifier increases the texture of food and consistency of food. Bioemulsifiers produced from different organisms are found helpful in this regard. Zouari et al. (2016) reported that rhamnolipid produced from microorganisms can enhance the quality of butter and frozen desserts. Biosurfactants are reported to be a strong antimicrobial agent in the food industry for inhibiting and retarding the development of common microbes in food. Biosurfactant produced from *L. plantarum* and *P. acidilactici* shows antimicrobial activity against a strain of *S. aureus* (Yan et al., 2019). Biosurfactants were found helpful in preventing the deterioration of protein and oxidation of lipid, hence increasing the quality of food. Apart from these, biosurfactants were also reported as an additive which, in terms useful for improving and maintaining the specific physical characteristics of food, including freshness, taste, texture and appearance (Sharma and Saharan, 2016a).

In agriculture:

Apart from industrial application biosurfactant are emerged as promising bio-based agents for sustainable agriculture as they are found to be helpful in reducing dependence on chemically derived agrochemicals. These amphiphilic molecules, produced mainly by soil rhizospheric bacteria, yeasts and fungi, help to reduce surface and interfacial tension. They are involved in enhancing the solubility, mobility and bioavailability of hydrophobic and poorly soluble substances in the soil environments (Banat et al., 2010; Datta et al., 2024). One of the most significant applications of biosurfactant in the field of agriculture involves the contaminated soil remediation, including desorption, complexation and mobilisation of heavy metals like cadmium, lead and zinc. Ultimately, promote the reduction in phytotoxicity and improve soil health (Mulligan, 2005). Biosurfactant are also increase the accessibility of indigenous degrading microorganisms to petroleum hydrocarbons and persistent pesticide residue, hence enhancing the biodegradation. In micronutrient-deficient or alkaline soils, anionic biosurfactants form stable metal-biosurfactant complexes that facilitate the release and plant uptake of essential trace elements. Many biosurfactant-producing microorganisms function as plant growth-promoting rhizobacteria, improving root architecture, nutrient acquisition, and overall crop productivity (Datta et al., 2024). Despite these applications, a strong antifungal and antibacterial activity of rhamnolipid and lipopeptide was reported against several phytopathogens, offering a promising biocontrol agent and reducing dependence upon chemical pesticides (Crouzet et al., 2020). Biosurfactants also work as adjuvants in agrichemical formulations and enhance spreading, wetting, adhesion and penetration efficiency, while maintaining the biodegradability and low toxicity (Banat et al., 2010). Although large-scale commercialisation remains limited by production and downstream processing costs, ongoing advances in microbial strain improvement and the utilisation of low-cost agro-industrial substrates are enhancing economic feasibility (Datta et al., 2024). Overall, the multifunctional characteristics of biosurfactants-including soil remediation, nutrient mobilisation, plant growth promotion, and pathogen suppression-highlight their substantial potential as eco-friendly tools to strengthen agricultural sustainability and environmental resilience.

Detergent industry:

Biodegradability, low toxicity and high surface activity have increasingly recognised biosurfactants as a sustainable substitute to chemically derived surfactants (Pardhi et al., 2022). Biosurfactants can remove oil, grease and hydrophobic dirt from the fabrics and hard surfaces as they reduce the efficiently surface and interfacial tension.

The effective cleaning performance at a minimum dose compared to a chemical surfactant, due to their relatively low critical micelle concentration, aids in improving formulation efficiency (De Almeida et al., 2016). An essential property required in a detergent system is strong emulsifying, dispersing and wetting properties exhibited by glycolipids such as rhamnolipid and lipopeptides like surfactin (Pardhi et al., 2022). Antimicrobial activity possessed by several biosurfactants helps in enhancing hygienic performance in laundry and household cleaning products (Hsu et al., 2023). Ability to remain stable under varying environmental factors, including pH, temperature and salinity conditions, makes biosurfactant a suitable at diverse washing environments, including low-temperature formulations (Pardhi et al., 2022). Despite challenges related to production costs and large-scale recovery, advances in bioprocess optimisation and strain development are improving economic feasibility. The combination of cleaning efficiency, environmental compatibility, and renewable production pathways positions biosurfactants as promising components in next-generation eco-friendly detergent formulations.

In medicine and Pharma:

Despite agriculture and the food industry, microbial-derived biosurfactants are attracting the world's attention in the field of medicine and the pharma industry due to their highly promising biomolecules in biomedical research and unique physiological and biological properties. Biosurfactants were found to play a crucial role in several advanced therapeutic strategies, including drug delivery, induction of tumour cell differentiation, antimicrobial agents, antiviral therapies, wound healing and immune modulation. Soberon – Chavez et al. (2021) reported and highlighted therapeutic potential in the field of oncology and infectious disease management. In addition to these modern biotechnological approaches, which include chemical modification and genetic engineering, they have been found useful in optimising biosurfactant functionality and enhancing their value for clinical application. The biosurfactant produced by bacteria was found ideal component of a nanocarrier system, where they increase the drug solubilization and membrane permeability. In the treatment of multidrug-resistant infections and cancer, improved therapeutic efficiency is critically needed, and the integration of biosurfactants plays an important role. Synergistic activity between biosurfactant and drugs allows them to interact with the cell membrane by increasing membrane permeability and facilitating drug uptake by target cells (Kubicki et al., 2019). To fully exploit their potential in nanomedicine, it is essential to understand the molecular interactions between biosurfactants and nanocarrier components, as well as their interactions with biological membranes.

In the cosmetics and healthcare industries:

A significant amount of attention has been paid to biosurfactants in this field too. These molecules possess a characteristic property that makes them a potential candidate in the cosmetics and healthcare industries, including various personal care products such as shampoo-based formulations, shower gels, facial cleansing products, toothpaste, and skin care formulations. Rhamnolipid, a type of biosurfactant, functions as a mild cleansing and conditioning agent, hence used in hair care products and maintaining scalp hygiene by preserving hair lustre (Desanto, 2008). Biosurfactants also have the property to remove impurities without changing the skin hydration and preventing irritation. They are used in moisturising cleansers and nourishing cream (Bhattacharya et al., 2017). Apart from this, biosurfactants were also reported to exhibit antioxidant activity, which can protect skin cells from oxidative stress and help delay visible signs of ageing like wrinkles and loss of elasticity (Takahashi et al., 2012). Additionally, antimicrobial and anti-adhesive properties of biosurfactant were demonstrated, which can be helpful in inhibiting the growth of harmful microorganism resides on the skin and scalp, making biosurfactant a valuable ingredient in anti-dandruff shampoos and related hygiene products (Rodrigues et al., 2006). The compatibility of biosurfactants with biological systems enhances their suitability for cosmetic applications. The increased awareness and consumer demand for natural and sustainable cosmetic ingredients encouraged the demand for biosurfactants as a strong alternative to synthetic surfactants in many formulations, making them promising natural ingredients that contribute to safer, environmentally friendly cosmetic products.

Challenges and future prospects:

As a strong, sustainable alternative to chemically derived surfactants, the major obstacles in the large-scale production are expensive substrate, complexity of fermentation process, and the cost of downstream purification techniques. In some cases, nearly 50-80% of

the total production cost of purification, including centrifugation, ion exchange or solvent extraction, makes biosurfactants less competitive compared with conventional chemical surfactants. Difficulties in large-scale fermentation, low product yield and microbial strain variability also add additional complications in the commercialisation of biosurfactant. Despite these restrictions, promising advantages of biosurfactant, including biodegradability, low toxicity, and eco-friendly nature, overcome their limitations and usability. Use of inexpensive renewable substrates like agricultural wastes, optimisation of the fermentation processes, and microbial strain development significantly reduce the production cost. With continuous research and development in technologies, microbial surfactant likely to become more economically viable and can be widely used in industries, including pharmaceuticals, cosmetics, and environmental remediation in future.

CONCLUSION:

Biosurfactants are a diverse group of biologically produced molecules with potential application in the cosmetic, pharmaceutical, detergent, food and agriculture industries as a sustainable and strong alternative to synthetic surfactants. Their properties make them attractive substitutes for chemically derived surfactants. Ability to reduce surface and interfacial tension, biosurfactants play a vital role in stabilising newly produced surfaces in different industrial processes. Antimicrobial, antiviral and antibiofilm properties of biosurfactant attracted the interest of researchers working in the field of medical and clinical applications. In pharmaceutical formulations, biosurfactants help in increasing the solubility and bioavailability of water-insoluble drugs. Despite these properties, wetting, foaming, emulsifying and dispersing activities shown by biosurfactants broaden their industrial utility. Through challenges like low production yield and high manufacturing cost limiting the widespread use of biosurfactant, ongoing research and technological advances are expected to minimise these barriers, so that biosurfactant will increasingly be recognised as a superior and promising alternative with potential for future industrial and biomedical applications.

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