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Review Article

Biosurfactants: An Alternative Approach to Synthetic Surfactants

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ABSTRACT

Biosurfactants are surface-active secondary metabolites, produced by microorganisms, such as bacteria, fungi, and yeasts. Biosurfactants have been identified as an alternative approach to chemical surfactants due to its remarkable characteristics such as eco-friendliness, biological protection, biodegradability, and lower toxicity. Initially, it was suggested that biosurfactants could serve as emulsifiers of biodegradable hydrocarbons. However, later on, many studies have explained clearly their multi properties, such as antimicrobial, anti-adhesive, and antioxidant. This has widened the applications of biosurfactants in many fields including; petroleum, agriculture, food production, chemistry, cosmetics and pharmaceutics etc. This review outlined the structural characterization, classification, properties, biosynthesis, and mechanism of action. As well, considerable space is given to emphasise their potential applications along with recent developments. Since, commercial productions of biosurfactants are expensive, future research should be targeted to find alternative and cost-effective raw materials (carbon sources) to cut down the production cost. Sources of most biosurfactants are restricted into several groups of terrestrial microorganisms, more research works need to be focused on targeting different other microbial populations, including, marine dwellings to find novel biosurfactants.

Key words: *Commercial production, Diverse structures, Eco-friendliness, Microorganisms, Potential applications*

INTRODUCTION

Global demand for surfactants has shown a robust rise in its market valuation. According to the statistics, the global market for surfactant was estimated to be USD 30·64 Billion in 2016 and expected to rise to USD 39·86 billion by 2021 [1]. The use of surfactants has become indispensable in our everyday routine [2]. Biosurfactants include in laundry detergents (e.g., washing powder and laundry soap), home cleaning supplies (e.g., detergent, floor cleaner, toilet cleaner), and personal care (e.g., toothpaste, bathing soap, shampoo, shower gel, hand liquid) etc. In most of these products, surfactants are incorporated as main ingredients [3,4]. At present, most of the commercially available surfactants are originated from the petrochemical industries and chemically synthesized due to low production costs [5,6]. Such petroleum-based surfactants are negatively reviewed by researchers due to the characters of non-biodegradability, capability of accumulation, environmental pollution and toxicity to living beings [3,7]. Researchers have also found the effectiveness of plant-based biosurfactants such as saponins, lecithin and soy proteins. However, this also out looked due to the several issues like limited production capacity, lower of production rate, solubility and hydrophobicity [8].

In this context, the uses of biosurfactants have been recognized as a promising alternative to chemical surfactants [9], and plant-based biosurfactants [8]. Biosurfactants are metabolic by-products of various microorganisms, including bacteria, yeasts, actinomycetes and filamentous fungi which exhibit surfactant properties [10–14]. However, a majority of biosurfactants are found to be produced by bacteria [15].

Due to the origin, biosurfactants are also known as microbial surfactants or green surfactants or natural surfactants. Biosurfactants can be produced extracellularly or as part of the cell membrane by microorganisms and considered as surface-active biomolecules [16–19]. Biosurfactants have tremendous ability to minimize the surface and interfacial surface tension and show major properties such as emulsification, detergency, solubilisation, lubrication and phase dispersion [5, 11]. Nevertheless, the functional properties of biosurfactants are largely determined by their structures, the position and size of their functional groups [20].

For the first time in the late 1960s, biosurfactants gained attention as hydrocarbon dissolution agents and subsequently, their applications have increased greatly over the last five decades, due to their advantages over the chemical surfactants such as biodegradability, less toxicity and health care, selectivity, higher surface activity and high specificity [4, 11].

As well, ability to tolerate the wide ranges of physicochemical and environmental changes like high salinity (≤20%), pH (2–12), and temperature (30-100 °C) has boosted its application [21]. The global market for biosurfactants was 3,44,068.40 tons in 2013 and it is projected that it may reach 540 kilotons by 2024 [1]. However, commercial availability of biosurfactants has become limited for several types such as surfactin, sophorolipids and rhamnolipids [22, 23].

Structural Characterization of Biosurfactants

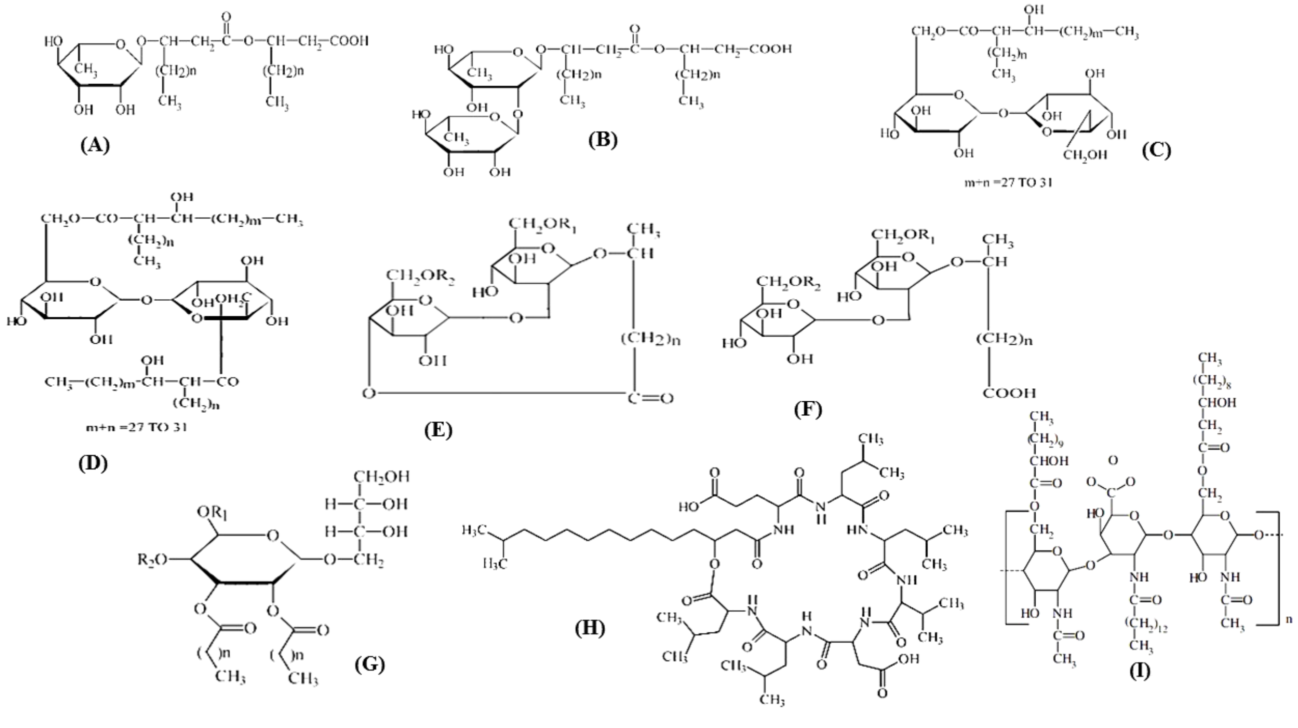

Figure.1. Chemical structure of the most studied biosurfactants (A). Mono-rhamnolipids (B). Dirhamnolipids (C). Trehalose monomycolates (D). Trehalose dimycolates (E). Lactonic sophorolipids (F). Acidic sophorolipids (G). Mannosylerythritol lipids (H). Surfactin (I). Emulsan [31].

Up to date, more than 2,000 structures of biosurfactants have been identified [24]. Nevertheless, the majority of biosurfactants are isolated from terrestrial microbes or where, they grow in the hydrocarbon-polluted areas, while very few studies have been carried out in relevant to marine microbes [25]. Because of the wide diversity of structures (Figure.1.), biosurfactants exhibits unique properties [26]. The molecules of typical biosurfactants are amphiphilic [27] contains both hydrophilic (polar) and hydrophobic (nonpolar) groups [28, 29]. Polar groups could be a carbohydrate, an amino acid, a phosphate group or can even some other group such as amino acid, cyclic peptide, carboxylic acid or alcohol. However, the nonpolar group generally contains long-carbon-chain fatty acid and also can be hydroxyl fatty acids or α-alkyl-β-hydroxy fatty acids [30]. The majority of biosurfactants are either anionic or neutral. Nevertheless, a few biosurfactants are also identified as cationic [30]. Hydrophilic portion, of the biosurfactant is responsible for its water solubility. As well, hydrophobic portion appears to be concentrated at the air-water interfaces or in the middle of the micelles, decreasing the surface tension of the solution [30].

Classification of Biosurfactants

Many microorganisms have been reported to produce several classes of biosurfactants [32]. Biosurfactants are classified according to their molecular weight, chemical composition, physico-chemical properties, mode of action and microbial origin [31, 33]. However, the biosurfactants have been preferably classified by many authors based on their molecular weight [31, 33], and categorized as i).low-molecular-mass and ii). high-molecular-mass biosurfactants. Glycolipids, lipopeptides and phospholipids are the major classes of low-molecular-mass biosurfactants, while polymeric and particulate surfactants are the major classes of high-molecular-mass biosurfactants (Table.1).

Low-molecular-mass biosurfactants are more important in lowering surface and interfacial tensions. While, high-molecular-mass biosurfactants show much effective action in stabilizing oil-in-water emulsions as they consist of polymers of polysaccharides, lipoproteins, and particulate surfactants [32].

Table.1. Classification of biosurfactants and microorganisms involved [32, 34]

Major classes	Sub classes	Microorganism
1. **Glycolipids**	Rhamnolipids	*Pseudomonas aeruginosa*
	Trehalose lipids/Trehalolipids	*Mycobacterium tuberculosis* *Rhodococcus erithropolis,*
	Sophorolipids	*Arthobacter* sp., *Candida apicola, C. bombicola, Torulopsis bombicola, Torulopsis petrophilum*
	Mannosylerythritol lipids	*Candida antartica, Pseudozyma antarctica, Pseudozyma aphidis, Pseudozyma parantarctica* *Pseudozyma rugulosa*
2. **Lipopeptides**	Surfactin/iturin/ fengycin	*Bacillus subtilis*
	Lichenysin, Serrawettin, Phospholipids, Viscosin,	*Acinetobacter* sp., *Bacillus licheniformis, Corynebacterium lepus, Serratia marcescens*
3. **Fatty acids, phospholipids, and neutral lipids**	Corynomycolic acid	*Corynebacterium lepus*
	Spiculisporic acid	*Penicillium spiculisporum*
	Phosphatidylethanolamine	*Acinetobacter* sp., *Rhodococcus erythropolis*
4. **Polymeric surfactants**	Emulsan	*Acinetobacter calcoaceticus* RAG-1
	Alasan	*Acinetobacter radioresistens* KA-53
	Biodispersan	*Acinetobacter calcoaceticus* A2
	Liposan	*Candida lipolytica*
	Mannoprotein	*Saccharomyces cerevisiae*
5. **Particulate**	Vesicles	*Acinetobacter calcoaceticus*
6. **Biosurfactants**	Whole microbial cells	*Cyanobacteria* sp.

Biosynthesis and Factors Influencing the Production of Biosurfactants

Biosynthesis of the biosurfactants is mainly dependent on the substrate and going through the multistep pathways. However, there is no clear understanding of the biosynthesis pathways of many biosurfactants. Conversely, biosynthesis of rhamnolipids like most popular biosurfactants are extensively studied by many researchers [22, 24, 35]. The outline of the biosynthesis mechanism is illustrated in figure.2.

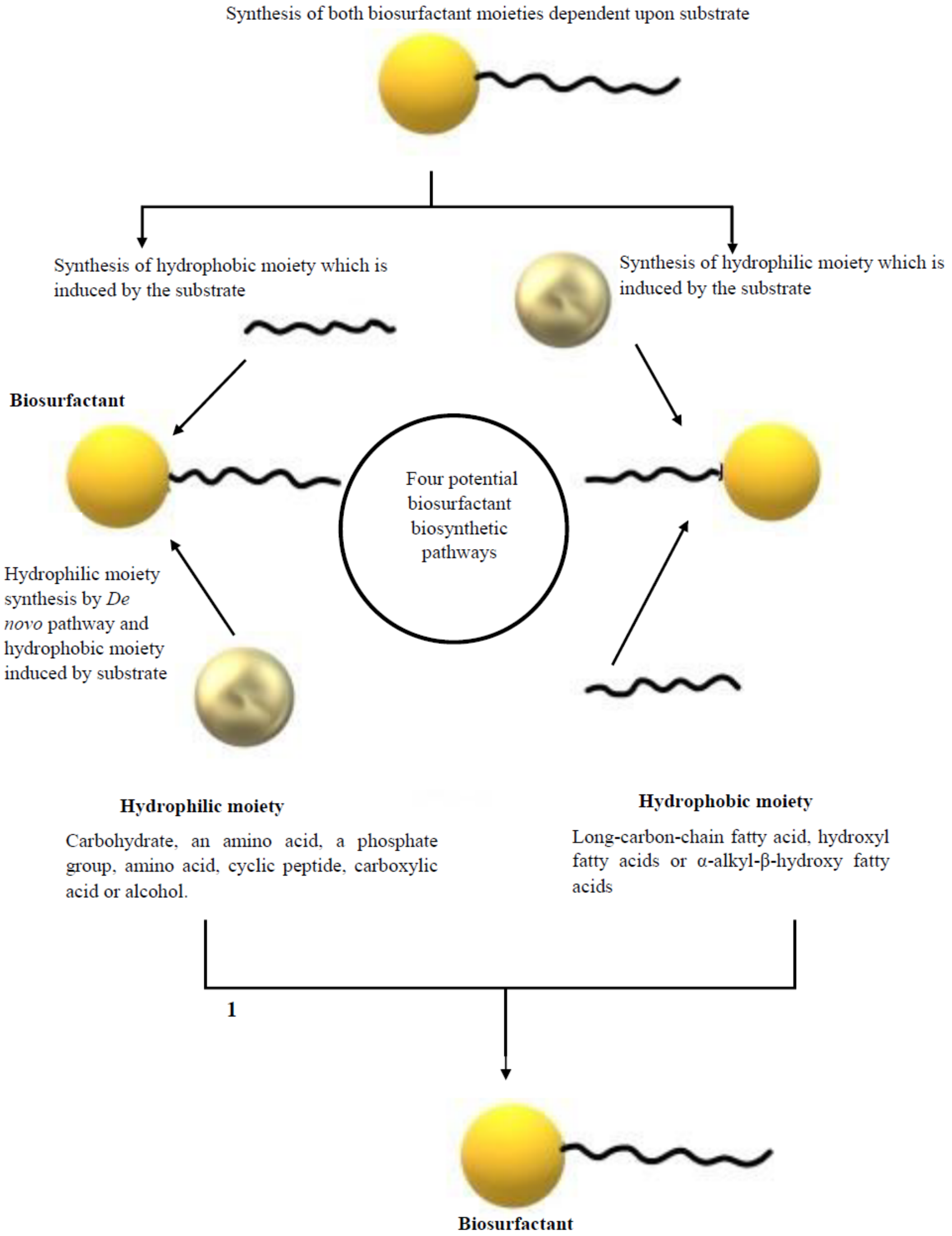

Figure.2. Overview of potential biosynthetic pathways of Biosurfactants in microorganisms [36].

Since biosurfactants producing microbes are usually heterotrophs, they have capability to produce biosurfactants in liquid media with the addition of carbon (C) sources such as; glucose, fructose, glycerol, mannitol, and olive oil [37]. C source is one of the major factors to produce biosurfactants in many microorganisms [38]. The Productions of biosurfactants are influenced by several other factors such as; types of microorganism, nitrogen (N) sources, concentration of C and N sources, pH, temperature, salinity, carbon to nitrogen ratio (C: N), incubation period, aeration and agitation [39–41].

Ilori et al. [42] identified that biosurfactant produced by *Aeromonas* spp. emulsified a range of hydrocarbons. They further noticed that the organism emulsified the diesel very well, while hexane found as the poorest. According to their demonstration, they further evidenced that production of the biosurfactants are depending on the type of substrate as the highest biosurfactants are yielded in medium with glucose and the lowest in the medium with diesel+acetate, while soybean found to be the best nitrogen source for biosurfactant production. In another study, Auhim and Mohamed [40] found that optimal temperature for biosurfactant production from the *Azotobacter chrococcum* was 30°C while optimum pH is 7. They further indicated that the production of biosurfactants seems to be very low at 6 pH. Several studies have also stated that pH and temperature like factors are contributing to the stability of biosurfactants after production [43]. Auhim and Mohamed.[40] further tested that effect of the incubation period on biosurfactant production. They recognized that on the 4th day of incubation, *A. chrococcum* shows optimum biosurfactants development, which decreases later. The speed and method of agitation used during incubation are crucial for biosurfactant production. It is important to ensure the flow of oxygen from the gas phase to the aqueous phase [44]. Wei et al. [45] Highlighted that rhamnolipid production from *Pseudomonas aeruginosa,* is dependents on the rate of agitation and they found that 200 rpm agitation were favourable for rhamnolipid production.

Potential Applications of Biosurfactants

Biosurfactants are commonly used in many sectors, such as agriculture, food processing, chemistry, cosmetics and pharmaceutics [46].

i. Biosurfactants in Petroleum Industry

Petroleum and petroleum hydrocarbons are considered to be one of the most omnipresent threats to the environment [47]. Release of large volumes of oily wastewater becomes unavoidable and so cleaning of petroleum-based pollutants becomes an urgent need [48]. It is estimated that approximately 4,00,000 tons of oil per year introduced into the environment in different ways [49] . Today, petroleum-related industries are the largest emerging markets for biosurfactants[48]. Biosurfactants produced by the hydrocarbon degradable bacteria have ability to remediate such pollutions [36, 50]. Biosurfactants can apply for various processes in the oil industry, including; microbial enhanced oil recovery, upgrading of crude oil, clean-up of oil containers and storage tanks, and formulation of petrochemicals [51].

Researchers have explained the two mechanisms, how the biodegradation of oil-derived hydrocarbons could take place. According to that, the bioavailability of the hydrophobic substrate to microorganisms is increased as a result of lowering the surface tension of the medium around the bacterium and minimizing interfacial tension between the cell wall and hydrocarbon molecules. Other mechanism explained the interaction between the biosurfactant and the cell surface, resulting to changes in the membrane, promoting adherence of hydrocarbons (increase in hydrophobicity), and dropping the lipopolysaccharide index of the bacterial cell wall without causing any damage to the membrane. Consequently, biosurfactants block the formation of hydrogen bridges and enable interaction between hydrophobic-hydrophilic that leads to rearranging the molecules and minimizes surface tension of the liquid by increasing its surface area and increase bioavailability (Figure.3). Finally, it enhances the biodegradability of petroleum hydrocarbons [52].

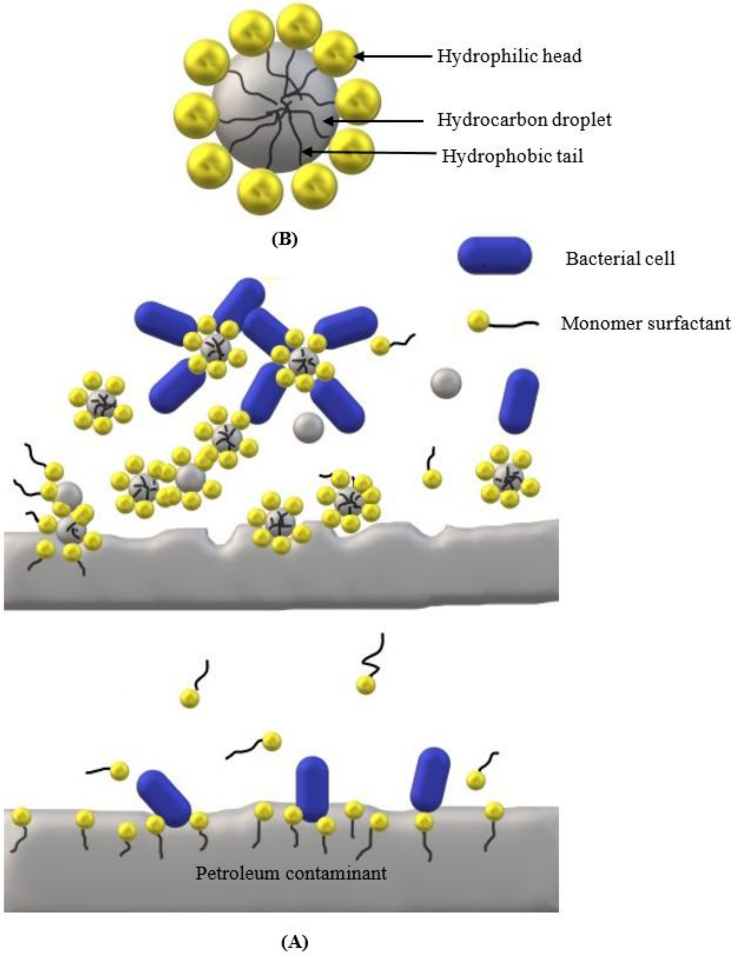

Figure.3. (A) The action of biosurfactants on petroleum [52]. (B). Simplified structure of micelle [41].

The application of biosurfactants can be enhanced the bioremediation process through; mobilization, solubilization and emulsification [53] (Figure.4). The mobilization occurs once the concentrations reached below the critical micelle concentration (CMC) of biosurfactants. At these concentrations, biosurfactants reduce the surface and interfacial tension between air/water and soil/water systems [32].

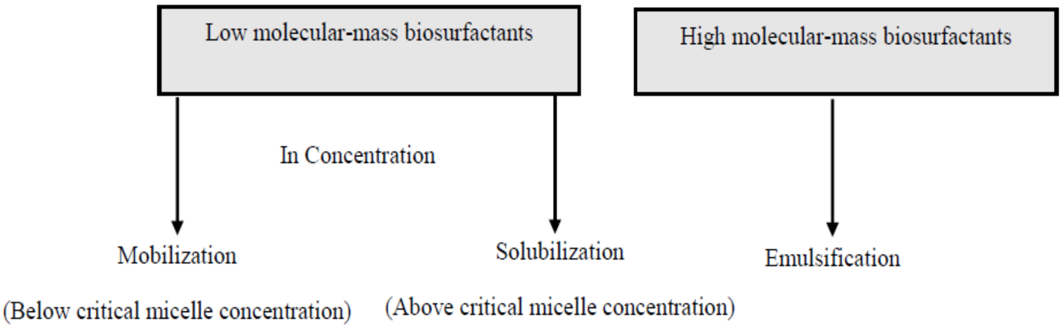

Figure.4. Mechanisms of hydrocarbon removal by biosurfactants based on its molecular mass and concentration [53].

In the case of contact of biosurfactants with soil/oil system, the reduction of the interfacial force leads to increases in the contact angle and decreases the capillary force holding oil and soil together. The solubilisation process has taken place above the biosurfactant critical micelle concentration. At such concentrations, biosurfactant molecules combine to form micelles, which significantly increase the solubility of oil. The hydrophobic ends of the biosurfactant molecules bind together within the micelle and hydrophilic ends of the biosurfactant are exposed to the aqueous phase on the outside. As a result, the interior of the micelle develops an environment compatible with hydrophobic organic molecules. The process of incorporation of these molecules into a micelle is called as solubilisation. In the process of emulsification, it creates a liquid which is containing tiny droplets of fat or oil suspended in a fluid (usually water). In order to remove oil substances from environments, biosurfactants that are having higher molecular weight and act as an additive to induce bioremediation [32].

Matsui et al. [54] investigated that potentiality of biosurfactants which are produced by *Gordonia polyisoprenivorans* to clean the bottom sludge of oil tanks. They have found that biosurfactants at a concentration of 1–10 g l^{-1}, with stable dispersion at 10 g l^{-1} for 3 weeks could effectively clean the sludge. A Study conducted by Whang et al. [55] found that incorporation of rhamnolipid which is produced by *Pseudomonas aeruginosa*; to diesel/water systems from 0 to 80 mg L^{-1} have shown diesel degradation at 40 to 100%. They also evidenced that the addition of 40 mg/L of surfactin (from *Bacillus subtilis*) could degrade the diesel at 94%. As well, Zhang et al. [56] evidenced that biosurfactants produced by *Bacillus atrophaeus* have also potentiality to remove the crude oil about 90% or even higher than that. In another study, Płaza et al. [57] recorded the effectiveness of biosurfactants that are produced by *Ralstonia picketti* and *Alcaligenes piechaudii* in the degradation of hydrocarbons by up to 80%. They further highlighted that the application of *R. Picketti* and *A. piechaudii* could significantly degrade the various hydrocarbons such as Hexadecane, pristane, cyclohexane, toluene, benzene and m+p-xylenes. Freitas et al. [49] also highlighted that ability of biosurfactant which is produced by *Candida bombicola* removes the oil spills in the ocean. A lab experiment conducted by Santos et al. [58] found that biosurfactant from *Candida lipolytica* has the potentiality to remove 70% of motor oil contaminants.

ii. Biosurfactants in Agriculture

Biosurfactants can be used to improve the soil quality of agricultural land, since the various types of pollution (e.g., hydrocarbon, heavy metals) degrade the agro soil and influence the plant growth. Biosurfactants produced by *Pseudomonas* sp., *Bacillus* sp., and *Acinetobacter* sp. shows potentiality to eliminate the hazardless of heavy metal (contaminants due to the application of pesticides) in agro lands [59]. Heavy metals can be accumulated at an elevated level in the environment due to other anthropogenic activities such as mining and smelting operations, electroplating, metallurgy, paint and batteries etc [60–62].

Bioremediation of heavy metals in soil is primarily based on their ability to form complexes with metals. The anionic biosurfactants build complexes by ionic bonds with a nonionic metallic form. These bonds are much stronger than the metal's bonds with the soil. Due to the lowering of the interfacial tension, metal-biosurfactant complexes are desorbed from soil matrix to soil solution (Figure.5). The cationic biosurfactants substitute the same charged metal ions through competition for some but not all negatively charged surfaces (ion exchange). Biosurfactant micelles could be allowed to remove heavy metal ions from soil surfaces [32]. Isolated biosurfactants from *Candida lipolytica* shows efficacy in removing copper and lead (about 30%) from standard sand [58].

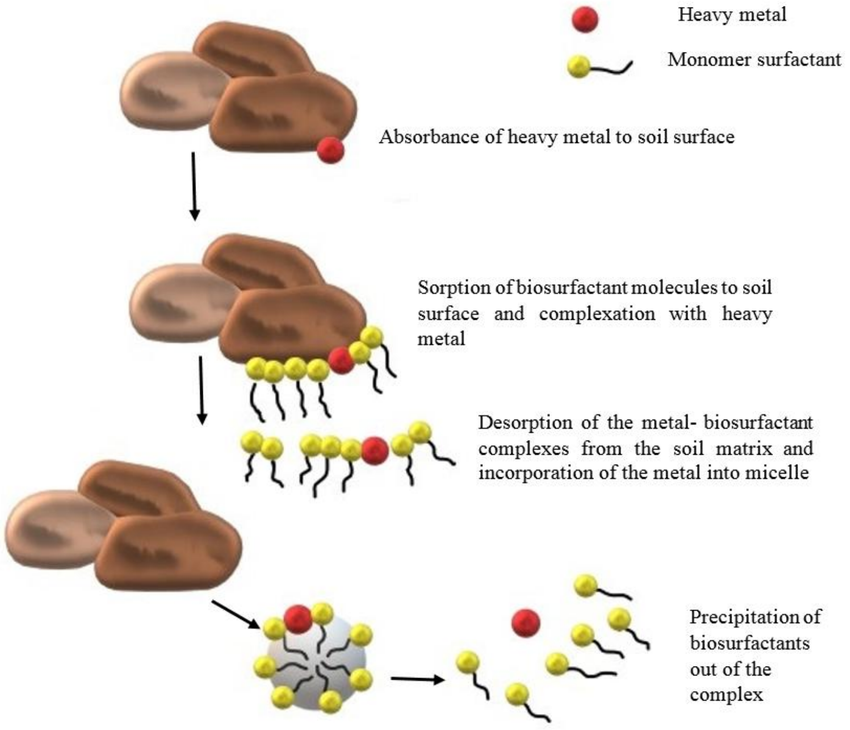

Figure.5. Mechanism of heavy metals removal by biosurfactants from contaminated soils [33].

Researchers also found that potentiality of bioremediation of octane contaminated soils with the help of biosurfactants produced by *Lactobacillus pentosus* [63]. Several studies have highlighted that ability of biosurfactants to promote the crop growth antagonistic activities in controlling plant pathogens (e.g., zoosporic plant pathogens) and increasing the bioavailability of nutrient for beneficial plant-associated microbes [59 , 64, 65].

Borah et al.[66] found that the antifungal activity of rhamnolipids against the *Fusarium verticillioides,* which is a major pathogen in *Zea mays* L (corn) and cause stalk and ear rot of maize. at higher concentration (50 mg l^{-1}) of rhamnolipids inhibit the pathogen completely including its mycelial and spores. Moreover, they found that using rhamnolipids over the 50 mg l^{-1} could improve the biomass and fruiting time compared to those of healthy control plants.

iii. Biosurfactants in Food Industry

Biosurfactants are used as food emulsifiers. Fungi (e,.g., *Candida valida, Candida utilis, Hansenula anomala, Rrhodotorula graminis, Rhodospiridium diobovatum*) and bacteria (*Klebsiella* sp. and *Acinetobacter calcoaceticus*) are the commonly used microorganism to produce bioemulsifiers [5]. While, in bakery and ice-cream formulations, biosurfactants are impotent to control the consistency, slowing staling and solubilizing the flavour oils. Adding rhamnolipid in bakery products can improve the stability of dough, volume and texture [67]. In the food industry biosurfactants (e.g., Xylolipids) also can be used as food preservatives [34].

Iv. Biosurfactants in Pharmaceutical Industry

Recently, biosurfactants have been considered as potential drug candidates and many studies have been conducted to evaluate the antibacterial, antifungal, antiviral and anti-adhesive activity against several pathogens. It also identified immune-modulators and enzyme inhibitors potentiality of biosurfactants [68]. The studies have also proved that great antimicrobial and antibiofilm ability of biosurfactants, against several drug-resistant pathogens [69].

Biosurfactants show importance in pharmaceutical industries due to its antimicrobial and anti-adhesive properties [34, 70]. Purified biosurfactants in the major class of glycolipids have a broad range of antibacterial activities and can be used for oral and dermal administration [71]. As an example biosurfactants like Rhamnolipids show antimicrobial properties against several microbes such as *Bacillus cereus*, *Micrococcus luteus*, *Staphylococcus aureus* and *Listeria monocytogenes* [8].

Moreover, a study conducted by Abalos and co-workers. [72] found that antifungal properties of rhamnolipids produced by *Pseudomonas aeruginosa* strains, against the fungi like *Aspergillus niger* and *Gliocadium virens*. Sambanthamoorthy et al. [69] demonstrated that capability of probiotic lactobacilli bacteria (*Lactobacillus jensenii* and *L. rhamnosus*) to inhibit biofilm formation by important drug-resistant pathogens; *Acinetobacter baumannii*, *Escherichia coli*, and *Staphylococcus aureus*. They further found that antimicrobial activities of biosurfactants by causing damage to the cell membrane of *A. baumannii* as well as damaging to the cell wall of *S. aureus*. Rodrigues et al. [73] have reported that antiviral activity of biosurfactants against several human viruses; treahalose lipid against the HSV and influenza virus, surfactin against human immunodeficiency virus 1 (HIV-1) and pumilacidin (surfactin analogue) against herpes simplex virus 1 (HSV-1). Besides, they further highlighted that potential of some more medicinal application of biosurfactants as; rhamnolipid against several bacterial and yeast strains isolated from voice prostheses, surfactin against fibrin clot formation and antitumour activity against Ehrlich's ascite carcinoma cells, and anti-adhesive activity of surfactin against several pathogens including enteric bacteria.

In a recent study, Ghasemi et al.[43] have found a considerable anti-adhesive activity of biosurfactants (Unknown, however structurally characterized as a lipoprotein) derived from *Pediococcus dextrinicus* against several microbes such as; *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Bacillus cereus*, *Enterobacter aerogenes* and *Salmonella typhimurium.*

v. Biosurfactants in Health and Beauty Industry

Biosurfactants also show an advantage over synthetic surfactants such as low irritancy or anti-irritating effects, better moisturizing properties and compatibility with skin and hence it is much demanded in beauty industries. Biosurfactants such as sophorolipids, rhamnolipids and mannosylerythritol lipids are widely using in cosmetics [65]. Sophorolipids which are produced by various yeast species (e.g., *Candida bombicola*) are incorporated with many cosmetics since it has good skin compatibility and excellent moisturizing properties [34, 65, 74].

Rhamnolipid show effectiveness via wound healing with reduced fibrosis and cure of burn shock and plays a vital role in skin treatments [8]. It also has properties of anti-dandruff, anti-wrinkle and anti-ageing and hence uses of Rhamnolipid also show wider its application in beauty products. As well, because of its high surface and emulsifying activities, several different formulations of Rhamnolipid also incorporated in deodorants, nail care products and toothpaste [65]. Mannosylerythritol lipids are incorporated with anti-ageing skincare products. It also shows moisturizing properties towards human skin cells, repairing effect on damaged hair along with making it smooth and flexible. As well, Mannosylerythritol lipids show stimulating ability for new hair growth [34]. Gharaei-Fathabad.[75] mentioned about possibilities to produce some more cosmetics items with incorporating the biosurfactants such as body massage accessories, lipsticks, lip makers, eyeshades, mascaras, soap, toothpaste and polishes, denture cleansers, adhesives, antiperspirants, baby products, foot care, mousses, antiseptics, shampoos, conditioners, shave and depilatory products, antacids, bath products, acne pads, contact lens solution and hair colours etc.

Recent Developments of Biosurfactants

i. Biosurfactants in Geological Carbon Storage

CO_2 is considered as one of the major candidate for Global warming and climate change and responsible to cause much more consequences along with CO_2 release to the atmosphere [76–78]. Researchers found that rather than emissions of CO_2 to the atmosphere, geological carbon storage is much less risky and important to stabilize the atmosphere atmospheric CO_2 concentration [79, 80]. A study by Park et al. [81] revealed that surfactin produced by *Bacillus subtilis* (strain ATCC6633) has an ability to store the CO_2. They further stated that *B. subtilis* will grow up and produce the surfactin even under high-pressure environments and supercritical CO_2. Moreover, Park et al. [81] confirmed that the use of naturally occurring biosurfactants to enhance geological carbon storage as a promising strategy to reduce the atmospheric accumulation of CO_2.

ii. Biosurfactants used to Produce Nanoparticles

Metallic nanoparticles such as; silver (Ag), gold (Au), platinum (Pt), and palladium (Pd), are used in the field of science and technology. The importance of nanoparticles running in the development of new devices or tools which are used in the biomedical and pharmaceutical fields includes drug delivery, diagnostic imaging, labelling, and as biosensors etc. The synthesis of metallic nanoparticles is generally carried out through the chemical method, which is downgraded due to its biological hazardness and environmental toxicity [82]. Hence, the production of metallic nanoparticles through the biosurfactants is highly encouraged by the scientist. A number of studies have been carried out recently to use biosurfactants for biosynthesis and stabilization of nanoparticles [15, 83].

Farias et al. [84] identified that possibility of synthesizing Ag nanoparticles in water-in-oil microemulsion stabilized by a biosurfactant produced by the *Pseudomonas aeruginosa.* In another study, Rane et al. [85] found that significance of biosurfactants produced by the *Bacillus subtilis,* on preparing nanoparticles of Ag and Au. In their study, purified biosurfactants from *B. subtilis* and incubated with Silver nitrate ($AgNO_3$) or Chloroauric acid ($HAuCl_4$) in order to produce nanoparticles. Rane and co-workers [85] further found that the production of biosurfactants from *B. subtilis* could be achieved in low cost by using industrial wastages like molasses, orange peels extract, bagasse extract, banana peels and potato peels extract. Hence, they further stated that the production of nanoparticles from biosurfactants is not only showing environmental friendliness but also cost-effective. Hence, biosurfactants are a better option for the synthesis of inorganic nanoparticles for industrial application [84]. Kumar et al. [86] highlighted those silver nanoparticles produced through the biosurfactant show a better broad-spectrum antimicrobial activity against both Gram-positive and Gram-negative pathogens bacteria.

iii. Biosurfactants in Anticancer treatment

Researchers are working on to find a novel treatment for many types of cancers including; breast, ovary, lung, brain, colon and pancreas [87–89] and much attentions have been paid recently to control human cancers through the biosurfactants. The biosurfactants show anticancer activity against the wide range of cancer cell lines [90]. Researchers found that inhibition of cell proliferation due to cancer, through biosurfactants [91]. Nevertheless, researchers are more favourably used surfactin to control cancers such as Ehrlich ascites, Breast, Colon, Leukemia, Hepatocellular, Oral epidermoid, Pancreatic, and Rat melanoma. However, the use of biosurfactants in this regard is still in progress and need to be studied further to find out the effects on human being [90].

Limitations in uses of Biosurfactants

Unfortunately, biosurfactants have not yet been commercially able to compete with synthetic surfactants [92]. Chemical synthesis of biosurfactants shows many difficulties while production of large quantities also restricted for very few biosurfactants, such as sophorolipids and mannosyloerythritol lipids. Productions of biosurfactants are also gain negative feedback due to its higher production costs [34]. Productions of biosurfactants are generally done by using high cost of raw materials and this leads to slow down the market growth [93]. Substrate composition may lead up to 50% of the total production costs and hence the use of inexpensive raw materials is highly important [48]. To overcome this production cost, many researchers were tried different cheap and renewable substrates to grow up the microbes [94]. Many studies have reported that the use of industrial carbon-rich wastes to improve the yield of biosurfactants [92]. Such cheaper raw material includes; glycerol (from biodiesel production), soya and sugar cane molasses, waste frying oils and ground-nut oil refinery residue, with the addition of corn steep liquor, crop residues such as bran and straw of wheat and rice, cassava wastewater, distillery wastes, mannitol, fructose, glucose, n-paraffins and animal fat etc [4, 93, 95, 96]. However, the selection of certain microorganisms, process and management of industrial by-products also need to be considered to produce cost-effective biosurfactants [4]. As well, the synthesis of nanoparticles through the biosurfactants also have drawbacks like long reduction time and complex downstream process [15].

CONCLUSION AND RECOMMENDATIONS

Due to the disadvantages over the synthetic surfactants, biosurfactants have drawn greater attention. Biosurfactants show similar or better performance, compared with synthetic surfactants. The non-harmless properties of biosurfactants lead to use in a number of different industries such as; petroleum, cosmetic, pharmaceutical, food, petroleum, wastewater treatment and agricultural sections. However, the applications of biosurfactants are restricted, mainly due to their higher production coast. Many studies have also been conducted to find alternative substrates, however, the application of such findings are yet to be developed. Hence, to cut down the production cost, more studies need to be done to find sustainable and cost-effective raw materials.

Also, more studies have been focusing on the biosurfactants of terrestrial microorganisms and there is an urgent need to discover the potential marine microorganisms as biosurfactants. Also, different strains of known microorganism should be found to enhance productivity. As well, future studies should also focus to enhance the application of biosurfactants in combination with other compounds like antibiotics or enzymes. In addition, genetic engineering technologies could also be combined to enhance the production capacity through minimum input.

Conflict of Interest

The authors declare no conflicts of interests any matter related to this paper. The submission has not been previously published, or it is not under the consideration for elsewhere.

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