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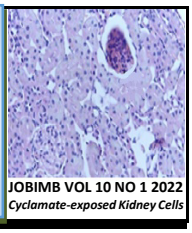

A Review on Biosurfactant Properties, Production and Producing Microorganisms

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ABSTRACT

Biosurfactants are structurally diverse surface-active agents mostly produced by various genera of bacteria, yeast and filamentous fungi that have a wide range of applications and properties. They have surface and interfacial activity, temperature and pH tolerance, biodegradability, low toxicity and anti-adhesive property. Their production was reported to be affected by temperature, PH, aeration and agitation, salt concentration and carbon and nitrogen sources. Bacteria species of the genera *Acinetobacter, Arthrobacter, Agrobacterium, Antarctobacter, Bacillus, Clostridium, Lactobacillus, Halomonas, Serratia, Rhodococcus* and filamentous fungi of the genera *Aspergillus, penicillium*, and yeast like *Candida, Yarrowia, Torulopsis, Pseudozyma, Saccharomyces* were the most notable biosurfactant producing microorganisms. Surfactin, lichenysin, rhamnolipid, Sapporolipid, liposan, viscosin, alasan, and subtilisin were among the most produced biosurfactants. The need to expand knowledge of physiology, genetics and biochemistry of biosurfactant-producing strains and the development of the process technology will help to reduce production costs.

INTRODUCTION

Amphipathic molecules known as surfactants (also known as surface active agents or wetting agents) can reduce the surface and interfacial tensions between liquids, solids, and gases [1]. Other names for surfactants include surface active agents and wetting agents. Every surfactant has a hydrophobic end and a hydrophilic end, but one end is always hydrophobic, and the other end is always hydrophilic [2]. The hydrophilic end can be anything from carbohydrate to an amino acid to a cyclic peptide to phosphate to a carboxylic acid to alcohol [3]. The hydrophobic end is often a hydrocarbon, which makes it less soluble in water. The hydrophobic end is typically a hydrocarbon. Storage, processing, and transportation facilities that generate oil waste have long presented a challenge for the petroleum industry.

Recent calls for a switch from chemically produced surface-active agents to natural surfactants of microbial origin reflect growing concern for the environment and the value placed on creating a sustainable, environmentally conscious society. Natural surfactants (**Figs. 1** to **3**) are preferable to chemical surfactants due to their many benefits, such as their adequate intrinsic biodegradability, low toxicity, and general acceptance by the environment. It is possible to produce these compounds from renewable resources at a low cost, and they can be used in environments with high levels of acidity, heat, and salt [4].

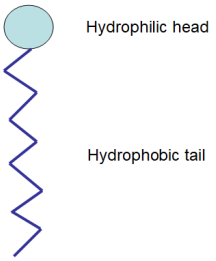

Fig 1. Surfactant molecule with nonpolar (hydrophobic) and polar (hydrophilic) moieties.

Biosurfactants, also known as microbial surfactants, are surface-active compounds that are created by microorganisms that degrade hydrocarbons and display a broad variety of structural diversity. Numerous industrial procedures depend on the usage of biosurfactants, which can be either low- or high-molecular-weight polymers, respectively. Glycolipids, lipopeptides, and phospholipids are all examples of low-molecular-mass biosurfactants, while polymeric and particulate surfactants can serve as emulsion stabilizers [1]. Glycolipids, rhamnolipids, sophorolipids, trehalolipids, lipoproteins, lipopeptides, fatty acids, phospholipids, and polymeric structures like emulsan and liposan are just some of the most frequent types of biosurfactants [4]. Many types of microorganisms are capable of secreting different biosurfactants. Among them, the most commonly used biosurfactant genera are *Pseudomonas* sp., *Bacillus* sp., *Rhodococcus* sp., *Candida* sp., *Lactobacillus* sp., *Arthrobacter* sp. and *Acinetobacter* sp. [5].

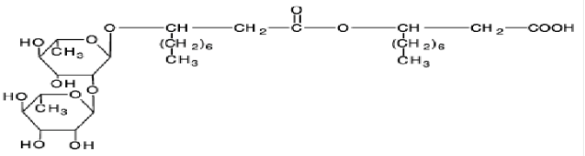

Fig. 2. Structure of Rhamnolipid (from [4]).

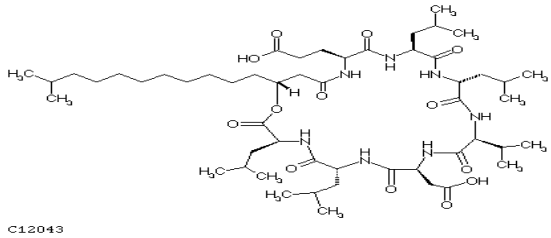

Fig. 3. Structure of Surfactin (from [4]).

Properties of Biosurfactants

Biosurfactants were found to be commercially viable due to their superior properties compared to chemically manufactured alternatives and their accessibility to a wide variety of substrates. Surface mobility, stability (against variations in pH, temperature, and ionic quality), biodegradability, low toxicity, emulsifying and demulsifying ability, and antibacterial action are all hallmarks of microbial surfactants [6]. In comparison to chemically manufactured alternatives, biosurfactants were shown to have superior characteristics, and due to their accessibility to a wide variety of substrates, they were determined to be commercially feasible. Microbial surfactants are distinguished by their surface activity, tolerance to pH, temperature, and ionic quality, biodegradability, low toxicity, emulsifying/demulsifying capacity, and antimicrobial action [6]. The following is an outline of the most prominent characteristics of biosurfactants.

Surface and interface activity

Surfactant aids in the reduction of surface tension and interfacial pressure. Surfactin generated by *B. subtilis* can reduce water's surface tension to 25mNm-1 and the interfacial strain between water and hexadecane to less than 1mNm^{-1}. *P. aeruginosa* produces rhamnolipids, which reduce water surface tension to 26mNm-1 and water/hexadecane interfacial strain to less than 1mNm^{-1}. Biosurfactants are stronger and more effective, and their Critical Micelle Concentration is a few times lower than chemical surfactants, implying that less surfactant is required for maximum surface strain reduction [7].

Temperature and pH tolerance

The commercial potential of producing biosurfactants from extremophiles has garnered a lot of attention over the past decade. Both the surface activity of biosurfactants and their stability under normal environmental circumstances (such as temperature and pH) are of great practical importance. It was reported by McInerney et al. that lichenysin from *Bacillus licheniformis* could withstand temperatures of up to 50 degrees Celsius, pH ranges of 4.5 to 9.0, and NaCl and Ca concentrations of up to 50 and 25 g/L, respectively. *Arthrobacter protophormiae* produces a biosurfactant that is both pH- and temperature-stable (30-100 °C) (2 to 12). Isolating novel microbes that can thrive in harsh environments like those seen in industrial settings is important because of the importance of these factors to production [8].

Biodegradability

Unlike synthetic surfactants, molecules produced by microorganisms degrade rapidly, making them ideal for use in bioremediation and biosorption. Concern for the environment has increased, prompting the search for viable alternatives such as biosurfactants. Biosurfactants from marine microorganisms were of concern for the biosorption of the inefficient solvent polycyclic sweet-smelling hydrocarbon, phenanthrene, which had fouled aquatic surfaces [9]. This is because synthetic chemical surfactants impose ecological challenges.

Low toxicity

Despite the way that there are few written works on the toxic nature of biosurfactants, they are generally regarded to be low or non-harmful substances that are suitable for medicinal, remedial, and nourishment applications. Poremba et al. [10] observed that a chemically generated surfactant had lower toxicity than rhamnolipids, with an LC_{50} against *Photobacterium phosphoreum* that was 10 times lower. Biosurfactant, sophorolipids from *Candida bombicola* have a reduced toxicity profile, making them useful in nutrition endeavours [11].

Antiadhesive property

To put it simply, biofilms are communities of bacteria and other forms of organic matter that have colonized an inorganic surface. The first step in biofilm formation is bacterial adhesion to the surface, which is influenced by many factors such as the type of microbe, the hydrophobicity and electrical charges of the surface, ecological conditions, and the ability of microbes to deliver extracellular polymers that help cells grapple to surfaces. Biosurfactants can alter a surface's hydrophobicity, which in turn affects the ability of microbes to adhere to the material. *Streptococcus thermophilus* produces a surfactant that inhibits the colonization of the steel by other thermophilic *Streptococcus* strains, which would otherwise cause fouling. P*seudomonas fluorescens* biosurfactant was found to inhibit *Listeria monocytogenes*' attachment to steel [12].

Biosurfactants production

Biosurfactants of various molecular architectures can be produced by a wide range of microorganisms. Biosurfactant-producing bacteria from the genera *Pseudomonas* and *Bacillus* have been described in the literature. *Pseudomonas aeruginosa* rhamnolipids have been extensively researched. The type of fermenter, pH, nutrients, substrates, and temperatures used all affect the composition and yield. Surfactin, a lipopeptide produced by *Bacillus subtilis*, has seven amino acids connected to carboxyl and hydroxyl groups of C14 acid. Surfactin concentrations of less than 0.005% reduce surface tension to 27 mN/m, making it one of the most powerful biosurfactants. Surfactin's solubility and surfactant capacity, on the other hand, are dependent on the type of substrate. *Candida* species have been successfully used in the fermentation of hydrocarbons and the subsequent synthesis of biosurfactants [13].

Factors affecting biosurfactant production

Production of biosurfactant and the type of polymer it forms are both affected by environmental and dietary factors, as well as chemical and physical parameters like temperature, aeration, divalent cation concentration, and pH.

Effect of Carbon Sources

Microbes that are utilized to make biosurfactants use a range of carbon sources and energy to thrive. For rhamnolipid formation, *Pseudomonas aeruginosa* uses water-soluble carbon sources such glycerol, mannitol, glucose, and ethanol. Glycerol behaves differently than the other carbon sources in that when the glycerol concentration exceeds 2%, the rhamnolipid level drops dramatically. According to Safi *et al.*, [14], fermentation of 3 per cent glycerol produces just 2 g/L rhamnolipids. He also discovered that grape seed oil and sunflower oil create 2 g/L of rhamnolipids at a concentration of 6% and 6%, respectively. In the presence of 6% glucose, the rhamnolipid production was calculated to be between 1400 and 1500 mg/L. With a 6 per cent and a 5% concentration of diesel and kerosene oil, respectively, 1.3 and 2.1g/L rhamnolipids were formed. Carbon sources for biosurfactant synthesis have also been discovered as soybean lecithin and crude oil [14]. Soybean lecithin is more efficiently used in biosurfactant generation than crude oil, as demonstrated by Zou et al. [15], with a minor modification. However, crude oil was found to be a useful carbon source for bacteria in the *Acinetobacter* genus. Hydrocarbons like n-hexadecane and paraffin were tried out by Jorge et al., [16] but were found to be ineffective as carbon sources for biosurfactant production. However, Onwosi and Odibo [17] discovered that glucose, at a concentration of 2%, yielded 5.28 g/L during rhamnolipids synthesis.

Effect of Nitrogen Source

Nitrogen sources are important for biomass growth and, by extension, biosurfactant formation. Pseudomonas aeruginosa was discovered to be an excellent strain for biosurfactant synthesis. However, as a result of the depletion of nitrogen sources, it has reached a stationary phase, resulting in a decrease in biosurfactant production. The biosurfactant-producing microbe was suppressed by an excess nitrogen supply, resulting in lower biosurfactant production [18]. Sodium nitrate, ammonium nitrate, and potassium nitrate were all used in the production of biosurfactants as nitrogen sources. Biosurfactant production was found to be most efficient with sodium nitrate (4.38 g/L yield) [17]. When synthesizing biosurfactants, ammonium nitrate is the preferred nitrogen source, according to research by Joshi and Shekhawat [14]. Similarly, Johnson et al. [109] discovered that potassium nitrate is a superior nitrogen source to ammonium sulphate or urea for the synthesis of *Rhodotorula glutinis* IIP-30 biosurfactant. As discussed by Jorge et al., [16], nitrogen can be obtained from a variety of organic sources, including meat extract and yeast extract, which can have a noticeable impact on biosurfactant production.

Effect of Temperature

One of the key elements in the creation of biosurfactants is temperature. The production of rhamnolipids increased as the temperature rose from 25 to 30°C, remained stable between 30 and 37°C, and then significantly decreased to 42 °C. The impact of temperature on the development of rhamnolipids and the proliferation of *Pseudomonas aeruginosa* was briefly examined by Vollbrecht et al [20]. Higher temperatures, such 47 °C, created unfavorable conditions for the growth of the culture, which is why rhamnolipid production was found to be lower at those temperatures. Similar to what happens for *Tsukamurella* sp. culture, increased temperature causes cell aggregation, which lowers glycolipid synthesis. However, the research conducted by Changjun Zoua [21] revealed that some microbes, like *Acinetobacter baylyi* ZJ2, could resist greater temperatures (40–45 °C). A temperature of 30°C was proposed as the ideal temperature where cell development was encouraged, and a higher glycolipid synthesis resulted. Additionally, Joice and Parthasarathi [22] demonstrated that *Pseudomonas aeruginosa* PBSCI produced the most biosurfactants at a temperature of 30 °C.

Effect of pH

Another significant element that has an impact on the development of biosurfactants is pH. It was discovered that the ambient pH for the synthesis of biosurfactants is between 6.0 and 6.5. The generation of biosurfactants was discovered to be reduced at pH levels higher than 6.5. Because the bacterium was unable to lower the surface tension of the growth medium at pH 4 to 4.5, the production of biosurfactant tended to decline. According to Cooper and Goldenberg [23], the development of microorganisms needed to produce biosurfactants was unaffected by a pH increase from 6.5 to 7.0. However, reducing the pH had an impact on the creation of biosurfactants. Changjun Zoua [21] found that growth was inhibited in an alkaline environment above pH 7 when researching the generation of biosurfactants utilizing *Acinetobacter baylyi* ZJ229. It was discovered that pH has an impact on microbial metabolism. Joice and Parthasarathi [22] researched the synthesis of biosurfactants by varying the pH from 5.0 to 8.5 and found that at pH 6.5, surface tension decreased by 29.19 mN/m, and at pH 7.0, emulsification activity increased by 75.12 per cent. According to Joice and Parthasarathi [22] pH 7.0 was the optimal pH for *Pseudomonas aeruginosa* PBSC1 to produce biosurfactants.

Effect of Aeration and Agitation

Foam buildup is connected to aeration. Both oxygen mass transfer and the components of the medium are impacted by agitation. In order to produce biosurfactants and promote cell growth, aeration and agitation must be taken into consideration, especially for aerobic organisms. Sen [24] used the response surface method to optimize the air flow rate at 0.75 vvm for the synthesis of biosurfactants. Similar studies on the effects of agitation found that increasing the agitation rate from 50 to 200 ppm boosted the growth rate from 0.2 to 0.72/hour and that at this setting, a maximum biosurfactant yield of 80% could be attained [24]. This is due to the fact that the system's dissolved oxygen level was significantly altered by the increase in agitation rate from 0.1 to 0.55 mg/L. Therefore, cell development was significantly influenced by higher dissolved oxygen levels, which led to higher biosurfactant synthesis.

Salt concentration

The cellular activities of microorganisms are regulated by salt concentration, and the salt content of a particular medium has a comparable effect on biosurfactant synthesis. However, some biosurfactant products were found to be unaffected by concentrations of up to ten per cent (weight/volume), despite minor CMC reductions [2].

Biosurfactant-producing Microorganism

Many different kinds of microorganisms, especially bacteria, fungi, and yeasts, produce biosurfactants. The microorganisms and their respective sources have a major impact on the yield of biosurfactants. It has become common practice to isolate microorganisms from polluted soils, effluents, and discharge point wastewater sources for use in the treatment of industrial waste products. This allows these microbes to thrive on substrates that would kill off bacteria that don't produce biosurfactants. Microbial biosurfactants come in many forms. Their production and quality can be affected by factors such as the carbon substrate's composition, the medium's phosphorous, nitrogen, iron, magnesium, and manganese ion concentrations, and other cultural factors such as pH, agitation, temperature, and dilution rate. Putting temperature, pressure, pH, and salinity at the top of the list when choosing microbes for microbial-enhanced oil recovery [25].

Biosurfactant producing Bacteria

In the generation of biosurfactants, bacteria are crucial. The primary genus engaged in the creation of biosurfactants is pseudomonas, followed by other species, as shown in **Table 1**. According to Coelho et al. [26], marine *Pseudomonas* sp. strain GU104 produced biosurfactants by decomposing quinoline. On a single *Pseudomonas* strain that produces polymeric biosurfactants, there is another paper available. Extracellular biosurfactants with emulsifying activity were discovered in *Pseudomonas nautica,* from the Mediterranean Sea's coast.[27]. Microorganisms produce several sorts of emulsifiers based on the different kinds of hydrocarbons and carbon sources. This feature was convincingly demonstrated by Desai et al. [28] in their 1988 study on the formation of trehalose lipid-o-dialkyl monoglyceride protein emulsifiers by *Pseudomonas fluorescens* that degrades hydrocarbons.

Biosurfactants from *Bacillus* species

Bacillus species are perhaps best recognized for their ability to produce a surfactant that is used by many other microorganisms. These microorganisms create lipopeptides, a kind of biosurfactants with a fatty acid and peptide group structure. A member of this class is surfactin, the first and best-known microbial surfactant. Research on the molecular genetics guiding Bacillus sp. generation of biosurfactants has recently been conducted all over the world [29].

Biosurfactants from *Pseudomonas* species

When it comes to biosurfactants, Pseudomonas species come in at a close second. Numerous Pseudomonas strains, and especially rhamnolipids, have been found to produce glycolipids. Arthrofactin, a lipopeptide biosurfactant, is produced by some *Pseudomonas* strains in addition to rhamnolipids. Other Pseudomonad biosurfactants include viscosin from *Pseudomonas fluorescens*, putisolvin from *Pseudomonas putida*, and amphisin from P*seudomonas* sp. DSS73 [30].

Biosurfactants from *Acinetobacter* species

Biosurfactants of high molecular weight, such as Emulsan and Alasan, are generated by some *Acinetobacter* species. RAG-1 emulsan is a protein and lipoheteropolysaccharide complex produced by *Acinetobacter*. D-galactosaminuronic acid, D-galactosamine, and diamino-dideoxy glucosamine are some of the sugar components of the polysaccharide apoemulsan. This biopolymer's intrinsic amphipathicity is due to the presence of fatty acids, which make up 12% of the total. Repeating heptasaccharide units of *Acinetobacter calcoaceticus* BD4 emulsan are composed of L-rhamnose, D-glucuronic acid, D-glucose, and D-mannose in the molar ratios of 4:1:1:3. In contrast, *Acinetobacter radioresistens* produces alasan, which is an anionic heteropolysaccharide and protein with a high molecular weight and alanine content [31].

Biosurfactants from *Serratia* species

Gram-negative bacterium *Serratia* produces three different surface-active cyclodepsipeptides called serrawettin W1, W2, and W3. Individual strains of *Serratia marcescens*, such as those used to produce serrawettins, are responsible for their production. Serrawettin W1 is produced by strains 274, ATCC 13880, or NS 38; Serrawettin W2 is produced by strain NS 25, and Serrawettin W3 is produced by strain NS 45. Also, *Serratia liquefaciens* produces serrawettin W2. Rubiwettin R1 and RG1 are two novel lipids produced by S*erratia rubidaea* that are temperature-dependent [32].

Biosurfactants from *Rhodococcus* species

Synthesis of glycolipid surface-active molecules is a distinguishing feature of *Rhodococcus* spp. On the island of Xiamen, off the western coast of Taiwan Strait, scientists found the oil-degrading bacterium *Rhodococcus erythropolis* strain 3C-9 in coastal soil. The biosurfactants made by *Rhodococcus erythropolis* and other *Rhodococcus* spp. include glycolipids, polysaccharides, free fatty acids, and trehalose dicorynomycolate [33].

Biosurfactants from *Holamonas* species

Halomonas sp. is most known for its ability to produce emulsifying exopolysaccharides (EPS). Few findings imply that *Halomonas* sp. produces emulsifying surface-active substances as well. *Halomonas* ANT-3b, a bacterial species that produces emulsifying glycolipids, was isolated from the sea ice-seawater interface at the Terra Nova Bay station in the Ross Sea, Antarctica. Physical and chemical descriptions of the glycoprotein (protein and Uronic acids) based bioemulsifiers produced by *Halomonas* sp. [34].

Biosurfactants from *Myroides* Species

The authors have described the use of a variety of fungal species for the manufacture of surfactants from various sources. Myroide is a nonmotile, aerobic, gram-negative, pigmented rod-shaped bacteria that is commonly found in the maritime environment. This investigation focused on the bioemulsifier-producing *Myroide* strain sp. SM1, which was isolated from oil-polluted waters in Songkhla Lake, Thailand. Extracellular bioemulsifiers (complex of L-ornithine lipids–Lornithine and a distinct combination of iso-3-hydroxy fatty acid and iso-fatty acid) produced by *Myroides* sp. SM1 has strong surface activity for oil displacement, allowing it to outgrow conventional surfactants and emulsify aged crude oil. Because of the extreme conditions under which they were created, bioemulsifiers from these regions have greater stability across a broader temperature spectrum. However, at high pH and high salt, their emulsification abilities rapidly deteriorate. However, with high salt concentrations and severe pH, their emulsification abilities rapidly deteriorate [35]. By sticking to weathered crude oil, cell-associated surface-active chemicals isolated from *Myroides* sp. have a strong emulsification activity [36].

Table 1. List of biosurfactant-producing bacteria.

Microorganisms	biosurfactants	Reference
Pseudomonas sp.	ornithine lipids	Desai and Banat [2].
Pseudomonas fluorescens	viscosin	Banat *et al*., [4].
Pseudomonas aeruginosa , *Pseudomonas chlororaphis*	rhamnolipids	Jadhav *et al*., [37].
Pseudomonas marginalis, Pseudomonas maltophilia	vesicles and fimbriae	Choi *et al*., [38].
Pseudomonas aeruginosa	rhamnolipid	Robert *et al*., [39].
Pseudomonas flourescens	lipopeptide	Neu *et al*., [40].
Pseudomonas nautical	proteins, carbohydrates, and lipids	Husain *et al*., [41].
Pseudomonas flourescens	trehaloselipid-o-diakyl, monoglyceride protein.	Desai *et al*., [28].
Pseudomonas aeruginosa	protein pa	Hisatsuka *et al*., [42].
Pseudomonas flourescens	carbohydrate-lipid complex	Nerurkar *et al*., [43].
Bacillus subtilis, Bacillus amyloliquefaciens	surfactin/iturin	Arguelles-Arias *et al*., [44].
Bacillus subtilis	subtilisin	Sutyak *et al*., [45].
Bacillus sp	amino acids-lipids	
Bacillus licheniformis, Bacillus subtilis	lichenysin	Yakimov *et al*., [46].
Bacillus licheniformis	peptide lipids	Begley *et al*., [47].
Bacillus licheniformis JF-2	lipopeptides	Mclnerney *et al*., [48].
Bacillus licheniformis 86	lipopeptides	Horowitz *et al*., [49].
Bacillus subtilis	surfactin	Arima *et al*., [50].
Bacillus pumilus A1	surfactin	Morikawa *et al*., [51].
Bacillus sp. AB-2	rhamnolipids	Banat, [52].
Bacillus sp. C-14	hydrocarbon-lipids protein	Eliseev *et al*., [53].
Acinetobacter sp.	phospholipids	Kosaric [54].
Acinetobacter calcoaceticus	vesicles and fimbriae	Choi *et al*., [38].
Acinetobacter calcoaceticus	emulsan	Barkay *et al*., [55].
Acinetobacter radioresistens	alasan	Limade *et al*., [56].
Acinetobacter calcoaceticus RAG-1	emulsan	Rosenberg *et al*., [57].
Acinetobacter calcoaceticus A2	biodispersion	Rosenberg and Ron [57].
Acinetobacter radioresistens	alasan	Navon-venezia *et al*., [58].
Acinetobacter calcoaceticus BD4	bd4 emulsan	Kaplan *et al*., [59].
Antarctobacter	high-molecular-weight glycoprotein with high uronic acids	Gutrierrez *et al*., [60].
Agrobacterium sp.	ornithine lipids	Desai and Banat [2].
Arthrobacter MIS 38	lipopeptide	Morikawa *et al*., [51].
Arthrobacter sp.	trehalose, sucrose, and fructose lipid	Suzuki *et al*., [61].
Rhodococcus erythropolis	trehalose dicorynomycolate	Shulga *et al*., [62].
Rhodococcus sp. ST-5	glycolipid	Drouin and Cooper [63].
Rhodococcus sp. H13-A	glycolipid	Singer and Finnerty [64].
Rhodococcus sp. 33	polysaccharide	Neu *et al*., [40].
Cyanobacteria	whole cell	Levy *et al*., [65].
Clostridium pasteurianum	neutral lipids	Cooper and Zajic [66].
Debaryomyces polymorphus	carbohydrate-lipid complex	Nerurkar *et al*., [43].
Halomonas	emulsifier he39 and he67	Gutierrez *et al*., [60].
Halomonas eurihalina	sulfated heteropolysaccharide	Gutierrez *et al*., [60].
Lactobacillus fermentum	diglocosyl diglycerides	Mulligan *et al*., [67].
Leuconostoc mesenteroides	viscosin	Banat *et al*., [4].
Myroides	l-ornthine lipids,iso-3-hydrofatty acid, and iso-fatty acid	Maneera and Dikit, [36].
Rhodotorula glutinis	carbohydrate protein complex	Oloke and Glick [68].
Sarratia rubidea	serrawettin	Lai *et al*., [69].
Serratia rubidea	rhamnolipids	Jadhav *et al*., [37].
Thiobacillus thiooxidan	ornithine lipids	Desai and Banat [2].
Enterobacter cloacae AYF1	rhamnolipid	Fardami *et al*., [41].

Biosurfactant producing Fungi

Different authors have documented the generation of surfactants from various sources using a variety of fungal species. In comparison to other fungal species, *Candida* sp. is the most typically available fungal species for surfactant synthesis, according to several sources (**Table 2**). *Candida bombicola* was found to produce sophorolipids by Casas and Garcia-Ochoa [70]. One of the well-known fungi for the generation of lipid carbohydrate protein-based bioemulsifiers is *Yarrowia lipolytica*. During the development phase, these polysaccharide-based bioemulsifiers might increase the hydrophobicity of the cells. When cells enter a stationary phase, Zinjarde and Pant [71] discovered that extracellular bioemulsifier synthesis occurs. A cell wall-associated emulsifier was discovered in *Yarrowia lipolytica* NCIM 3589, which was isolated from the maritime environment.

Table 2. List of biosurfactant-producing fungi.

Microorganisms	biosurfactants	References
Candida Antarctica	mannosylerthritol lipid	Kitamoto *et al*., [72].
Candida bombicola	sophorous lipids	Gobbert *et al*., [73].
Candida tropicalis	mannan-fatty acid	MALLEE-III, [74].
Candida lipolytica Y-917	sophorous lipid	Lesik *et al*., [75].
Candida utilis	nda	Shepherd *et al*., [76].
Candida ingens	fatty acids	Amezcua-vega *et al*., [77].
Candida lipolytica UGP0988	carbohydrate-protein-lipid complex	Sarubbo *et al*., [78].
Candida bombicola, Candida apicola, Candida antartica, Candida botistae, candida stellate, Candida bogoriensis, Candida riodocensis	sophorolipids	Felse *et al*., [79].
Candida tropicalis	liposan	Cirigliano and carman [80].
Candida bombicola	sophorolipids	Cavalero and cooper [81].
Candida (torulopsis) apicola	sophorolipids	Hommel *et al*., [82].
Candida bogoriensis	sophorolipids	Tulloch *et al*., [83].
Candida antarctica	mannosylerythritol lipids	Kitamoto *et al*., [72].
Candida lipolytica IA 1055	carbrohydrate protein lipid complex	Singh and Desai [84].
Candida tropicalis	carbrohydrate protein lipid complex	Singh and Desai [84].
Candida lipolytica ATCC 8662	carbrohydrate protein lipid complex	Cirigliano and Carman [80].
Candida Antarctica	mannosylerthritol lipid	Kitamoto *et al*., [72].
Corynebacterium hydrocarbolastus	protein-lipid carbohydrate	Zajic *et al*., [85].
Corynebacterium insidiosum	phospholipids	Akit *et al*., [86].
Corynebacterium lepus	fatty acids	Cooper *et al*., [87].
Penicillium chrysogenum	polyketide derivative	Gao *et al*., [88].
Penicillium chrysogenum	monoketide derivative	Gao *et al*., [88].
Penicillium spiculisporum	spiculisporic acid	Ban and Sato [52].
Yarrowia lipolytica IMUFRJ 50682	carbohydrate protein complex	Amaral *et al*., [89].
Yarrowia lipolytica NCIM 3589	carbrohydrate protein lipid complex	Zinjarde *et al*., [90].
Yarrowia lipolytica NCIM 3589	bioemulsifier	Zinjarde and Pant [91].
Yarrowia lipolytica IMUFRJ 50682	yansan	Trindade *et al*., [92].
Ustilago maydis	cellobiose lipids	Teichmann *et al*., [93].
Strian MM1	glucose, lipid and hydroxydecanoic acids	Passeri *et al*., [94].
Nocardiua erythropolis	neutral lipids	Macdonald *et al*., [95].
Ochrobactrum anthropic	protein	Wasko and Bratt [96].
Phaffia rhodozyma	carbohydrates-lipid complex	Lesik *et al*., [97].
Torulopsis bombicola	sophorose lipids	Ito and Inoue [98].
Aspergillus versicolor	chromone derivatve	Lin *et al*., [99].
Emericella unguis	depside	Nielsen *et al*., [100].
Microsphaeropsis sp.	eremophilane derivative	Holler *et al*., [101].

Biosurfactant-producing Yeast

Remarkably, a biosurfactant/bioemulsifier that effectively emulsifies kerosene and crude oil have also been reported to be produced by a peculiar yeast isolate (80 per cent). It has also been found to be effective at separating crude oil from impurities (by 76 per cent). *Pseudozyma* sp. was the most frequently reported yeast species for biosurfactant synthesis (**Table 3**). Cooper and Paddock [102] found that *Torulopsis petrophilum* was responsible for the production of sophorolipids. Kakugawa et al. [103] isolated *Kurtzmanomyces* sp. I-11 for producing mannosylerythritol lipids (MEL), and this strain, along with *Ustilago maydis* and *Schizonella melanogramma*, generated novel MEL.

Table 3. List of biosurfactant-producing yeast.

Microorganisms	biosurfactants	References
Torulopsis petrophilum	sophorolipids	Cooper and Paddock [102].
Torulopsis apicola	sophorolipids	Weber *et al*., [104].
Pseudozyma rugulosa	mannosylerythritol lipids	Morita *et al*., [105].
Pseudozyma aphidis	mannosylerythritol lipids	Rau *et al.,* [106].
Pseudozyma siamensis	mannosylerythritol lipids	Kitamoto *et al*., [72].
Pseudozyma fusiformata, Pseudozyma parantarctica	mannosylerythritol lipids	Morita *et al*., [105].
Kurtzmanomyces sp.	mannosylerythritol lipids	Kakugawa *et al*., [103].
Kurtzmanomyces sp. I-11	mannosylerythritol lipids	Kakugawa *et al*., [103].
Debaryomyces polymorphus	carbohydrate protein lipid complex	Singh and Desai [84].
Saccharomyces cerevisiae	mannanoprotein	Cameron *et al*., [107].
Kluyveromyces marxianus	mannanoprotein	Lukondeh *et al*., [108].

CONCLUSION

The discovery that biosurfactants possessed excellent properties that made it simple to manufacture them led to the naming of these substances. The name "biosurfactant" was given to these substances after the discovery. A diverse assortment of microorganisms, such as yeasts, molds, and bacteria, are capable of producing biosurfactants. Bacteria are another type of organism that can be found within this diverse group. The production of it is significantly influenced by a number of factors and having a better understanding of those factors will significantly contribute to increased production by making those factors easier to comprehend. This will, in turn, significantly contribute to increased production. In a subsequent turn of events, this will significantly contribute to increased production.

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