A Review on Biosurfactant Properties, Production and Producing Microorganisms

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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 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, thammolipid, 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.
Biosurfactants, also known as microbial surfactants, are surface-active compounds 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, 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].

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 25mN/m-1 and the interfacial strain between water and hexadecane to less than 1mN/m². P. aeruginosa produces rhamnolipids, which reduce water surface tension to 26mN/m-1 and water/hexadecane interfacial strain to less than 1mN/m². 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 polyecyclic 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 LC50 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].

Antiahesive 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. Pseudomonas 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 as 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 Sait et al. [14], fermentation of 3 per cent glycerol produces just 2 g/L rhamnolipids. He also discovered that crude palm 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 2.1 g/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 bayllyi* 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 bayllyi* 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* PBSCI 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 dilution rate.

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. Arthrobacterin, 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 Pseudomonas sp. DSS73 [30].

Biosurfactants from Acinetobacter species
Biosurfactants of high molecular weight, such as Emulson and Alasan, are generated by some Acinetobacter species. RAG-1 emulsan is a protein and lipophosphopolysaccharide complex produced by Acinetobacter. D-galactosaminuronic acid, D-galactosamine, and diamino-dideoxyglucosamine 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 radioreisistens 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. Rubiwitchin R1 and RG1 are two novel lipids produced by Serratia 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 Halomonas 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 Myroide 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 Myroide sp. have a strong emulsification activity [36].

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### Table 1. List of biosurfactant-producing bacteria.

| Microorganisms                        | biosurfactants                           | Reference |
|---------------------------------------|------------------------------------------|-----------|
| Pseudomonas sp.                       | ornithine lipids | Desai and Banat [2] |
| Pseudomonas fluorescens              | vesicles and fimbria | Choi et al. [38] |
| Pseudomonas aeruginosa               | rhomholipids | Banat et al. [4] |
| Pseudomonas chlororaphis             | lipopeptide proteins, carbohydrates, and lipids | Desai et al. [28] |
| Pseudomonas marginalis,              | trehaloselipid-o- diakyl, monoglyceride protein | Robert et al. [39] |
| Pseudomonas aeruginosa               | protein pa carbohydrate-lipid complex | Hirata et al. [42] |
| Pseudomonas fluorescens              | surfactin/inulin | Arguelles-Arias et al. [44] |
| Bacillus subtilis, Bacillus          | subtilisin | Sutyk et al. [45] |
| amyloliquefaciens                    | lichenin | Yakimov et al. [46] |
| Bacillus licheniformis,              | peptide lipids | Begley et al. [47] |
| Bacillus licheniformis               | lipopeptides | Melmerney et al. [48] |
| Bacillus licheniformis 50682         | surfactin | Arima et al. [50] |
| Bacillus licheniformis               | mannolipids | Morikawa et al. [51] |
| Bacillus licheniformis               | hydrocarbon-lipids protein phospholipids | Eliseev et al. [53] |
| Bacillus subtilis                    | trehalose and fimbria | Choi et al. [38] |
| Acinetobacter sp.                    | emulason | Barkay et al. [55] |
| Acinetobacter calcoaceticus          | emulason | Limade et al. [56] |
| Acinetobacter calcoaceticus          | emulason | Rosenberg et al. [57] |
| RAG-1                                | biodispersion | Rosenberg and Ron [57] |
| Bacillus sp. AB-2                    | alusan | Navon-venezia et al. [58] |
| Acinetobacter calcoaceticus          | b44 emulason | Kaplan et al. [59] |
| Acinetobacter calcoaceticus          | high-molecular-weight glycoprotein with high uronic acids | Gutierrez et al. [60] |
| Arthrobacter M15 38                  | ornithine lipids | Desai and Banat [2] |
| Arthrobacter sp.                     | trehalose, sucrose, and fructose lipids | Suzuki et al. [61] |
| Rhodococcus erythropolis             | trehalose dicorymycolate glycolipid | Shulgina et al. [62] |
| Rhodococcus sp. ST-5                 | glycolipid | Drouin and Cooper [63] |
| Rhodococcus sp. H13-A                | glycolipid | Singar and Finnerty [64] |
| Rhodococcus sp. 33                   | polysaccharide | Neu et al. [40] |
| Corynebacteria                       | whole cell neutral lipids | Levy et al. [65] |
| Clostridium pasteurianum             | carbohydrate-lipid complex | Cooper and Zajic [66] |
| Debaryomyces polymorphus             | carbohydrate-lipid complex | Neukirch et al. [43] |
| Halomonas                            | emulsifier hec39 and hec77 | Gutierrez et al. [60] |
| Halomonas eurhadinula               | sullated heteropoly saccharide diglycosyl | Mulligan et al. [67] |
| Lactobacillus fermentum              | diglycerides | Banat et al. [4] |
| Leuconostoc mesenteroides            | viscous | Banat et al. [4] |
| Myxobacteria                         | l-ornithine lipids,iso-3-hydroxy fatty acid, and iso-3-fatty acid carbohydrate protein complex | Oloke and Glick [68] |
| Rhodotula glutinis                   | serrawettin | Lai et al. [69] |
| Serratia rubidea                     | rhamnolipid | Jadhav et al. [37] |
| Serratia rubidea                     | ornithine lipids | Desai and Banat [2] |
| Thiobacillus thiooxidan              | ornithine lipids | Desai and Banat [2] |
| Enterobacter cloacae AYF1            | rhamnolipid | Fardam 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 authors (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 marine environment.

### Table 2. List of biosurfactant-producing fungi.

| Microorganisms                        | biosurfactants                           | Reference |
|---------------------------------------|------------------------------------------|-----------|
| Candida Antartica                     | liposomal for | Migliorati et al. [72] |
| Candida bombicola                     | sophorolipids for | Gobbert et al. [73] |
| Candida tropicalis                     | mann-an-fatty acid | MALLEE-ELL [74] |
| Candida lipolytica Y-917              | sophorolipids for | Lesik et al. [75] |
| Candida utilis                        | nda | Shepherd et al. [76] |
| Candida ingens                        | fatty acids | Amecusa-vega et al. [77] |
| Candida lipolytica UG9988              | carbohydrate-protein-lipid complex | Sarabho et al. [78] |
| Candida bombicola, Candida           | lipopolyetherslipids | Felse et al. [79] |
| apicola, Candida antarctica, Candida | lipopolyetherslipids | Kitamoto et al. [72] |
| botissiae, Candida stellae, Candida | carbohydrate lipid protein Singh and Desai [84] |
| bogoriensis, Candida riodocensis      | carbohydrate lipid | Cummings et al. [80] |
| Candida tropicalis                     | | Cummings et al. [80] |
| Candida lipolytica IA 1055            | | Cummings et al. [80] |
| Candida tropicalis                     | | Cummings et al. [80] |
| Candida lipolytica ATCC 8662           | | Cummings et al. [80] |
| Candida Antartica                     | liposomal for | Migliorati et al. [72] |
| Corynebacterium hydrocarboxactin      | | Cummings et al. [80] |
| Corynebacterium insidium              | phosypholipids | Akita et al. [86] |
| Corynebacterium lusus                 | fatty acids | Cooper et al. [87] |
| Penicillium chrysogenum               | polyketide derivative | Gao et al. [88] |
| Penicillium chrysogenum               | monoketide derivative | Gao et al. [88] |
| Penicillium spiculiflorus             | spiculipodicic acid | Ban and Sato [52] |
| Yarrowia lipolytica UG0156            | carbohydrate protein complex | Amaral et al. [89] |
| Yarrowia lipolytica NCIM 3589         | carbohydrate protein lipid Zajic et al. [90] |
| Yarrowia lipolytica NCIM 3589         | bioemulsifier | Zinjarde and Pant [91] |
| Yarrowia lipolytica UG0156            | yansan | Trivede et al. [92] |
| Ustilago maydis                       | cellbiose lipids | Teichmann et al. [93] |
| Systain MM1                           | glucose, lipid and hydroxydecanoic acids | Passeri et al. [94] |
| Nocardia erythropolis                 | neutral lipids | Macdonald et al. [95] |
| Ochrobactrum anthropicus              | protein | Wasko and Banat [96] |
| Phaffia rhodozyma                     | carbohydrates-lipid complex | Lesik et al. [97] |
| Torulopsis bombicola                  | sophorolipids | Ito and Imoue [98] |
| Aspergillus versicolor                | chromone derivative | Lin et al. [99] |
| Emericella angios                               | | Nielsen et al. [100] |
| Microhaezopori sp.                    | eremophilane derivative | Eliseev 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. Kagukawa et al. [103] isolated *Kurtzmannomyces* sp. I-11 for producing mannosylerythritol lipids (MEL), and this strain, along with *Ustilago maydis* and *Schizellena 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*    | mannosylerythritol lipids           | Morita et al., [105] |
| *Kurtzmannomyces sp.*       | mannosylerythritol lipids           | Kagukawa et al., [103] |
| *Kurtzmannomyces sp. I-11*  | mannosylerythritol lipids           | Kagukawa et al., [103] |
| *Debaryomyces polymorphus*  | carbohydrate protein lipid complex   | Singh and Desai [84] |
| *Saccharomyces cerevisiae*  | mannanoprotein                      | Cameron et al., [107] |
| *Klyuyveromyces marxianus*  | mannanoprotein                      | Lukonde 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 easier to comprehend. This will, in turn, significantly contribute to increased production.

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