# Biosurfactants-Types, Sources and Applications

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## ABSTRACT

In recent years, heavy metals pollution is found to be a serious environmental issue and various technologies are being discovered for their cleanup from environment. The use of biosurfactants for this purpose was found to be an eco-friendly approach and also an alternate to conventional complex remediation systems. Due to their diversity, biosurfactants are considered as a potential candidate for the environmental cleanup of pollutants. Therefore, a greater attention was paid on biosurfactants and identifying their potential applications. By considering the importance of biosurfactants, the present review article presents an exhaustive evaluation of different sources of biosurfactants and also their properties and applications which is the focus of future studies.



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## INTRODUCTION

Biosurfactants can be defined as the surface-active biomolecules produced by microorganisms with wide-range of applications. In recent years, due to their unique properties like specificity, low toxicity and relative ease of preparation, these surface-active biomolecules have attracted wide interest. Due to their unique functional properties, biosurfactants were used in several industries including organic chemicals, petroleum, petrochemicals, mining, metallurgy (mainly bioleaching), agrochemicals, fertilizers, foods, beverages, cosmetics, pharmaceuticals and many others. They can be used as emulsifiers as well as demulsifiers, wetting agents, foaming agents, spreading agents, functional food ingredients and detergents. The interfacial surface tension reducing ability of biosurfactants made them to play important role in oil recovery and bioremediation of heavy crude oil (Volkering *et al*., 1998).

The three major functions played by biosurfactants including (Rosenberg and Ron, 1999). They were used to increase the surface area of hydrophobic substrates. Biosurfactants also used to increase the **bioavailability** of hydrophobic substrates through solubilization/desorption. They also regulate the attachment and removal of microorganisms from the surfaces.

Biosurfactants possess both hydrophilic and hydrophobic regions causing them to aggregate at interfaces between fluids with different polarities such as hydrocarbons and water (Banat, 1995; Karanth *et al*., 1999) hence, decrease interfacial surface tension (Volkering *et al*., 1998). They also found to be enhancing the nutrient transport across membranes and affect in various host-microbe interactions.

When compared to chemical or synthetic surfactants, biosurfactants gained several advantages including their biodegradability, biocompatability and digestibility. The biosurfactants can be used in environmental cleanup by biodegradation and detoxification of industrial effluents and in bioremediation of contaminated soil. Their specificity and availability of raw materials also made them most preferred surfactants (Olivera *et al*., 2003).

**Properties:** The unique and distinct properties of biosurfactants when compared to their chemically synthesized counterparts and broad substrate availability made them suitable for commercial applications. The distinctive features of microbial surfactants are related to their surface activity, tolerance to pH, temperature and ionic strength, biodegradability, low toxicity, emulsifying and demulsifying ability and **antimicrobial activity** (Chakrabarti, 2012). The major distinctive features of each property of biosurfactant are discussed below.

**Surface and interface activity:** Surfactant helps in reducing surface tension and the interfacial tension. Surfactin produced by *B. subtilis* can reduce surface tension of water to 25 mN $m^{-1}$ and interfacial tension water/hexadecane to less than 1 mN $m^{-1}$ (Cooper *et al*., 1981). The rhamnolipids produced by *P. aeruginosa* decreased surface tension of water to 26 mN $m^{-1}$ and interfacial tension of water/hexadecane to value less than 1 mN $m^{-1}$ (Syldatk *et al*., 1985). In general, biosurfactants are more effective and efficient and their Critical Micelle Concentration (CMC) is about several times lower than chemical surfactants, i.e., for maximal decrease on surface tension, less surfactant is necessary (Desai and Banat, 1997).

**Temperature and pH tolerance:** The biosurfactant production from extremophiles has gained attention in last decades for their considered commercial interest. Most of the biosurfactants and their surface activity are resistant towards **environmental factors** such as temperature and pH. McInerney *et al*. (1990) reported that lichenysin from *Bacillus licheniformis* was found to be resistant to temperature up to 50°C, pH between 4.5 and 9.0 and NaCl and Ca concentrations up to 50 and 25 g $L^{-1}$, respectively. Another biosurfactant produced by *Arthrobacter protophormiae* was found to be both thermostable (30-100°C) and pH (2 to 12) stable (Singh and Cameotra, 2004). Since, industrial processes involve exposure to extremes of temperature, pH and pressure, it is necessary to isolate novel microbial products that able to function under these conditions (Cameotra and Makkar, 2004).

**Biodegradability:** Microbial derived compounds can be easily degraded when compared to synthetic surfactants (Mohan *et al*., 2006) and are suitable for environmental applications such as bioremediation/biosorption (Mulligan *et al*., 2001). The increasing environmental concern forces us to search for alternative products such as biosurfactants (Cameotra and Makkar, 2004). Synthetic chemical surfactants impose environmental problems and hence, biodegradable biosurfactants from marine microorganisms were concerned for the biosorption of poorly soluble polycyclic aromatic hydrocarbon, phenanthrene contaminated in aquatic surfaces (Olivera *et al*., 2003). Lee *et al*. (2008) controlled the blooms of marine algae, Cochlodinium using the biodegradable biosurfactant sophorolipid with the removal efficiency of 90% in 30 min treatment.

**Low toxicity:** Although, very few literatures were available regarding the toxicity of biosurfactants, they are generally considered low or non-toxic products and are appropriate for pharmaceutical, cosmetic and food uses. Poremba *et al*. (1991) demonstrated the higher toxicity of the chemical-derived surfactant (Corexit) which displayed a LC50 against *Photobacterium phosphoreum* and was found to be 10 times lower than of rhamnolipids. Flasz *et al*. (1998) compared the toxicity and mutagenicity profile of biosurfactant from *Pseudomonas aeruginosa* and chemically derived surfactants and indicated the biosurfactant as non-toxic and non-mutagenic. The low toxicity profile of biosurfactant, sophorolipids from *Candida bombicola* made them useful in food industries (Cavalero and Cooper, 2003).

**Emulsion forming and emulsion breaking:** Biosurfactants may act as emulsifiers or de-emulsifiers. An emulsion can be described as a heterogeneous system, consisting of one immiscible liquid dispersed in another in the form of droplets, whose diameter in general exceeds 0.1 mm. Emulsions are generally two types: oil-in-water (o/w) or water-in-oil (w/o) emulsions. They possess a minimal stability which may be stabilized by additives such as biosurfactants and can be maintained as stable emulsions for months to years (Velikonja and Kosaric, 1993). Liposan is a water-soluble emulsifier synthesized by *Candida lipolytica* which have been used to emulsify edible oils by coating droplets of oil, thus forming stable emulsions. These liposans were commonly used in cosmetics and food industries for making oil/water emulsions for making stable emulsions (Cirigliano and Carman, 1985).

**Antiadhesive agents:** A biofilm can be described as a group of bacteria/other **organic matter** that have colonized/accumulated on any surface (Hood and Zottola, 1995). The first step on biofilm establishment is bacterial adherence over the surface was affected by various factors including type of microorganism, hydrophobicity and electrical charges of surface, environmental conditions and ability of microorganisms to produce extracellular polymers that help cells to anchor to surfaces (Zottola, 1994). The biosurfactants can be used in altering the hydrophobicity of the surface which in turn affects the adhesion of microbes over the surface. A surfactant from *Streptococcus thermophilus* slows down the colonization of other thermophilic strains of *Streptococcus* over the steel which are responsible for fouling. Similarly, a biosurfactant from *Pseudomonas fluorescens* inhibited the attachment of *Listeria monocytogenes* onto steel surface (Chakrabarti, 2012).

**Types of biosurfactants:** The chemically synthesized surfactants are usually classified according to their polarity, whereas, biosurfactants are generally categorized by their microbial origin and **chemical composition** as following.

**Glycolipid:** They are carbohydrates linked to long-chain aliphatic acids or hydroxyaliphatic acids by an ester group. Biosurfactants are majorly glycolipids. Among the glycolipids, the best known are rhamnolipids, trehalolipids and sophorolipids (Jarvis and Johnson, 1949). The sources and properties of the different glycolipids were discussed below:

- **Rhamnolipids:** Rhamnolipids are glycolipids, in which, one or two molecules of rhamnose are linked to one or two molecules of hydroxydecanoic acid. It is the

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| | widely studied biosurfactant which are the principal glycolipids produced by *P. aeruginosa* (Edwards and Hayashi, 1965) |
| • | **Trehalolipids:** These are associated with most species of *Mycobacterium, Nocardia* and *Corynebacterium*. Trehalose lipids from *Rhodococcus erythropolis* and *Arthrobacter* spp. lowered the surface and interfacial tension in culture broth from 25-40 and 1-5 mNm, respectively (Asselineau and Asselineau, 1978) |
| • | **Sophorolipids:** These are glycolipids which are produced by yeasts and consist of a dimeric carbohydrate sophorose linked to a long-chain hydroxyl **fatty acid** by glycosidic linkage. Sophorolipids, generally a mixture of at least six to nine different hydrophobic sophorolipids (Gautam and Tyagi, 2006) and lactone form of the sophorolipid is preferable for many applications (Hu and Ju, 2001) |

**Lipopeptides and lipoproteins:** These consist of a lipid attached to a polypeptide chain (Rosenberg and Ron, 1999). Several biosurfactants have shown antimicrobial action against various bacteria, algae, fungi and viruses. Besson *et al*. (1976) reported the antifungal property and Singh and Cameotra (2004) reported the antibacterial property of the lipopeptide, iturin which was produced by *Bacillus subtilis*. Iturin from *B. subtilis* was found to be active even after autoclaving, pH 5-11 and with a shelf life of 6 months at -18°C (Nitschke and Pastore, 1990).

**Surfactin:** The cyclic lipopeptide surfactin are one of the most powerful biosurfactants composed of a seven amino-acid ring structure coupled to a fatty-acid chain via lactone linkage (Arima *et al*., 1968). Previous study reported that various physic-chemical properties of surfactin from *B. subtilis*. They found that the surfactin are able to reduce the surface tension and interfacial tension of water. The inactivation of herpes and retrovirus was also observed with surfactin.

**Lichenysin:** *Bacillus licheniformis* produces several biosurfacants which exhibit excellent stability under extreme temperature, pH and salt conditions which are similar to surfactin. McInerney *et al*. (1990) reported that lichenysin from *B. licheniformis* are able to reduce the surface tension and interfacial tension of water to 27 and 0.36 mN $m^{-1}$, respectively.

**Fatty acids, phospholipids and neutral lipids:** Several bacteria and yeast produce large quantities of fatty acids and phospholipid surfactants during growth on n-alkanes.
In *Acinetobacter* spp. 1-N, phosphatidyl ethanolamine-rich vesicles are produced which form optically clear micro-emulsions of alkanes in water. These biosurfactant are essential for medical applications. Gautam and Tyagi (2006) reported that the deficiency phospholipid protein complex is found to be the major cause for the respiration failure in the prematurely born children. They have also suggested that the isolation and cloning of the genes responsible for such surfactant can be employed in their fermentative production.

**Polymeric biosurfactants:** These are the best-studied polymeric biosurfactants including emulsan, liposan, alasan, lipomanan and other polysaccharide-protein complexes. Emulsan is an effective emisifying agent for hydrocarbons in water, even at a concentration as low as 0.001-0.01% (Hatha *et al*., 2007). Liposan is an extracellular water-soluble emulsifier synthesized by *Candida lipolytica* and is composed of 83% carbohydrate and17% protein (Cooper and Paddock, 1984; Chakrabarti, 2012). The application of such polymeric biosurfactant, liposan, as emulsifier in food and cosmetic industries were discussed by Chakrabarti (2012).

**Particulate biosurfactants:** These form the extracellular membrane vesicles partition to form a microemulsion which plays an important role in alkane uptake by microbial cells. Vesicles of *Acinetobacter* spp. strain HO1-N with a diameter of 20-50 nm and a buoyant density of 1.158 cubic gcm are composed of protein, phospholipids and lipo-polysaccharide (Kaeppeli and Finnerty, 1979; Chakrabarti, 2012).

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| Table 1: | Biosurfactants derived from bacteria and fungi |

| Organisms | Biosurfactants | References |
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| **Bacteria** | | |
| *Serratia marcescens* | Serrawettin | Lai *et al.* (2009) |
| *Rhodotorula glutinis, R. graminis* | Polyol lipids | Amaral *et al.* (2006) |
| *Rhodococcus erythropolis, Arthrobacter* spp., *Nocardia erythropolis, Corynebacterium* spp., *Mycobacterium* spp. | Trehalose lipids | Muthusamy *et al.* (2008) |
| *Pseudomonas* spp., *Thiobacillus thiooxidans, Agrobacterium* spp. | Ornithine lipids | Desai and Banat (1997) |
| *Pseudomonas fluorescens, Leuconostoc mesenteriods* | Viscosin | Banat *et al.* (2010) |
| *Pseudomonas aeruginosa, Pseudomonas chlororaphis, Serratia rubidea* | Rhamnolipids | Jadhav *et al.* (2011) |
| *P. fluorescens, Debaryomyces polmorphus* | Carbohydrate-lipid | Nerurkar *et al.* (2009) |
| *P. aeruginosa* | Protein PA | Hisatsuka *et al.* (1971) |
| *Lactobacillus fermentum* | Diglycosyl diglycerides | Mulligan *et al.* (2001) |
| **Fungi** | | |
| *Torulopsis bombicola* | Sophorose lipid | Kim *e al.* (1997) |
| *Candida bombicola* | Sophorolipids | Casas *et al.* (1997) |
| *Candida lipolytica* | Protein-lipidpolysaccharide complex | Sarubbo *et al.* (2007) |
| *Candida lipolytica* | Protein-lipidcarbohydrate complex | Rufino *et al.* (2007) |
| *Candida ishiwadae* | Glycolipid | Thanomsub *et al.* (2004) |
| *Candida batistae* | Sophorolipid | Konishi *et al.* (2008) |
| *Aspergillus ustus* | Glycolipoprotein | Alejandro *et al.* (2011) |
| *Trichosporon ashii* | Sophorolipid | Chandran and Das (2010) |

**Sources of biosurfactants:** Many of the biosurfactant producing microorganisms are found to be hydrocarbon degraders (Willumsen and Karlson, 1997; Volkering *et al*., 1998). However in the past decades, many studies have showed the effects of microbially produced surfactants not only on bioremediation but also on enhanced oil recovery (Volkering *et al*., 1998; Tabatabaee *et al*., 2005). The biosurfactants produced from microbial sources were listed in Table 1.

**Bacterial biosurfactants:** Microorganisms make use of a wide range of organic compounds as a source of carbon and energy for their growth. When the **carbon source** is in an insoluble form like a hydrocarbon, microorganisms make possible their diffusion into the cell by producing a variety of substances, the biosurfactants. Some of the bacteria and yeasts excrete ionic surfactants which emulsify the CxHy substance in the growth medium. A few examples of this group of biosurfactant are rhamnolipids that are produced by different *Pseudomonas* spp. (Burger *et al*., 1963; Guerra-Santos *et al*., 1986) or sophorolipids that are produced by several *Torulopsis* spp. (Cutler and Light, 1979; Cooper and Paddock, 1984).

Some other microorganisms are able to change the structure of their cell wall which are achieved by them by producing nonionic or lipopolysaccharides surfactants in their cell wall. Some examples of this group are: *Rhodococcus erythropolis* and various *Mycobacterium* spp. and *Arthrobacter* spp. which produce nonionic trehalose corynomycolates (Ristau and Wanger, 1983; Kilburn and Takayama, 1981; Kretschmer *et al*., 1982). There are lipopolysaccharides, such as emulsan, produced by *Acinetobacter* spp. (Kretschmer *et al*., 1982) and lipoproteins such as surfactin and subtilisin, that are produced by *Bacillus subtilis* (Cooper *et al*., 1981).

**Fungal biosurfactants:** Where the field of production of biosurfactants by bacterial species is well explored, relatively fewer fungi are known to produce biosurfactants. Among fungi, *Candida bombicola* (Casas *et al*., 1997), *Candida lipolytica* (Sarubbo *et al*., 2007), *Candida ishiwadae* (Thanomsub *et al*., 2004), *Candida batistae* (Konishi *et al*., 2008), *Aspergillus ustus* (Alejandro *et al*., 2011) and *Trichosporon ashii* (Chandran and Das, 2010) are the explored ones. Many of these are known to produce biosurfactant on low cost raw materials. The major type of biosurfactants produced by these strains is sophorolipids (glycolipids). *Candida lipolytica* produces cell wall-bound lipopolysaccharides when it is growing on n-alkanes (Rufino *et al*., 2007).

## Applications

**Food industries:** The surfactants can have various other functions in food industries, apart from their obvious role as agents that decrease surface and interfacial tension, thus facilitating the formation and stabilization of emulsions. For example, to control the aggregation of fat globules, stabilization of aerated systems, improvement of texture and **shelf-life** of products containing starch, modification of rheological properties of wheat dough and improvement of constancy and texture of fat-based products (Kachholz and Schlingmann, 1987). In bakery and ice-cream formulations, biosurfactants act by controlling the consistency, slowing staling and solubilizing the flavour oils; they are agents during cooking of fats and oil. Improvement in the stability of dough, volume, texture and conservation of bakery products is obtained by the addition of rhamnolipid surfactants (Van Haesendonck and Vanzeveren, 2004). The study also suggested the use of rhamnolipids to improve the properties of butter cream and frozen confectionery products. L-Rhamnose has substantial potential as a forerunner for flavouring.

**Removal of oil and petroleum contamination:** Itoh and Suzuki (1972) were the first to show that hydrocarbon culture media stimulated the growth of a rhamnolipid producing strain of *P*.

*aeruginosa*. Recent research findings confirmed the effects of biosurfactant on hydrocarbon biodegradation by increasing microbial accessibility to insoluble substrates and thus enhance their biodegradation (Zhang and Miller, 1992; Hunt *et al*., 1994). Various experiments have been conducted that the effects of biosurfactants on hydrocarbons; enhancing their water solubility and increasing the displacement of oily substances from soil particles. Thus, biosurfactants increase the apparent solubility of these organic compounds at concentrations above the Critical Micelle Concentration (CMC) which enhance their availability for microbial uptake (Chang *et al*., 2008). For these reasons, inclusion of biosurfactants in a bioremediation treatment of a hydrocarbon polluted environment could be really promising, facilitating their assimilation by microorganisms (Calvo *et al*., 2009).

Many of the biosurfactants known today have been studied to examine their possible technical applications (Nayak *et al*., 2009). Most of these applications involve their efficiency in bioremediation, dispersion of oil spills and enhanced oil recovery. *Alcanivorax* and *Cycloclasticus* genera are highly specialized hydrocarbon degraders in marine environments. *Alcanivorax borkumensis* utilizes aliphatic hydrocarbons as its main **carbon source** for growth and produces an anionic glucose lipid biosurfactant and thus potentials of *Alcanivorax* strains during bioremediation of hydrocarbon pollution in marine habitats have been studied (Olivera *et al*., 2009); thus, this property needs to be studied extensively in soil to ensure its effectiveness.

Several species of *P. aeruginosa* and *B. subtilis* produce rhamnolipid, a commonly isolated glycolipid biosurfactant and surfactin, a lipoprotein type biosurfactant, respectively; these two biosurfactants have been shown by Whang *et al*. (2008) to increase solubility and **bioavailability** of a petrochemical mixture and also stimulate indigenous microorganisms for enhanced biodegradation of diesel contaminated soil. *Gordonia* species BS29 grows on aliphatic hydrocarbons as sole **carbon source** has been found to produce Bioemulsan which effectively degrade crude oil, Polycyclic Aromatic Hydrocarbons (PAH) and other recalcitrant branched hydrocarbons from contaminated soils. The rate of biodegradation is dependent on the **physicochemical properties** of the biosurfactants and not by the effects on microbial metabolism (Franzetti *et al*., 2008).

**Bioremediation of toxic pollutants:** Bioremediation involves the acceleration of natural biodegradative processes in contaminated environments by improving the availability of materials (e.g. nutrients and oxygen), conditions (e.g., pH and moisture content) and prevailing microorganisms. Thus, bioremediation usually consists of the application of nitrogenous and phosphorous fertilizers, adjusting the pH and water content, if necessary, supplying air and often adding bacteria. The addition of emulsifiers is advantageous when bacterial growth is slow (e.g. at cold temperatures or in the presence of high concentrations of pollutants) or when the pollutants consist of compounds that are difficult to degrade, such as PAHs. Bioemulsifiers can be applied as an additive to stimulate the bioremediation process, however with advanced genetic technologies it is expected that the increase in bioemulsifier concentration during bioremediation would be achieved by the addition of bacteria that overproduce bioemulsifiers. This approach has been recently used successfully in the cleaning of oil pipes. Cultures of *A. radioresistens* (Navon-Venezia *et al*., 1995) which produce the bioemulsifier alasan but are unable to use hydrocarbons as a carbon source, were added to a mixture of oil-degrading bacteria to enhance oil bioremediation.

Persistent organic pollutants found in oil containing wastewater and sediments, such as PAHs (phenanthrene, crysene) are also hydrophobic in nature and thus water solubility of PAHs normally decrease with the increasing number of rings in molecular structure. This property induces the low **bioavailability** of these organic compounds that is a crucial factor in the biodegradation of PAHs. The water solubility of some PAHs can be improved by addition of biosurfactants owing to their amphipathic structure by several folds (Yin *et al*., 2009). In addition, most hydrocarbons exist in strongly adsorbed forms when they are introduced into soils. Thus, their removal efficiency can be limited in low **mass transfer** phases. However, additions of solubilization agents, such as biosurfactants to the system enhance the **bioavailability** of low solubility and highly sorptive compounds (Shin *et al*., 2004).

**Mechanism behind bioremediation:** There are at least two ways in which biosurfactants are involved in bioremediation: increasing the surface area of hydrophobic water-insoluble substrates and increasing the **bioavailability** of hydrophobic compounds.

**Increasing the surface area of hydrophobic water insoluble substrates:** For bacteria growing on hydrocarbons, the growth rate can be limited by the interfacial surface area between water and oil (Sekelsky and Shreve, 1999). When the surface area becomes limiting, biomass increases arithmetically rather than exponentially. The evidence that emulsification is a natural process brought about by extracellular agents is indirect and there are certain conceptual difficulties in understanding how emulsification can provide an (evolutionary) advantage for the microorganism producing the emulsifier. Stated briefly, emulsification is a cell-density-dependent phenomenon: that is, the greater the number of cells, the higher the concentration of extracellular product. The concentration of cells in an open system, such as an oil-polluted body of water, never reaches a high enough value to effectively emulsify oil. Furthermore, any emulsified oil would disperse in the water and not be more available to the emulsifier-producing strain than to competing microorganisms.

One way to reconcile the existing data with these theoretical considerations is to suggest that the emulsifying agents do play a natural role in oil degradation but not in producing macroscopic emulsions in the bulk liquid. If emulsion occurs at, or very close to, the cell surface and no mixing occurs at the microscopic level, then each cluster of cells creates its own microenvironment and no overall cell-density dependence would be expected.

**Increasing the bioavailability of hydrophobic water-insoluble substrates:** The low water solubility of many hydrocarbons, especially the Polycyclic Aromatic Hydrocarbons (PAHs), is believed to limit their availability to microorganisms which is a potential problem for bioremediation of contaminated sites. It has been assumed that surfactants would enhance the **bioavailability** of hydrophobic compounds. Several non-biological surfactants have been studied and both negative and positive effects of the surfactants on biodegradation were observed. For example, the addition of the surfactant Tergitol NP-10 increased the dissolution rate of solid-phase phenanthrene and resulted in an overall increase in the growth of a strain of *Pseudomonas stutzeri* (Grimberg *et al*., 1996). A similar effect was obtained by the addition of Tween 80 to two *Sphingomonas* strains, the rate of fluoranthene mineralization was almost doubled. By contrast, the same surfactant inhibited the rate of fluoranthene mineralization by two strains of *Mycobacterium* (Willumsen *et al*., 2001) and no stimulation was observed in other studies using several surfactants (Bruheim and Eimhjellen, 1998).

## CONCLUSION

Biosurfactants show several properties which could be useful in many fields of food industry; recently, their antiadhesive activity has attracted attention as a new tool to inhibit and disrupt the biofilms formed in food contact surfaces. The combination of particular characteristics such as emulsifying, antiadhesive and antimicrobial activities presented by biosurfactants suggests potential application as multipurpose ingredients or additives. Scant information regarding toxicity, combined with high production costs seems to be the major cause for the limited uses of biosurfactants in food area. However, the use of agroindustrial wastes can reduce the biosurfactants production costs as well as the waste treatment expends and also renders a new alternative for food and food-related industries not only for valorizing their wastes but also to becoming microbial surfactant producers. Biosurfactants obtained from Generally Regarded As Safe (GRAS) microorganisms like lactobacilli and yeasts are of great promise for food and medicine applications though, much more research is already required on this field. The prospect of new types of surface-active compounds from microorganisms can contribute for the detection of different molecules in terms of structure and properties but the toxicological aspects of new and current biosurfactants should be emphasized in order to certify the safe of these compounds for food utilization.

**Future trends:** A promising approach seems to be the application of inoculants of biosurfactant producing bacteria in phytoremediation of hydrocarbon polluted soil to improve the efficiency of this technology. Application of the biosurfactants in phytoremediation on a large scale requires studies to identify their potential toxic effect on plants. Although the biosurfactants are thought to be ecofriendly, some experiments indicated that under certain circumstances they can be toxic to the environment. Nevertheless, careful and controlled use of these interesting surface active molecules will surely help in the enhanced cleanup of the toxic environmental pollutants and provide us with a clean environment.