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Research Article

INDUSTRIAL AND BIOLOGICAL APPLICATIONS OF BIOEMULSIFIERS: A MINI REVIEW

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ABSTRACT

Microorganisms produce bioemulsifier/biosurfactants having a wide structural and functional diversity. This review highlights the method of investigation to determine these ampiphilic molecules, bioemulsifier produced by different microorganisms from various origins its classification based on its molecular weight, its chemical composition and that are capable of producing bioemulsifier of industrial and biological applications.

Keywords: Bioemulsifier (BS), Glycolipids, Lipopeptides, Industrial potential, Biological applications.

INTRODUCTION

Bioemulsifiers are surface active compounds that reduce surface interfacial tension between immiscible liquids or solid liquid interfaces leading to the formations of more stable emulsions or bioemulsans. Bioemulsifiers were discovered as extracellular compounds of fermentation by bacteria. They are mainly ampiphilic molecules initially produced by microorganisms including bacteria, yeast and fungi (Mujumdar 2002, Nerurkar et al 2007 and Maniyar et al 2011).

The hydrophobhic and hydrophilic moieties of bioemulsifiers display a variety of surface activities, which also help in solubilizing hydrophobic substrates. It acts on both on liquid-liquid and solid-liquid emulsions etc. All biosurfactants are bioemulsifiers, but all bioemulsifiers are not biosurfactants. Bioemulsifiers are produced generally by microorganisms in their growth phase and in conditions such as extreme pH, temperature and salinity (Patil and Chopade 2001, Banat 2012).

Bioemulsifiers are highly effective, they can be easily degraded, and less toxic to the human health and environment (environmental friendly). As compared to synthetic emulsifiers, they have higher foaming capacity and as a result of this bioemulsifiers are studied extensively in industries. Bioemulsifiers exhibit a broad diversity of chemical structures such as glycolipids, phospholipids, fatty acids and polymeric lipids (Patil and Chopade 2001, Ron and Rosenberg 2002).

They form a molecular interfacial film which affects the properties of the original surface. This molecular layer also lowers interfacial tension between different liquid phases on the interfacial boundary existing between immiscible phases and therefore can have an impact on the interfacial rheological behavior and the mass transfer (Doshi et al 2011, Bashetti et al 2012).

The hydrophobic moiety of the surface active molecules at the interface aggregates at the surface facing the hydrophobic phase (oil phase) while the hydrophilic moiety (water phase) is directed towards the solution (Patil and Chopade 2001Mujumdar 2002).

The high molecular weight bioemulsifiers have the molecular weight higher than 1MDa. This include mostly the amphipathic polysaccharide, protein, lipopolysaccharide and lipoprotein which help to stabilize oil in water emulsion (Kaplan et al 1987, Patil and Chopade 2001, Tabatabaee et al 2005; Kokare et al 2007, Rakade et al 2013; Chab et al 2013).

The low molecular weight bioemulsifiers has molecular weight 1-2 KDa which include glycolipid and lipopeptides which actively lowers the interfacial and surface tension (Kaplan et al 1987, Kokare et al 2007, Rakade et al 2013).

Two closely related organisms that share the same species and same genus can produce different type of bioemulsifier isoforms with different physiochemical properties which help the microorganism to survive or sustain in particular environmental condition such

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as extreme pH, temperature, salinity etc (Ron and Rosenberg 2001, Banat 2012, Rakade, et al 2013, Banat 2015).

Functional Properties:

Functional properties of bioemulsifiers are namely emulsification, wetting, foaming, cleaning, phase separation, surface activity, heavy metal binding, bacterial pathogenesis, antibacterial activity, antiviral activity, antifungal activity and reduction in the viscosity of the heavy liquids such as crude oil enables them to be utilized for many industrial and domestic application (Mujumdar 2002, Satpute et al 2010, Doshi et al 2010, Maniyar et al 2011). In comparison to synthetic surfactants, bioemulsifiers are less toxic (Mujumdar 2002, Satpute et al 2010, Maniyar et al 2011).

Conventional Methods:

Conventional screening methods for detection of bioemulsifiers producers are as follows:

- **Haemolysis of erythrocytes :** It is a qualitative screening test for detection of bioemulsifier producers. Solid media such as Luria Bertani (LB) and nutrient agar (NA) are used supplemented with 5% fresh whole blood (Carillo et al 1996). Visual inspection for haemolysis may be an indication of red blood cell rupture caused by presence of surface active molecules (Satpute et al 2010).
- **Cell surface hydrophobicity:** There is a direct correlation between cell surface hydrophobicity and BS production. The cell surface are harvested by centrifugation (1200/30min/4° C) and washed twice with 50mM of phosphate buffer (pH 7.0) and re-suspended using the same buffer to absorption (A_{600}) of 0.5. Cell suspensions (3ml) are added to hydrocarbons (0.5ml) and vortexed for 3min and allowed to settle for 10min for the hydrocarbon phase to rise completely. The aqueous phase is removed and transferred to 1ml cuvette to measure A_{600}. The decrease in A_{600} of the aqueous phase is taken as a measure of the cell surface hydrophobicity (H%) which is calculated as follows

$$H\% = \frac{[(A_0 - A)]}{A_o}$$

Where A_0 and A are A_{600} before and after mixing the hydrocarbon, respectively (Satpute et al 2010).

- **Modified Drop collapse method:** Mocrotitre plates thinly coated with Pennzoil. A sample of 5µl (culture broth) is added to the center of the well and observations are carried out for 1mi. If the drop of the sample collapses from the coated oil it is the indication of BS in the culture broth (Jain et al 1991, Bouder and Miller –Maier 1998).
- **Blue agar plate method:** This method can be applied for detection of similar type of BS from other Gram negative isolates, Cetyltrimethyl ammonium bromide –methylene blue media are used. Anionic BS forms insoluble ion pair with cationic CTAB-MB and formation of dark blue halo around the culture is considered as positive for BS production. It has been generally used in glycopeptide BS (Satpute et al 2010).
- **Direct colony chromatography technique:** This method characterizes BS producers

A bacterial mass is directly placed on pre-developed (Chloroform-methanol 2:1) TLC plate. After drying the bacterial mass, the plate is run in chloroform-methanol and 5M ammonia (85:25:4 v/v) and developed with developers. The resulting chromatograph indicates the lipid compositions of bioemulsifier producing organism (Matsuyama et al 1987).

- **Oil spread method:** In this method of detection, 20µl of crude oil is added to 50ml of distilled water (DW) petri plate. Ten microliter of culture broth is added and oil coated water surface. Colony surrounded by an emulsified halo is considered positive for BS production (Morikawa et al 2000).

Extraction methods include :

Solvent extraction, acid precipitation, filtration, centrifugation.

Purification methods include:

- **Ion exchange:** Charged BS such as rhamnolipids which carry negative charge at higher pH environments may be attached to ion exchange resins and can be eluted with buffer containing 10% (v/v) ethanol. Addition of a minimum 0.6M NaCl to the buffer leads release of rhamnolipid from resin. This method can be repeated until a purified form of BS is extracted. Rhamnolipid BS from *Pseudomonas aeruginosa* has been purified by this method (Herman et al, 1995).
- **Adsorption-desorption:** Some BS can adsorb and desorb from Amberlite XAD 2 or 16 polystyrene resins and therefore this interaction is used for purification of BS. The process cell-free culture broth is applied directly to the adsorbent column and 0.1M phosphate buffer (pH 6.1) is used to equilibrate it. SFT or ultra violet is used to observe exhaustion of the absorbent resin (Reiling et al 1986). Further,

elution is carried out with methanol, which can be evaporated to obtain crude BS. Wood based activated carbon can also be used for this purpose (Dubey et al, 2005).

- **Preparative TLC:** This technique is used to identify the glycolipid compound in biosurfactant. Preparative TLC is a method that employs silica-coated glass plate having variable thickness. The BS sample is applied on the TLC plate allowed to run in a solvents system. Bands are visualized under UV and are then scraped and extracted with solvent (Thaniyavarn, et al ,2006).
- **GC-MS:** This method is used in quantification of glycolipids in BS. To analyze the bioemulsifier or biosurfactant sample in GC-MS device the sample needs hydrolytic cleavage between the carbohydrate and the protein part of BE/BS and the lipid portions. The esterification by diazomethane is important for detection of compounds using GC-MS. The biosurfactant from oil degrading bacteria *R. erythropolis* 3C-9 was characterized by GC-MS (Peng et al, 2007). Fatty acids from crude extracts was esterified with HCL in methanol at 100^{o}C. Fatty acid methyl esters were recovered by freeze drying the aqueous phase and extracting with pyridine to remove all ions. Pyridine was then removed by rotary evaporation and the saccharide portion was dissolved in DW which was used for further analysis (Satpute et al 2010).
- **NMR- NMR:** It provides information about the functional group and the position of linkages within the carbohydrate and lipid molecules. A series of NMR experiment gives exact location of each functional group and structural isomers. Solvents such as acetic acid, benzene, acetone, benzene, chloroform,dimethyl sulfoxide, methanol pyridine and water are used. Samples are hydrolysed with HCl (Satpute, et al, 2010).

Role of bioemulsifiers:

Bioemulsifiers due to their diverse structural availability exhibit various important roles. They play an important role in regulation of attachment and detachment of microorganisms from surfaces. They are responsible for cell to cell interaction. For e.g. bacterial pathogenesis, quorum sensing, biofilm formation, maintenance and maturation. Rhamnolipids are capable of maintaining the biofilm architecture and is considered as virulence factor in *Pseudomonas spp* (Patil and Chopade 2001, Mujumdar 2002, Doshi et al 2010, Bashetti et al 2012, Fracchia et al 2012).

Cellular differentiation, substrate accession, resistance to toxic compounds are some of the important roles of microbial surface active compounds. Bioemulsifiers bring about interaction between microbes and insoluble substrates such as hydrocarbons. They can enhance growth of bacteria on hydrophobic water insoluble substrates by increasing their bioavailability and increase surface area, desorbing them from surfaces and their apparent solubility (Mujumdar 2002, Maniyar et al 2011, Bashetti et al 2012, Fracchia et al 2012).

Classification of microbial surface active compounds:

Depending upon structural features, organism producing bioemulsifiers and molecular mass bioemulsifiers are classified accordingly. The hydrophilic moiety is comprised of acid, peptide cations or anions, mono di or polysaccharides while the hydrophobic moiety can be unsaturated or saturated chains of fatty acids (Maneerat and Dixit 2007, Satpute et al 2010). Microbial surface active compounds can be classified into low molecular weight compounds that can effectively reduce surface interfacial tension and high molecular weight polymers that can stabilize emulsions but do not lower the surface tension remarkably. The low molecular weight compounds include lipopeptides and glycolipids (Maneerat and Dixit 2007, Satpute et al 2010, Chen et al 2010).

Lipopeptides are mainly produced by *Bacillus subtilis* which has been extensively studied. The low molecular weight microbial surface active compounds reported are surfactins, IturinA, mono and di-Rhamnolipids, mannosylerythritol, lipids ,dimycolates trehalose lipids ,acidic and lactonic sophorolipids (Mujumdar 2002, Chen et al 2010, Doshi et al 2011, Bashetti et al 2012). Table 1,2 and 3 shows the classification of biosurfactant or bioemulsifier.

Low Molecular Weight Compounds:

Table 1: Micro-organisms producing Lipopeptides

Name of organism	Name of surface active compound	Chemical composition	Application.	Reference
Myroids	Lipopeptide.	L-Ornithine, lipids and a different couple of iso-3-hydroxyfattyacid (C15-C17) and iso-fattyacid 1:1:1 ratios.	Superior surface activity as compare with other surfactants. High stability, Emulsion activity.	Maneerat and Dixit 2007; Heun et al 2011
B.licheniformis	Lichenysin.	Glutamine amino acid.	High emulsion activity.	Gomma et al 2014
B.subtilis	IturinA.	Heptapeptide interlinked with a β amino acid fatty acid with a carbon chain C14-C17.	Antifungal property.	Cooper and MacDonald 1981
Serretia marcescens	Serrrawettins.	Nonionic cyclopeptides.	Antitumor and antinematode activity.	Ahmed and Hassn 2013
Azatobacter chroococcum	Lipopeptide.	Lipid and protein (3.3:68.7).	High emulsion activity.	Thavasi et al 2009.
Bacillus circulans	Lipopeptide.	Lipid and protein.	Powerful emulsion stabilizers.	Yakimov et al 1995

Table 2: Microorganisms producing Glycolipids

Name of organism	Name of surface active compound	Chemical composition	Application property	Reference
Pseudomonas aeruginosa	Rhamnolipids	Composed of one or two rhamnose sugar moieties linked to one or two β hydroxyl fatty acid chains.	High surface activity,antibacterial, antiviral and antiadhesive, also used in preparation of nanoparticles	Ahmed and Hassan 2013
Yeast strains of *Pseudomyza sp* and *Ustilago sp*	Mannosylerythritol(MELS).	Acylated derivative of 4-o-mannopyranosyl-D-erythritol	Antimicrobial,antitumor, immunomodulating, molecules, gene and drug delivery, and skin moisturizers.	Arutchelvi and Doble 2010.
Mycobacteria and *Corynebacteria*	Trehaloseipids.	Trehalose as a sugar moiety a non-reducing disaccharide,two glucose units are linked in a, α 1-1 glycosidic linkage.	Antitumor therapeutic agent.	Fukuoka and Konishi 2007
Flavobacterium ulginosum	Marinactan.	Glucose mannose and fructose (7:2:1).	Oil in water emulsion.	Maneerat and Dixit 2005

***Note: The glycolipids present in microorganisms producing bioemulsifiers are commonly mono or disaccharides acylated with a long chain fatty acids or hydroxyl compounds (Ron and Rosenberg et al 2010).**

Table 3: High molecular weight Bioemulsifier or Biosurfactants:

Name of organism	Name of bioemulsifiers.	Chemical composition	Application property	Reference
Yarrowia lipolytica	Liposan	Carbohydrates 45%, Protein 47%, lipid 5%.	High emulsification activity. Oil in water emulsion.	Amral et al 2006
Sacchromyces cerviciae	Mannoprotein	Carbohydrates 44% and Protein 17%.	Ability to emulsify hydrocarbons and organic solvents, oil in water emulsion.	Cameron et al 1988 Alcantara et al 2012
Acinetobacter calcoaceticus RAG-1	Emulsan.	Lipoheteropolysaccharide, D-galactosamine, D-galactominuronic and diaminodideoxy glucosamine.	Powerful emulsion stabilizers	Pines and Gutnik 1986
Acinetobacter calcoaceticusBD4	BD4 Emulsan.	Heptasaccharide unit linked to L-Rhamnose, D-Glucose, D-Glucoronic acid, D-Mannose (4:1:1:1).	Stabilization of oil in water emulsion.	Navon et al 1995
Streptomyces	Protein polysaccaharide.	Protein (82%),reducing sugars(1%),polysaccharide(17%).	It increases the self-life of the product, it is use in formulation of pesticides, food and medicine.	Kokare et al 2007
Rhodotorula glutinis	Sophorolipids.	Carbohydrates-protein complex.	Emulsifies Kerosene and crude oil efficiency.	Satpute et al 2010.
Acinetobacter calcoaceticus A2	Biodispersan.	Four reducing sugars: Glucosamine,6-methylaminohexose,galactosamine,uronic acid.	Substrate specificity, Dispersion of limestone and titanium dioxide.	Kaplan et al 1987
A. radioresistens	Alsan.	An anionic alanine containing heteropolysaccharide protein, C16 48% and C18 42%.	It is involved in molecular signals required in quorum sensing.Effective stabilization of oil in water emulsion.	Ron and Rosenberge 2002; Toren et al 2001
S.liquefacians	Surfactine.	Fatty acids: Stearic acid(49.5µg/ml),Palmitic acid(42.6µg/ml),Linolenic acid(50.6µg/ml),Arachidic acid(23.2µg/ml). Carbohydrates:Glucose(7.3µg/ml),fructose(55.4µg/ml),rhamnose(55.1µg/ml)	Anti-microbial activity.	Ahmed and Hassn 2013
Yarrowia lipolyticaNCIM 3589	Yansan	Lipid-carbohydrate protein	Emulsion activity.	Amrala et al 2006
Halomonas	Emulsifier HE39 and HE67	High molecular weight glycoprotein with high content of protein and uronic acid.	High emulsifying activity, Highly stable at neutral,acidic pH and even at room temperature.	Satpute et al 2010.
Halomonas TG39	HE39	Sulfated heteropolysaccharide.	Emulsification	Nerurkar 2009
Candida lipolytica	Liposan	Carbohydrate(83%),protein(17%).	Used in food,cosmetics and petroleum industries.	Cooper et al 1981; Cirigliano and Carmon 1984, 1985

Industrial and environmental potentials of bioemulsifier:

Bioemulsifier has a potential application in biological field as anti-viral, anti-fungal and anti-bacterial agents. They have proved to be a potent applicator in environmental bioremediation, cleaning the environment polluted with the crude oil or polyaromatic hydrocarbons, in industrial

emulsifications and stabilization process (Reddy et al 1983; Desai et al 1988, Boles et al 2005, Sathe et al 2012;Rakade et al 2013, Ramos and Portillo 2010).

The microorganisms producing exopolysaccharides such as *Alcaligen spPHY9L.86* is able to degrade 98% of the hydrocarbon substrate within 48 hour and also plays important role in the remediation of the crude oil contaminated sites (Desai et al 1988, Dastgheib et al 2008; Rakade et al 2013).

Pseudomonas putida M12 produces EPS that possess good emulsification activity and could emulsify various hydrocarbons and vegetable oil. The bio emulsifier shows stability up to 45 days and hence the strain have potential application in industries for oil recovery (Banat 2012, Maniyar et al 2011, Rakade et al 2013).

Antarctobacter sp produces AE22 emulsifier that forms stable emulsion and forms better stabilizing agents. This bioemulsifier has application in health care and food oil formulation. AE22 can be applied as a biosorbent for the treatment of contaminated environment (Doshi et al 2010, Bashetti et al 2012, Rakade et al 2013).

Bioemulsifier produced by *Corneybacterium kutscheri* show an efficient emulsification activity when added with fertilizers and have proven to be and potent in environmental remediation (Desai et al 1988, Das et al 2005, Rakade at al 2013).

Antibacterial Activity:

The antibiotic activity of bioemulsifiers is due to the ability of molecules of lipopeptide to self-associate and form a pore bearing channel or micellular aggregate inside a lipid membrane. For e.g. Surfactins is able to penetrate into the membrane through hydrophobic interactions, thus influencing the order of hydrocarbon chains and varying membrane thickness. The another bioactive surfactants produced by *Bacillus circulans* has antimicrobial action against Gram-positive Gram negative pathogenic and semi pathogenic bacteria such as *Bacillus pumilis, E.coli, Serretia marcescens* and *Proteus vulgaris* (Kaplan et al 1987, Omar 2006, Kokare et al 2007, Ahmed and Hussan 2013).

Antiviral activity:

Surfactins and its analogues have shown to possess antiviral activity, they show physico-chemical interactions with virus envelope. Surfactins has shown effective inactivation of enveloped virus such as retrovirus and herpes virus. Rhamnolipids another surface active compound has shown antiviral activity against herpes virus.(Cirigliano and Carman 1984,1985; Maneerat et al 2007, Fracchia et al 2012).

Antifungal activity:

The cellobiose lipid flocculosin synthesized by *Pseudomonas flocculosa* has shown antifungal activity against pathogenic yeast such as *Cryptococcus neoformans,Trichosporon asahii and Candida albicans*(Tanaka et al 1997, Amaral et al 2006, Omar 2006, Ahmed and Hassn 2013).

Anti-adhesion activity of biosurfactants /bioemulsifiers:

Formation of microbial biofilm on medical and technical equipment's causes hazardous effect such that the bacteria within biofilm become highly resistant to antibiotics and create adverse environmental challenges. Biomedical device such as urinary catheters heartvalves, central venous catheters are susceptible to biofilm formation on its surface. Biosurfactants/Bioemulsifiers are able to interfere with biofilm formation, modulating microbial interaction with interfaces. For e.g. Surfactin is capable of inhibiting biofilm formation of *Salmonella typhimurium, E. coli* and *Proteus mirabilis* in polyvinyl chloride walls, as well as vinyl urethral catheters, *B. licheniformis* V19T21 showed the ability to selectively inhibit biofilm formation pathogenic strains on polystyrene. Rhamnolipids is also capable of inhibition of adhesion of microorganisms on silicone rubber. This indicates biosurfactants/ bioemulsifiers can be used as coating agents for medical intentional materials that may lead to reduction in large number of hospital infections without the need for use of synthetic drugs and chemicals (Ron and Rosenberg 2002, Kokare et al 2007, Fracchia et al 2012).

Anti-biofilm activity:

There are many Microorganisms such as *Pseudomonas* which is capable of forming colonization that results into formation of a sticky layer called as biofilm. Biofilm are found on surface of urinary catheters, central venous catheters, heart valves which forms a coat on the surface. However treatment of instruments with biosurfactant produced by *S. typhimurium* showed inhibition of the biofilm formation. Lipopeptide bioemulsifier produced by *Bacillus* sp successfully inhibited the biofilm formation by pathogenic stains on polystyrene (Banat et al 1995).

Anti-mycoplasma activity:

Mycoplasma contamination in the cell culture is frequently occurring due to the limitation in the biomedical research especially in the case of mammalian cell lines. However, it have been proved that treatment of the mammalian cell lines with the bioemulsifier/ biosurfactants such as surfactin kill mycoplasma without damaging the cell lines. It is necessary to perform the cytotoxicity testing in order to avoid the damaging of the cell lines (Banat et al 1995, Fehri, et al 2007).

Antitumor Activity:

Bioemulsifiers are considered to participate in various intercellular molecular recognitions such as signal transduction, cell differentiation and cell immune response. Surfactins induces apoptosis in human breast cancer MCF-7 cells through a ROS/JNK-mediated mitochondrial/caspase pathway. Another surface active compound visconsin which is a cyclic lipopeptide recovered from *s* M9-3 inhibited the migration of metastatic prostate cancer cell line without any toxic effects (Noordan et al 2002,Fracchia et al 2012).

Biosurfactants/Bioemulsifiers potential in drug delivery: Detergency, emulsification, foaming, dispersion are such properties of bioemulsifiers make them suitable for use in drug delivery. Rhamnolipids and sophorolipids have been mixed with lecithin's to prepare biocompatible micro emulsions in which phase behavior was unaffected by changes in temperature and electrolyte concentration making them desirable for drug delivery. Rhamnolipids liposomes are used as microcapsules for drugs, proteins, nucleic acids and dyes. The lipopeptide, fengycin and surfactins act as enhancers for transdermal penetration and skin accumulation of acyclovir (Novon et al 2010, Fracchia et al 2012).

Anti-Inflammatory Activity:

Bioemulsifier shows anti-inflammatory activity. Surfactin is capable of down regulating LPS induced nitric oxide, it also down regulates primary macrophages by inhibiting NF-κβ activation which shows a good potential as bacterium derived anti-inflammatory agent (Tanaka et al 1997, Ramarathnan et al 2007, Satpute et al 2010). *Bacillus subtilis* secrete surfactin which are known to inhibit phospholipase A2, involved in the pathophysiology inflammatory bowel diseases. (In the rat model oral administration of PB6 as probiotic suppressed acid induced colitis. Lipopeptides have a strong inhibitory properties on production of nitric oxide (Ramarathnan et al 2007. Satpute et al 2010). Surfactins isomers derived from *Bacillus spp* showed anti-inflammatory activities (Banat et al 2010).

Nanoparticals :Surfactants is used for the synthesis of metal bound nanoparticles which is used widely in the field such as catalysis, mechano and electrical application and biomolecules. Surfactin mediated gold nanoparticles are used in field of drug delivery, gene delivery, targeted therapy (Fiechter 1992, Yakimov et al 1995, Satpute et al 2010; Gosh et al 2012).

Bioremediation:

Treatment of hydrocarbon polluted soil can be done by using biosurfactant/bioemulsifier. The emulsification properties of bioemulsifier make them utilize hydrocarbon degrade it efficiently. The bioemulsifier produced by *Azotobacter vinelandii* was efficient in degrading the hydrocarbons when used in bioremediation of oil contaminated soil (Pekdremir et al, 1990, Harman et al 1995; Uram et al 2003, Banat 2015).

Cosmetics and Soap:

Bioemulsifier are widely used in cosmetics fields and in soap as it have various advantages. An emulsan bioemulsifier is generally added in the soap which can make the skin smooth and creamy to touch. Shampoos containing bioemulsifier can make the hair conditioned and shiny and because it have a cleaning properties it helps to keep the hair free oh dust and static build up. Along with that a survey showed that shampoo containing emulsan helps to fight against some common skin and scalp problems such as dandruff, dermatitis, acne, eczema etc therefore potentially useful in medical field (Fracchia et 2012, Salen et al 2012).

Conclusion:

This review provides the information about the role of bioemulsifier in different industries and its biological applications. From this review it is sure that in future, biemulsifiers will replace the synthetic emulsifiers because of their benefits to the environment.

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