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# RESEARCH ARTICLE

# PROSPECTIVE BIOSURFACTANT APPLICATIONS IN FOOD INDUSTRY – OPPORTUNITIES AND CHALLENGES

***Parthasarathi, R. and Subha, K.S.**

Department of microbiology, Faculty of Agriculture, Annamalai University, AnnamalaiNagar, 608002, India

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## ABSTRACT

Biosurfactant are surface active compounds released by microorganisms. They are biodegradable non-toxic and ecofriendly materials. Biosurfactant have paying attention by many scientists because of their low toxicity, ecological acceptability. The increasing environmental concern about chemical surfactants triggers attention to microbial- derived surface-active compounds essentially due to the low and biodegradable nature. At present, biosurfactants are predominantly used in remediation of pollutants; however, they show potential applications in many sectors of Food Industry.Associated with emulsion farming and stabilization, antiadhensive and antimicrobial activities are some properties of biosurfactant, which could be explored in food processing and formulation. Potential applications of microbial surfactants in food area and the use of agroindustrial wastes as alternative substrates for their production are discussed.

***Key words:*** Biosurfactant, Ecofriendly, Low toxicity, Antiadhensive, Antimicrobial



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## INTRODUCTION

Surfactants are amphiphilic compounds containing both hydrophilic and lipophilic moieties. Surfactants can be derived from both chemically based ("chemical surfactants" or "synthetic surfactants") and biologically based ("biosurfactants") sources [Urum *et al*., 2004]. Biosurfactant is a surfactant directly derived from a natural source (i.e., from a plant, animal or microorganism), but this term is often used in a broader sense to include surfactants synthesized from natural raw materials. They possess the characteristic property of reducing the surface and interfacial tension using the same mechanisms as chemicals surfactants (Singh *et al*.,2007). Microorganisms showed a high capacity of synthesizing a wide range of surface-active compounds, generally called biosurfactants. Biosurfactant reduce surface tension, Critical Micelle Concentration (CMC) and interfacial tension in both aqueous solutions and hydrocarbon mixtures (Rahman et al., 2002; Banat, 1995). Non-toxic nature, excellent biodegradability, high surface/interfacial activity, low toxicity, high thermal/chemical stability, production from renewable resources and the ability to form micro emulsions (Long *et al.,* 2013 ;Nguyen *et al.*,2011). These compounds are mainly classified according to their Surfactants are widely used for industrial, agricultural, food, cosmetics and pharmaceutical molecular weight, physico-chemical properties and mode of action (Radhika *et al*., 2014 ;Banat *et al.,*2014). application however most of these compounds are synthesized chemically and potentially cause environmental and toxicology problem due to the recalcitrant and persistent nature of these substances (Makkar *et al.*,2003). Biosurfactant are biocompatibility and digestibility which allows their application in cosmetic, pharmaceuticals and as functional food additives kosaric (2001). Their properties and potential application, have encouraged many researchers to improve their production and have become the most investigated biosurfactants (Zgola-Grzeskowiak *et al.,* 2011). Surfactants are widely used for industrial, agricultural, food, cosmetics and pharmaceutical application however most of these compounds are synthesized chemically and potentially cause environmental and toxicology problem due to the recalcitrant and persistent nature of these substances (Makkar *et al*.,2003) .Rhamnolipids from Pseudomonas aeruginosa, surfactin from Bacillus subtilis, emulsan from Acinetobacter calcoaceticus and sophorolipids from Candida bombicola are some examples of microbial-derived surfactants.Nowadays, the applications of biosurfactants mostly focused on bioremediation of pollutants (Mulligan, 2005). Currently, according to the literature no research works have been focused on applications of biosurfactants in foods. Researchers also stated that, these microbial compounds (biosurfactants) exhibit a variety of useful properties for the food industry specially as emulsifiers, foaming, wetting, solubilizers (Banat *et al*., 2000), antiadhesive

****Corresponding author:*** **Parthasarathi, R.,**
Department of microbiology, Faculty of Agriculture, Annamalai University, AnnamalaiNagar, 608002, India.

and antimicrobial agents (Singh and Cameotra, 2004).The major goal for the food processing industries is to provide safe, wholesome and acceptable food to the consumer and control of microorganisms (Baggen-Ravn *et al.,* 2003; Karthik *et al*., 2013). Moreover, an increasing consciousness among consumers demands for reducing the use of artificial or chemically synthesized compounds by replacing it for more natural food ingredients and additives (Shepherd *et al*., 1995). The use of artificial and/or chemically synthesized compounds changes the natural flavor, texture and nature of the food (Rasooli, 2007). Despite the advantages demonstrated by biosurfactants, few reports are available regarding their use on food products and food processing. To manufacture commercial products with long shelf lives and resistances to environmental stresses, stabilizers are therefore required (McClements 2015). Numerous types of stabilizers are available to improve emulsion stability, including emulsifiers, thickeners, weighting agents, and ripening inhibitors. In this article, we primarily focus on emulsifiers because these ingredients are critical to the proper performance of any emulsion-based product. The demand for the use of natural and sustainable ingredients in food products is growing because of increasing awareness of the importance of healthy eating and environmental sustainability (Karaca *et al*. 2015; Lam and Nickerson 2013). For this reason, many food manufacturers are trying to replace synthetic emulsifiers with natural alternatives, as well as trying to replace animal-based ingredients with plant-based ingredients (Baines and Seal 2012).

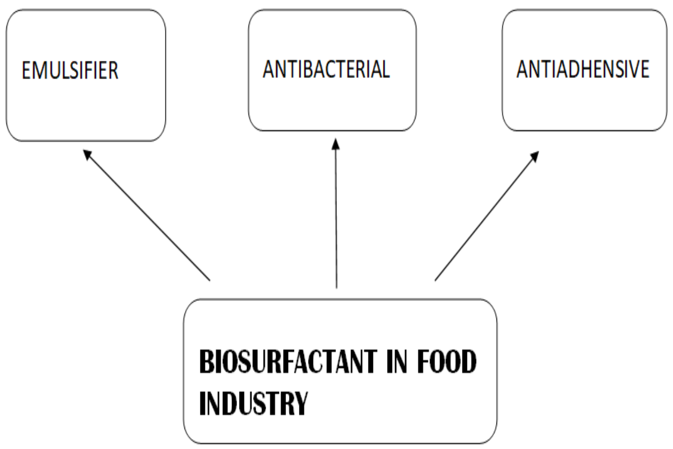
**Review of Literature**

**Biosurfactant as food additives**

The particular combination of characteristics such as emulsifying, anti adhesive and antimicrobial activities presented by biosurfactants suggests their application as multipurpose ingredients or additives. The development of these biomolecules should represent, in the near future, an increasing significant part of the market for food additives.

**Applications of Biosurfactant in dairy industry**

Surfactin are biodegradable and non-toxic compounds so they can be used in dairy industry (Krishnaswamy, 2008) for the following properties.




Yeh *et al*. (2005) demonstrated biosurfactant has the best emulsion stability and concentration of 0.16g/L when added to ice cream mix over lecithin (1g/L).

It increases quality, improves overrun and organoleptic attributes. Huang *et al.* (2009) demonstrated that *Salmonella enteritidis* strain sensitive to 6.25 µg/mL of surfactin. This was done by Agar well diffusion test method 6.25 µg of surfactin added to wells it shows clear zone to *Salmonella enteritidis.* Then demonstrated that when surfactin was added to milk in the amount 6.25 µg/mL containing 7 log counts of *Salmonella enteritidis*, counts reduced by 6 logs. Meena and Kanwar (2015) showed surfactin gives anti adhesive activity by inhibiting the biofilm formation by two selected pathogenic strains of *Salmonella aureus* and *E.coli* by 97% and 90% dairy cans and vats. Biosurfactants have been used for various food processing application but they usually play a role as food formulation ingredient and anti-adhesive agents, as food formulation ingredient they promote the formation and stabilization of emulsion due to their ability to decrease the surface and interfacial tension. It is also used to control the agglomeration of fat globules, stabilize aerated systems, improve texture and shelf -life of starch-containing products, modify rheological properties of wheat dough and improve consistency and texture of fat based products (Krishnaswamy *et al.,* 2008).

**Emulsifiers**

Food makers use emulsifiers to reduce the surface tension between two immiscible phases at their interface allowing them to mix (Shepherd *et al.,* 1995). Biosurfactants exhibit surface-active and emulsifier action, there is a great potential market for effective biosurfactants in the food industry not only due to their surface activity, but also for their environmental friendly nature (Mohan *et al.,* 2006), low toxicity (Flasz *et al.,* 1998).

**Antimicrobial Agent**

A wide range of biosurfactants has shown antimicrobial activity against bacteria, yeast, fungi, algae, and viruses (Nitschke and Costa 2007). Among biosurfactants, lipopeptide from the widely reported class having antimicrobial action. The genus Bacillus is responsible for producing the most well-known lipopeptides biosurfactants. *B. subtilis* produces the first biosurfactant presenting this antimicrobial property, that is, surfactin (Das *et al.,* 2008). It also produces other lipopeptides with the same property: fengycin, iturin, bacillomycins, and mycosubtilins (Das *et al.,* 2008).

**Antiadhesive Agent**

It is important to review some concepts to understand why one would use the antiadhesive properties of biosurfactants in the food industry. Usually, in nature, bacteria do not stand as alone cells, but they organize themselves as communities, which may be more or less structuralized. (Rodrigues *et al.,* 2004) studied the influence of two biosurfactants produced by probiotic bacteria *(Lactococcus lactis* and *Streptococcus thermophilus*) biofilms development by *Streptococcus epidermidis*. *salivarius*, *Streptococcus aureus*, *Rothia dentocariosa*, *C.albicans*, and *C.tropicalis* in voice prostheses. Both biosurfactants showed antimicrobial activity but, depending on the microorganism, they presented different concentrations. Surfactants provide multifunctional properties for food additives as emulsifiers, dispersants, wetting agents and solubilizers in foods which contain fats and oils such as baked goods, dairy foods, salad dressings, shortenings and margarine. Researchers also stated that, these microbial compounds (biosurfactants) exhibit a variety of useful properties for the food industry specially as emulsifiers, foaming, wetting, solubilizers (Banat *et al.,*2000), antiadhesive and antimicrobial agents (Singh and Cameotra, 2004). The major goal for the food processing industries is to provide safe, wholesome and acceptable food to the consumer and control of microorganisms (Baggen-Ravn *et al.,* 2003; Karthik *et al.,* 2013). Moreover, an increasing consciousness among consumers demands for reducing the use of artificial or chemically synthesized compounds by replacing it for more natural food ingredients and additives (Shepherd *et al.,* 1995). The use of artificial and/or chemically synthesized compounds changes the natural flavor, texture and nature of the food (Rasooli *et al*., 2007). The present study aimed to determine antimicrobial activity of biosurfactants derived from bacterial strains such as *Saccharomyces cerevisiae* and *Pseudomonas aeruginosa* and its applications on fruit salads. The maximum antimicrobial effect of biosurfactant produced by *Pseudomonas aeruginosa* may be due to the presence of Rhamnolipids (Toribio *et al.,* 2010). Generally, the Rhamnolipids molecules of rhamnose are linked to β-hydroxy-decanoic acid and they have many industrial applications. Da rosa *et al*. (2010) also reported that the biosurfactant production by *P. aeruginosa* DS10-129 and *P. aeruginosa* LBM10 have rhamnolipid type biosurfactant. Abalos *et al.*2001 reported that, the rhamnolipid mixture obtained from P. aeruginosa showed inhibitory activity against the bacteria (*Escherichia coli, Micrococcus luteus* and *Alcaligenes faecalis*, *Serratia marcescens*, *Mycobacterium phlei* and *Staphylococcus epidermidi*) and fungi (*Aspergillus niger*, *Chaetonium globosum*, *Penicillium crysogenum*, *Aureobasidium pullulans, Botrytis cinerea* and *Rhizoctonia solani* in various concentrations. (Bodour *et al., 2004)* have recently described a new class of biosurfactants named flavolipids produced by a soil isolated *Flavobacterium sp.* The new surfactant showed strong surface activity and emulsifying ability, and exhibits a polar moiety that features citric acid. In dairy products (soft cheese and ice creams) the addition of emulsifiers improves the texture and creaminess. This quality is of special value for low-fat products (Rosenberg and Ron., 1999). A lipopeptide obtained from *Bacillus subtilis* able to form stable emulsions with soybean oil and coconut fat, suggesting its potential as emulsifying agent in foods (Nitschke and Pastore., 2006). A large variety of *Bacillus subtilis* strains produces lipopeptide biosurfactants which possess a high surfactant activity such as surface active properties and antibacterial activity (Rashedi *et al.,*2005). They possess the characteristic property of reducing the surface and interfacial tension using the same mechanisms as chemicals surfactants (Singh *et al.,* 2007).

**Biosurfactant and Bioemulsifier**

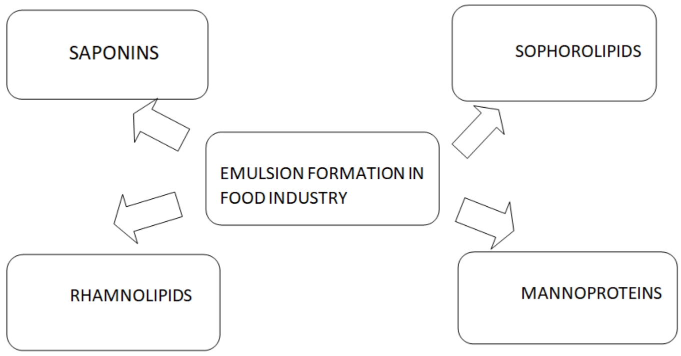
A number of small surface-active molecules can be isolated from natural sources, e.g., glycolipids, lipoproteins, and lipopeptides (De *et al.,* 2015, Varvaresou and Iakovou 2015). These molecules are typically either extracted from plant materials or produced by fermentation using specific microorganisms (bacteria, yeasts, or fungi) (De *et al*. 2015, Uzoigwe *et al.,*2015).In both cases, the biosurfactants typically have to be isolated from a complex mixture of other molecules and then purified before they can be used as food ingredients.

**Molecular and physiochemical characteristics**

Biosurfactants are that they are natural, biodegradable, and sustainable and often have low toxicity (Kralova and Sjoblom 2009, Uzoigwe *et al.* 2015). Some examples of biosurfactants include glycolipids (sophorolipids, rhamnolipids, and trehalose lipids) and lipopeptides (surfactin, iturin, and fengycin) (Uzoigwe *et al.,* 2015). A few studies have investigated the potential use of bioemulsifiers in food systems, e.g., mannoproteins (da Silva Araujo *et al*. 2014, Torabizadeh *et al*. 1996) and hydrophobins (Lumsdon *et al*. 2005, Tchuenbou-Magaia *et al*. 2009).

**Emulsion formation**

In this section, only the properties of a select number of biosurfactants and bioemulsifiers that may have potential application within the food industry are discussed: saponins, sophorolipids, rhamnolipids, and mannoproteins.




**Saponin**

They are a broad class of natural surface-active molecules that have hydrophilic regions (e.g., sugar groups) and hydrophobic regions (e.g., phenolic structures) on the same molecule (Mitra and Dungan 1997, Sidhu and Oakenfull 1986). Although they can be isolated from different natural sources, the most commonly used saponins in the food industry are extracted from the bark of the Quillaja saponaria tree. Indeed, a food emulsifier based on the quillaja saponin extract is already sold under the trade name Q-Naturale R for utilization in food and beverage products (Ingredion, Bridge water, NJ). This ingredient is provided in both powdered and liquid forms that can be conveniently incorporated into food. Quillajs saponin absorb to water interfaces and reduce the interfacial tension, and are capable of forming and stabilizing oil-in-water emulsions (Yang *et al.,* 2013). Saponin based emulsifiers (Q-NaturaleR) are commercially available and are already being used in many commercial food applications. Sophorolipids have been used to encapsulate structured lipids (interesterified soybean and rice bran oils) in oil-in-water emulsions (Xueet *et al.,* 2013).

**Sophorolipids**

Sophorolipids are glucolipids produced by some species of microorganisms, particularly yeasts (de Oliveira *et al.,* 2015, Rosenberg and Ron 1999). They can be produced on an industrial scale using microbial fermentation processes utilizing suitable yeast strains (such as *Candida batistae* and *Candida bombocola*) and substrates (such as carbon and nitrogen sources) (de Oliveira *et al.,*2015, De *et al.,*2015). These molecules consist of a hydrophilic sophorose group (a disaccharide) attached to a hydrophobic hydrocarbon tail (a fatty acid chain) (de Oliveira *et al.,* 2015). The nature of the sophorose head group and hydrocarbon tails depends on the microbial strain, fermentation conditions, and substrates used, which leads to biosurfactants with different physicochemical and functional properties (Lang 2002, Ribeiro *et al.,* 2013). In 2013, the production costs associated with synthesizing sophorolipids by industrial fermentation processes were estimated to be approximately $2.54/kg (Ashby *et al.,* 2013).

**Rhamnolipids**

Rhamnolipids are another type of glycolipid that can be obtained from certain microorganisms (e.g., *Pseudomonas aeruginosa*) using fermentation processes (Henkel *et al.,* 2012, Jirku *et al.,* 2015, Muller *et al.,* 2012). As with other biosurfactants, the microbial strain, fermentation conditions, and substrates must be optimized.

**Conclusion**

Biosurfactant are non- toxic, non- polluting, eco friendly and biodegradable in nature. The major goal for the food processing industries to provide safe, wholesome and acceptable food to the consumer and control microorganisms. An increasing consciousness among consumer's demands for reducing the use of chemically or artificial synthesized compounds changes the natural flavor, texture and nature of the food. The uses of chemical or synthesized compounds change the natural flavor, texture and nature of the food. Biosurfactant should be emphasized in order to certify the sale of these compounds for food utilization.

## REFERENCES


Alcantara, VA., Pajares, IG., Simbahan, JF. and Edding SN. 2013. Downstream recovery and purification of a bioemulsifier from *Saccharomyces cerevisiae,* 2031. *Philipp. Agric. Sci.* 96:349–58.

Bai, L. and Mc Clements, DJ. 2016. Formation and stabilization of nanoemulsions using biosurfactants: rhamnolipids.*J. Colloid Interface Sci.* 479:71–79.

Banat, IM., Satpute, SK., Cameotra, SS., Patil, R. and Nyayanit, NV. 2014. Cost effective technologies and renewable substrates for biosurfactants' production. *Front Microbiol.,* 5: 697.

Banat, I. M., Makkar, R. S., and Cameotra, S. S. 2000. Potential commercial applications of microbial surfactants. *Applied Microbiology and Biotechnology,* 53, 495-508.

Barriga, JA., Cooper, DG., Idziak, ES. and Cameron, DR. 1999. Components of the bioemulsifier from *S. cerevisiae. Enzyme Microb. Technol.,* 25:96–102.

Benjamin, O., Silcock, P., Beauchamp, J., Buettner, A. and Everett, DW. 2014. Emulsifying properties of legume proteins compared toβ-lactoglobulin and Tween 20 and the volatile release from oil-in-water emulsions. *J. Food Sci.,* 79:E2014–22.

Berlin/Heidelberg: Springer-Verlag (Chapter 17).

Cameotra, S. S. and Makkar, R. S. 1998. Synthesis of biosurfactants in extreme conditions. *Applied Microbiology and Biotechnology,* 50, 520-529.

Cameron, DR., Cooper, DG. and Neufeld, R. 1988. The mannoprotein of *Saccharomyces cerevisiae* is an effective bioemulsifier. *Appl. Environ. Microbiol.* 54:1420–25.

Cirigliano, M. C. and Carman, G. M. 1985. Purification and characterization of liposan, a bioemulsifier from Candida lipolytica. *Applied and Environmental Microbiology*, 50, 846-850.

Cox, AR. and Kim, H. 2013. Oil-in-water emulsion. *Patent No. WO2010136355-A1* Lam RSH, Nickerson MT. 2013. Food proteins: a review on their emulsifying properties using a structurefunction approach. *Food Chem*., 141:975–84.

Da Silva Araujo, VB., de Melo, ANF., Costa, AG., Castro-Gomez, RH. and Madruga MS, *et al.* 2014. Followed extraction of β-glucan and mannoprotein from spent brewer's yeast (*Saccharomyces uvarum*) and application of the obtained mannoprotein as a stabilizer in mayonnaise. *Innov. Food Sci. Emerg. Technol.,* 23:164–70.

Das, P., Mukherjee, S., and Sen, R. 2008. Antimicrobial potential of a lipopeptide biosurfactant derived from a marine *Bacillus circulans. J. Appl. Microbiol*., 104:1675–1684.

Dikit P, Maneerat S, Musikasang H, H-Kittikun A. 2010. Emulsifier properties of the mannoprotein extract from yeast isolated from sugar palm wine. *Science Asia,* 36:312–18.

Fox, S. L. and Bala, G. A. 2000. Production of surfactant from Bacillussubtilis ATCC 21332 using potato substrates. *Biore source Technology,* 75, 235-240.

Freire, D. M. G. L., Araujo, V. D., . Kronemberger, F. D. A. *et al.,* 2009. *Innovation in Food Engineering*, CRC Press, New York, NY,USA.

Gomez-Guillen, MC., Gimenez, B., Lopez-Caballero, ME., and Montero, MP. 2011. Functional and bioactive properties of collagen and gelatin from alternative sources: a review. *Food Hydrocoll*., 25:1813–27.

Haba, E., Espuny, M. J., Busquets, M., and Manresa, A. 2000. Screening and production of rhamnolipids by Pseudomonas aeruginosa 47T2 NCBI 40044 from waste frying oils. *Journal of Applied Microbiology,* 88, 379-387.

Henkel, M., Muller, MM., Kugler, JH., Lovaglio, RB., Contiero, J. *et al.* 2012. Rhamnolipids as biosurfactants from renewable resources: concepts for next-generation rhamnolipid production. *Process Biochem*., 47:1207–19.

Huang, X.F., Yang, D.H. and Zhou, Q. 2009. Evaluation of screening methods for demulsifying bacteria and characterization of lipopeptide bio-demulsifier produced by*Alcaligenes* sp. *Biores. Technol.,* 100(3): 1358–1365.

In N. Kosaric, W. L. Carns, and N. C. C. Gray (Eds.), *Biosur factants and biotechnology,* (pp. 183e210). New York: Marcel Dekker Biotechnology, 40, 207-217.

In N. Kosaric, W. L. Carns, and N. C. C. Gray (Eds.), *Biosurfactants and biotechnology,* (pp. 183-210). New York: Marcel Dekker.

Irfan-Maqsood, M. and Seddiq-Shams, M. 2014 Rhamnolipids- Well-Characterized Glycolipids with Potential Broad Applicability as Biosurfactants. *Ind Biotechnol.,* 10: 285-291.

Iyer, A., Mody, K. and Jha, B. 2006) Emulsifying properties of a marinebacterial exopolysaccharide. *Enzyme and Microbial Technology,* 38, 220-222.

Joe, MM., Bradeeba, K., Parthasarathi, R., Sivakumaar, PK. Chauhan, PS. *et al.* 2012. Development of surfactin based nanoemulsion formulation from selected cooking oils: evaluation for antimicrobial activity against selected food associated microorganisms. *J. Taiwan Inst. Chem. Eng.* 43:172–80.

Kachholz, T. and Schlingmann, M. 1987) Possible food and agricultural applications of microbial surfactants: an assessment.

Kosaric, N. 2001. Biosurfactants and their Applications for Soil Bioremediation. *Food Technol Biotechnol*., 39: 295-304.

Kosaric, N. 2001. Biosurfactants and their application for soil bioremediation. *Food Technology and Biotechnology*, 39(4), 295-304.

Kralova, I. and Sjoblom, J. 2009. Surfactants used in food industry: a review. *J. Dispers. Sci. Technol.* 30:1363–83.

Krishnaswamy, M., Subbuchettiar, G., Ravi, T.K. and Panchaksharam, S. 2008. Biosurfactants properties, commercial production, and application. *Curr Sci.,* 94: 736-747.

Lam, RSH. and Nickerson, MT. 2013. Food proteins: a review on their emulsifying properties using a structurefunction approach. *Food Chem*. 141:975–84.

Long, X., Zhang, G., Shen, C., Sun, G., Wang, R. *et al.* 2013 Application of rhamnolipid as a novel biodemulsifier for destabilizing waste crude oil. *Bioresour Technol.,* 131: 1-5.

Lukondeh, T., Ashbolh, N. J. and Rogers, P. L. 2003. Evaluation of Kluyveromyces marxianus FII 510700 grown on a lactose-based medium as a source of natural bioemulsifier. *Journal of Industrial Microbiology and Biotechnology,* 30, 715-720.

Lumsdon, SO., Green, J., Stieglitz, B. 2005. Adsorption of hydrophobin proteins at hydrophobic and hydrophilic interfaces. *Colloids Surf. B* 44:172–78.

Makkar, R. S. and Cameotra, S. S. 1997. Utilization of molasses forbiosurfactant production by two Bacillus strains at thermophilicconditions. *Journal of the American Oil Chemists' Society*, 74,887-889.

Makkar, R. S. and Cameotra, S. S. 2002. *Applied Microbiology and Biotechnology*, 58, 428–434.

Makkar, RS. and Rockne, KJ. 2003. Comparison of synthetic surfactants and biosurfactants in enhancing biodegradation of polycyclic aromatic hydrocarbon. *Environ Toxicol Chem.,* 22: 2280-2292.

Mandal, S. M., Sharma, S., Pinnaka, A. K., Kumari, A. and Korpole, S. 2013. "Isolation and characterization of diverse antimicrobial lipopeptides produced by *Citrobacter* and *Enterobacter*," *BMC Microbiology*, vol. 13, no. 1, article 152.

Mc Clements, DJ. and Gumus, CE. 2016. Natural emulsifiers—biosurfactants, phospholipids, biopolymers, and colloidal particles: molecular and physicochemical basis of functional performance. *Adv. Colloid Interface Sci.* 234:3–26.

Meena, K.J. and Kanwar, S.J. 2015. Lipopeptides as the antifungal and antibacterial agents: applications in food safety and therapeutics. *Bio. Med. Res. Int.,* 1: 1-9.

Misurcova, L., S krovnkova, S., Samek, D., Ambrozova, J. and Machu, L. 2012. Health benefits of algal polysaccharides in human nutrition. *Advances in Food and Nutrition Research*, 66, 75.

Mitra, S. and Dungan, SR. 1997. Micellar properties of quillaja saponin. 1. Effects of temperature, salt, and pH on solution properties. *J. Agric. Food Chem.,* 45:1587–95.

Mohan, P. K., Nakhla, G. and Yanful, E. K. 2006. Biokinetics of biodegradability of surfactants under aerobic, anoxic and aerobic conditions. *Water Research,* 40, 533-540.

Muller, MM., Kugler, JH., Henkel, M., Gerlitzki, M., Hormann, B, *et al.* 2012. Rhamnolipids-next generation surfactants. *J Bio technol.,* 162: 366-380.

Mulligan, C. N. 2005. Environmental applications for biosurfactants. *Environmental Pollution*, 133, 183-198.

Nguyen, TT. and Sabatini, DA. 2011. Characterization and emulsification properties of rhamnolipid and sophorolipid biosurfactants and their applications. *Int J Mol Sci.,* 12: 1232-1244.

Nitschke, M. and Costa, SGVAO . 2007. Biosurfactants in food industry. *Trends Food Sci Tech.,* 18: 252-259.

Nitschke, M. and S. G. V. A. O. 2007.Costa, "Biosurfactants in food industry," *Trends in Food Science and Technology*, vol. 18, no. 5, pp. 252–259.

Nitschke, M. and Costa, S. G. V. A. O. 2007. Biosurfactants in food industry. *Trends Food Sci.Tech*., 18:252–259.Science 94: 736-747.

Nitschke, M., and Pastore, G. M. 2006. Production and properties of a surfactant obtained from Bacillus subtilis grown on cassava wastewater. Bioresource Technology, 97, 336-341.

Nitschke, M., Costa, S. G. V. A. O., Haddad, R., Gonc¸alves, L. A. G.,Eberlin, M. N., and Contiero, J. (2005). Oil wastes as unconventional substrates for rhamnolipid biosurfactant production by Pseudomonas aeruginosa LBI. Biotechnology Progress, 21(5), 1562-1566.

Piorkowski DT,McClements DJ. 2014. Beverage emulsions: recent developments in formulation, production,and applications.*Food Hydrocoll*. 42:5–41.

Radhika, C., Jun, S., Minmin, C., Kanaji, M., Jain, AK. *et al.* 2014. Properties and characterization of biosurfactant in crude oil. *Fuel.,* 122: 140-148.

Reis, RS., Pereira, AG., Neves, BC. and Freire, DM. 2011. Gene regulation of rhamnolipid production in Pseudomonas aeruginosa-a review. *Bioresour Technol.,* 102: 6377-6384.

Rodrigues, L., Banat, I. M., Teixeira, J. and Oliveira, R. 2006. *Journal of Antimicrobial Chemotherapy*, 57,609-618.

Rodrigues, L., Moldes, A., Teixeira, J. and Oliveira, R. 2006. Kinetic study of fermentative biosurfactant production by Lactobacillusstrains. *Biochemical Engineering Journal*, 28, 109-116.

Rosenberg, E. and Ron, E. Z. 1999. High- and low-molecular-mass microbial surfactants. *Applied Microbiology and Biotechnology,* 52, 154-162.

Shepherd, R., Rockey, J., Sutherland, I. W. and Roller, S. 1995. Novel bioemulsifiers from microorganisms for use in foods.

Singh, A., Van Hanne, J.D. and Ward, O.P. 2007. Surfactants in microbiology and biotechnology:Part-2. Application aspects. *Biotechnol. Adv.,* 25: 99-121.

Singh, P. and Cameotra, S. S. 2004. Potential applications of microbial surfactants in biomedical sciences. *Trends in Biotechnology,* 22(3),142-146.

Singh, S. N., Kumari, B. and Mishra, S. 2012. Microbial degradation of alkanes. In S. N. Shing (Ed.), Microbial degradation of xenobiotics environmental science and engineering.

Singha, T. K. 2012. Microbial extracellular polymeric substances: Production, isolation and applications. *IOSR Journal of Pharmacy, 2*(2), 276.

T. Stein, 2005. "*Bacillus subtilis* antibiotics: structures, syntheses and specific functions," *Molecular Microbiology*, vol. 56, no. 4, pp. 845–857.

Taherian, AR., Britten, M., Sabik, H. and Fustier, P. 2011. Ability of whey protein isolate and/or fish gelatin to inhibit physical separation and lipid oxidation in fish oil-in-water beverage emulsion. *Food Hydrocoll*., 25:868–78.

Tchuenbou-Magaia, FL., Norton, IT., Cox, PW. 2009. Hydrophobins stabilised air-filled emulsions for the food industry. *Food Hydrocoll*., 23:1877–85.

Thompson, D. N., Fox, S. L. and Bala, G. A. 2000. Biosurfactants frompotato process effluents. *Applied Biochemistry and Biotechnology,* 84-86, 917-929.

Torabizadeh, H., Shojaosadati, SA. and Tehrani, HA. 1996. Preparation and characterisation of bioemulsifier from

*Saccharomyces cerevisiae* and its application in food products. *LWT Food Sci. Technol.* 29:734–37.

Torabizadeh, H., Shojaosadati, SA. and Tehrani, HA. 1996. Preparation and characterisation of bioemulsifier from *Saccharomyces cerevisiae* and its application in food products. *LWT Food Sci. Technol.,* 29:734–37.

Urum, K. and Pekdemir, T. 2004. Evaluation of biosurfactants for crude oil contaminated soil washing. *Chemosphere, 57*, 1139–1150.

Uzoigwe, C., Burgess, JG., Ennis, CJ. and Rahman, PK. 2015. Bioemulsifiers are not biosurfactants and require different screening approaches. *Front. Microbiol.,* 6:245.

Van Haesendonck, I. P. H. and Vanzeveren, E. C. A. 2004. Rhamnolipids in bakery products. W.O. 2004/040984, *International application patent* (PCT).

Van, HI. and Vanzeveren, E. 2004. Rhamnolipids in bakery products. US 20060233935 A1.

Vatsa, P., Sanchez, L., Clement, C., Baillieul, F and Dorey, S. 2010. Rhamnolipid biosurfactants as new players in animal and plant defense against microbes. *Int J Mol Sci.,* 11: 5095-5108.

Velikonja, J. and Kosaric, N. 1993. Biosurfactants in food applications.In N. Kosaric (Ed.), Biosurfactants: Production, *properties and applications* (pp. 419-446). New York: Marcel Dekker.

Waller, GR. and Yamasaki, K. 1996a. *Saponins Used in Food and Agriculture*. New York: Plenum Press Yang Y, Leser ME, Sher AA, McClements DJ. 2013. Formation and stability of emulsions using a natural small molecule surfactant: quillaja saponin (Q-NaturaleR). *Food Hydrocoll*. 30:589–96.

Wilde, PJ. 2009. Emulsions and nanoemulsions using dairy ingredients. In *Dairy-Derived Ingredients: Food Nutraceutical Uses*, ed. M Corredig, pp. 539–64. Cambridge, UK: Woodhead Publ. Anton M. 2013. Egg yolk: structures, functionalities and processes. *J. Sci. Food Agric.,* 93:2871–80.

Xue, CL., Solaiman, DKY., Ashby, RD,, Zerkowski, J., Lee, JH. *et al.* 2013. Study of structured lipid-based oil-inwater emulsion prepared with sophorolipid and its oxidative stability. *J. Am. Oil Chem. Soc.,* 90:123–32.

Yeh, M.S., Wei, Y.H. and Chang, J.S. 2005. Enhanced production of surfactin from *Bacillus subtilis* by the addition of solid carriers. *Biotechnol. Progress,* 2(1): 1329–1334.

Zezzi do Valle Gomes, M. and Nitschke, M. 2012. Evaluation of rhamnolipid and surfactin to reduce the adhesion and remove biofilms of individual and mixed cultures of food pathogenic bacteria. *Food Control.,* 25: 441-447.

Zgola-Grzeskowiak, A. and Kaczorek, E. 2011. Isolation, preconcentration and determination of rhamnolipids in aqueous samples by dispersive liquid-liquid microextraction and liquid chromatography with tandem mass spectrometry. Talanta 83: 744-750

Zhu, L., Yang, X., Xue, C., Chen, Y., Qu, L. *et al.* 2012. Enhanced rhamnolipids production by Pseudomonas aeruginosa based on a pH stage-controlled fed batch fermentation process. *Bioresource Technology,* 117: 208-213.

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