Textile Surfactants: Unseen Chemical Threats to the Environment

Vaishali[1]*, Mona Verma[2], Nikita[3], and Shubham Disodia[4]

[1,3,4]M.Sc. Student, [2]Assistant Professor,
Department of Apparel and Textiles Science, I.C. College of Community Science,
CCS Haryana Agricultural University, Hisar-125 004, India

Corresponding Author
Vaishali
Email: raovaishali77@hau.ac.in

OPEN ACCESS

Keywords

Emulsification, Wetting, Industrial Sustainability, Biodegradability

How to cite this article:

Vaishali, Verma, M., Nikita, and Disodia, S. 2025. Textile Surfactants: Unseen Chemical Threats to the Environment. *Vigyan Varta* 6(1): 16-22.

ABSTRACT

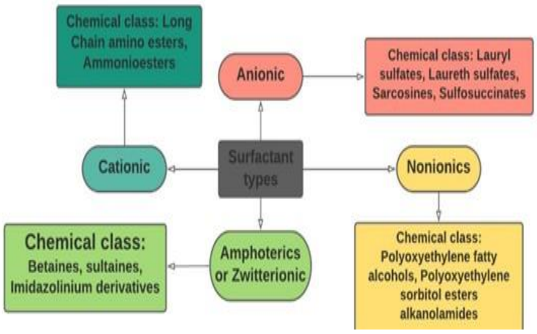
The Increasing environmental challenges posed by synthetic surfactants, which are derived from petrochemical sources, necessitate the development of more sustainable alternatives. Biosurfactants, natural compounds produced by microorganisms, offer significant advantages over traditional surfactants, including biodegradability, non-toxicity, and lower environmental impact. They are widely used in various industries, including cosmetics, textiles, pharmaceuticals, and wastewater treatment, due to their ability to effectively lower surface and interfacial tensions. In textile processing, biosurfactants show promise in emulsifying, wetting, and enhancing the removal of oils and dyes from fabrics. Additionally, their use in the textile dyeing industry helps improve dye solubility and reduce the environmental impact of dyeing processes. Strategies to optimize biosurfactant production, such as nutrient management and genetic engineering, are essential for their cost-effective, large-scale application. Biosurfactants, with their multifunctional properties and environmental benefits, are poised to play a key role in reducing the reliance on harmful chemical surfactants and contributing to more sustainable industrial practices.

INTRODUCTION

The world is facing major challenges in protecting the environment and tackling climate change. One such challenge is the widespread use of synthetic surfactants made from petrochemicals. These surfactants are toxic, not biodegradable, and harm marine life. Every year, over 15 million MT of surfactants are used, with 60% ending up in water systems. This makes synthetic surfactant production unsustainable. A more sustainable alternative is biosurfactants. These are natural, biodegradable, and non-toxic, and can reduce CO2 emissions. Biosurfactants are used in industries such as cosmetics, pharmaceuticals, food, and wastewater treatment, providing an environmentally friendly solution. Pre-treating textiles is key to producing quality products. Natural and synthetic fibres, sizing agents, and impurities need to be removed from the fabric surface before further processing. For washing, strong emulsifying surfactants are needed to clear oil and soil without allowing them to redeposit. Synthetic surfactants are commonly used for this, both in industry and home laundry. However, these are toxic, slow to degrade and contribute to water eutrophication. As a result, there is growing interest in replacing petrochemical surfactants with biosurfactants, which are eco-friendly and effective for wetting, detergency, emulsification, and other textile processes. Akbari *et al.*, (2018)

Surfactants that are chemically synthesized from petrochemical or oleochemical sources play a crucial role in many everyday products and are vital in numerous industrial, agricultural, and food-related applications (Desai and Banat 1997). The global demand for surfactants exceeds 13 million tons annually, but due to environmental concerns, there is an increasing effort by companies to substitute some or all their chemical surfactants with natural alternatives, mainly produced by microorganisms using renewable feedstocks (Marchant and Banat 2012). These natural surfactants, referred to as biosurfactants and bio emulsifiers, have several benefits over synthetic surfactants, including being biodegradable, non-toxic, biocompatible, and digestible. They also offer better stability in extreme conditions, such as high temperatures, and can be produced from cost-effective raw materials (Makkar *et al.* 2011). Furthermore, biosurfactants can be engineered through genetic or biochemical methods to alter their structure, enabling customization to meet specific functional requirements.

Biosurfactants are amphiphilic molecules, typically produced on the surface of microbial cells or released into the surrounding environment. These compounds possess both hydrophobic and hydrophilic regions, allowing them to accumulate at or align along interfaces, which reduces the surface and interfacial tension of liquids. They can form molecular aggregates, such as micelles. The formation of micelles begins when the concentration of biosurfactants reaches a certain threshold known as the critical micelle concentration, which typically ranges from 1 to 200 mg/L. Notably, this concentration is 10 to 40 times lower than that required for most synthetic surfactants (Martinotti *et al.*, 2013).

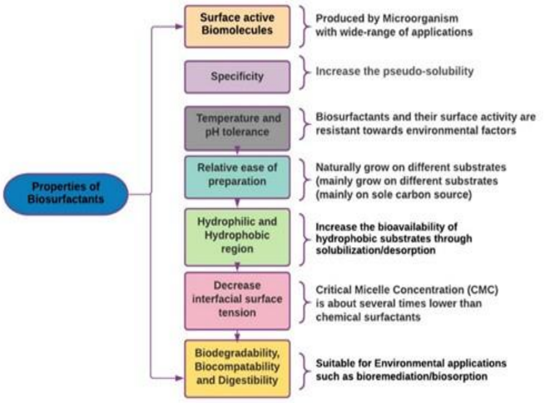


Source: Gayathiri *et al.*, (2022).

Use of Biosurfactants in Wetting, Emulsification, and Detergent Formulation: Microorganisms synthesize various hydrocarbon-based compounds known as biosurfactants during their growth cycles. These naturally occurring surface-active agents are classified according to their microbial origin, molecular structure, or functional mechanisms. The hydrophilic component typically includes amino acids, peptides, or a spectrum of sugars ranging from simple to complex, while the hydrophobic segment often comprises fatty acids that may be linear, branched, saturated, unsaturated, or hydroxylated. Low-molecular-weight biosurfactants are especially adept at minimizing surface tension at the air-water interface and interfacial tension at the oil-water boundary. The efficiency of a surfactant is quantified by its Critical Micelle Concentration (CMC), which for biosurfactants generally falls between 1 and 2000 mg/L, depending on their molecular composition. Biosurfactants with superior surface and interfacial activity can reduce water's surface tension from 72 mN/m to as low as 35 mN/m and lower oil-water interfacial tension from 40 mN/m to 1 mN/m. Conversely, high-molecular-weight biosurfactants, known as bio-emulsifiers, are highly effective in stabilising oil-in-water emulsions. The remarkable ability of biosurfactants to reduce surface and interfacial tension renders them invaluable across various applications. Compared to synthetic surfactants, biosurfactants exhibit superior efficiency due to their significantly lower CMC values. Additionally, they possess desirable characteristics such as minimal foaming, enhanced emulsifying capabilities, improved solubility, and exceptional cleaning properties, making them ideal candidates for applications like textile processing (Shah et al., 2016).

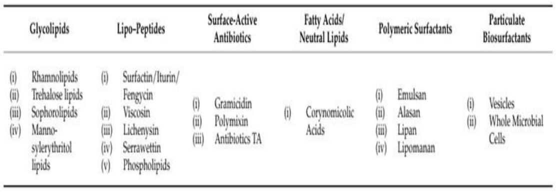
Properties of Biosurfactants: Biosurfactants like rhamnolipid and green zyme are known for their ability to significantly reduce water's surface tension and the interfacial tension of n-hexadecane Cooper (1986). These biosurfactants exhibit key physicochemical properties, such as temperature stability, low critical micelle concentration (CMC), and reduced interfacial tensions, enabling the formation of microemulsions that aid in hydrocarbon solubilisation in water.

Micelle formation is a crucial property of surfactants. As the surfactant concentration increases, surface tension gradually decreases Butt *et al.*, (2004). Above the critical micelle concentration (CMC), surfactants like rhamnolipids help stabilize micelle formation Andersen *et al.*, (2014). In place of synthetic surfactants, the synergistic effects of antioxidants have led to using various biosurfactant extracts in the cosmetic industry. Rodrigues (2015). When different concentrations of biosurfactants were tested on dyed hair, results showed that adsorption was higher above the CMC, while still maintaining the hair's condition, highlighting their potential in cosmetic applications. Urum *et al.*, (2006). Additionally, biosurfactants enhance water retention, improving the wetting of solid surfaces. Cooper (1986).



Source: Gayathiri *et al.*, (2022).

Classification of Biosurfactants: Surfactants represent one of the most adaptable categories of chemicals utilized across numerous industries. They command a substantial portion of the market, with manufacturers increasingly prioritizing environmentally responsible production methods. The rising demand for affordable and sustainable biosurfactants has heightened interest in biological alternatives. The vast structural variety and diverse functional attributes of biosurfactants position them as a highly promising group of molecules for applications in industrial, environmental, and biotechnological sectors. Advances in screening techniques have streamlined the detection of microorganisms capable of synthesizing biosurfactants. Moreover, a range of purification and analytical methods are available for the detailed characterization of these compounds. Biosurfactants are typically categorized by their chemical composition and biological origin, with a further classification based on molecular weight, dividing them into two principal groups (Zuckerberg et al., 1979). Glycolipids and lipopeptides are examples of low molecular weight biosurfactants, while lipoproteins, lipopolysaccharides, and amphipathic polysaccharides fall under the category of high molecular weight biosurfactants. The low molecular weight biosurfactants are effective in reducing surface and interfacial tensions, whereas the high molecular weight biosurfactants excel in stabilizing emulsions. Rosas-Galván *et al.*, (2018). Other types of biosurfactants include phospholipids, polymeric surfactants, and particulate surfactants Desai *et al.*, (1997).



Glycolipids	Lipo-Peptides	Surface-Active Antibiotics	Fatty Acids/ Neutral Lipids	Polymeric Surfactants	Particulate Biosurfactants
(i) Rhamnolipids (ii) Trehalose lipids (iii) Sophorolipids (iv) Manno-sylerythritol lipids	(i) Surfactin/Iturin/ Fengycin (ii) Viscosin (iii) Lichenysin (iv) Serrawettin (v) Phospholipids	(i) Gramicidin (ii) Polymixin (iii) Antibiotics TA	(i) Corynomicolic Acids	(i) Emulsan (ii) Alasan (iii) Lipan (iv) Lipomanan	(i) Vesicles (ii) Whole Microbial Cells

Source: Gayathiri *et al.*, (2022)

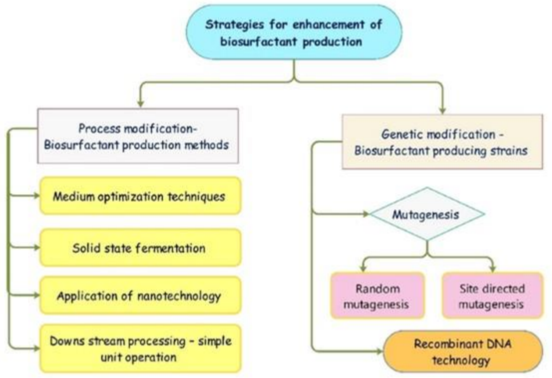
Applications: Applications of different types of biosurfactants used in the textile industry are given below:

Type of Biosurfactant	**Microorganisms**	**Applications**	**References**
Rhamnolipid	--	Elimination of Chocolate and Oil Stains from Cotton Fabrics	Bafghi and fazaelipoor (2012)
Sorphorolipid	Candida bombicola ATCC22214	Extraction of Edible Oil Residues	Joshi-warfare and Prabhu (2013)
Glycolipid	Candida Lipolitica UCP 0988	Cleaning of Motor Oil from Soiled Cotton Garments	Santos *et al.*, (2017)
Lipopeptide	Bacillus subtilis SPBI	Enhancing Oil and Tea Stain Removal with Textile Detergents	Bouassida *et al.*, (2018)
Rhamnolipid	Aspergillus versicolour	Elimination of Textile Dyes	Gula (2020)
Rhamnolipid	Pseudomonas aeruginosa	Management of Textile Effluents	Silva (2021)
Lipopeptide	Kurthia gibsonii	Bio-Decolorization and Biodegradation of Textile Wastewater	Noe *et al.*, (2021)

Source: Santos et al., (2023)

Strategies to improve the production of Biosurfactant

The availability or absence of essential nutrients like phosphorus, manganese, sulphur, iron, nitrogen, and carbon, along with their ratios—particularly C: N, C: Fe, C:P, and C—has a significant impact on the biosurfactant fermentation process (Maas *et al.*, 2016; Noha *et al.*, 2018). Therefore, optimizing these factors is crucial to boost biosurfactant production and ensure cost-effectiveness for large-scale industrial applications (Kanna *et al.*, 2014; Lee *et al.*, 2018). Additionally, to make biosurfactant production economically viable, it is essential to integrate efficient downstream processing and explore alternative strategies. This can be achieved through innovative approaches like statistical surface methodology.



Source: Ambaye *et al.*, (2021).

Future Opportunities for Biosurfactants

Biosurfactants are proposed for use in textile processing due to their ability to increase the bioavailability of water-insoluble substrates and their broader range of properties compared to synthetic surfactants. They are effective in emulsification, solubilization, dispersion, wetting, and detergency while reducing environmental pollution (Kesting *et al.*, 1996; Mohan *et al.*, 2006). Studies have shown that *Rhodococcus erythropolis* biosurfactants are more efficient at removing oils from fibres compared to surfactant-free methods.

Biosurfactants also have significant applications in the textile dyeing industry. They enhance dye solubility and improve dye dispersion, leading to more uniform dye penetration into fibres (Quagliotto *et al.*, 2006; Montgomery *et al.*, 2008). With 15% of global dye production lost to the environment, biosurfactants offer a way to reduce the environmental impact of dyes, which can release carcinogenic amines when metabolized (Robinson *et al.*, 2001; Gottlieb, 2003).

CONCLUSION

Biosurfactants present a promising and sustainable alternative to synthetic surfactants, addressing critical environmental concerns associated with petrochemical-based products. These natural compounds, derived from microorganisms, are biodegradable, non-toxic, and highly effective in a variety of industrial applications, including textile processing, detergency, emulsification, and wetting. Their ability to lower surface and interfacial tensions makes them ideal for removing stains, enhancing dye solubility, and improving the quality of textile treatments. With the growing demand for eco-friendly solutions, the potential for biosurfactants in industries such as cosmetics, pharmaceuticals, and wastewater treatment is vast. Moreover, through optimizing production methods and exploring innovative strategies, such as genetic engineering and statistical approaches, the economic feasibility and scalability of biosurfactants will be further enhanced, paving the way for their widespread adoption and reducing the ecological footprint of traditional surfactants.

REFERENCES

Akbari, S., Abdurahman, N. H., Yunus, R. M., Fayaz, F., & Alara, O. R. (2018). Biosurfactants—a new frontier for social and environmental safety: A mini-review. *Biotechnology Research and Innovation*, *2*(1), 81-90.

Andersen, K. K., & Otzen, D. E. (2014). Folding of outer membrane protein, A in the anionic biosurfactant rhamnolipid. *FEBS Letters*, *588*(12), 1955–1960.

Ambaye, T. G., Vaccari, M., Prasad, S., & Rtimi, S. (2021). Preparation, characterization, and application of biosurfactants in various industries: A critical review on progress, challenges, and perspectives. *Environmental Technology and Innovation*, *24*, 102090.

Bouassida, M., Fourati, N., Ghazala, I., Ellouze-Chaabouni, S., & Ghribi, D. (2018). Potential application of Bacillus subtilis SPB1 biosurfactants in laundry detergent formulations: compatibility study with detergent ingredients and washing performance. *Engineering in Life Sciences*, *18*(1), 70-77.

Butt, H. J., Graf, K., & Kappl, M. (2004). Surfactants, micelles, emulsions, and foams. In *Physics and Chemistry of Interfaces* (pp. 246–279). Weinheim: Wiley-VCH Verlag GmbH & Co. KgaA.

Cooper, D. G. (1986). Biosurfactants. *Microbiological Sciences*, *3*, 145–149.

da Silva, V. L., Dilarri, G., Mendes, C. R., Lovaglio, R. B., Goncalves, A. R., Montagnolli, R. N., & Contiero, J. (2021). Rhamnolipid from Pseudomonas aeruginosa can improve the removal of Direct Orange 2GL in textile dye industry effluents. *Journal of Molecular Liquids*, *321*, 114753.

Desai, J. D., & Banat, I. M. (1997). Microbial production of surfactants and their commercial potential. *Microbiology and Molecular Biology Reviews*, *61*(1), 47–64.

Dos Santos, J. C. V., de Santana Costa, A. F., de Lima e Silva, T. A., Sarubbo, L. A., & de Luna, J. M. (2023). New trends in the textile industry: Utilization and application of biosurfactants. In *Advancements in Biosurfactants Research* (pp. 215-223). Cham: Springer International Publishing.

Fracchia, L., Ceresa, C., Franzetti, A., Cavallo, M., Gandolfi, I., Van Hamme, J., ... & Banat, I. M. (2014). Industrial applications of biosurfactants. In *Biosurfactants: Production and Utilization—Processes, Technologies, and Economics* (pp. 245–260). Chichester: John Wiley & Sons

Gayathiri, E., Prakash, P., Karmegam, N., Varjani, S., Awasthi, M. K., & Ravindran, B. (2022). Biosurfactants: Potential and eco-friendly material for sustainable agriculture and environmental safety—a review. *Agronomy*, *12*(3), 662.

Güla ÜD (2020) A green approach for the treatment of dye and surfactant contaminated industrial wastewater. Braz J Biol 80(3):615-620

Kanna, R., Gummadi, S. N., & Kumar, G. S. (2014). Production and characterization of biosurfactant by *Pseudomonas putida* MTCC 2467. *Journal of Biological Sciences*, *14*, 436–445.

Khaje Bafghi, M., & Fazaelipoor, M. H. (2012). Application of rhamnolipid in the formulation of a detergent. *Journal of Surfactants and Detergents*, *15*, 679-684.

Maass, D., Moya Ramirez, I., Garcia Roman, M., Jurado Alameda, E., Ulson de Souza, A. A., Borges Valle, J. A., Altmajer Vaz, D. (2016). Two-phase olive mill waste (alpeorujo) as a carbon source for biosurfactant production. *Journal of Chemical Technology and Biotechnology*, *91*(8), 1990–1997

Makkar, R. S., Cameotra, S. S., & Banat, I. M. (2011). Advances in the utilization of renewable substrates for biosurfactant production. *Applied Microbiology and Biotechnology Express*, *1*(1), 5.

Marchant, R., & Banat, I. M. (2012). Microbial biosurfactants: Challenges and opportunities for future exploitation. *Trends in Biotechnology*, *30*(10), 558–565.

Marte, A., Indolfi, P., Ficociello, C., Russo, D., Oreste, M., Bottigliero, G., ... & Casale, F. (2013). Inflammatory myofibroblastic bladder tumour in a patient with Wolf-Hirschhorn syndrome. *Case reports in Urology*, *2013*(1), 675059.

Martinotti, M. G., Allegrone, G., Cavallo, M., & Fracchia, L. (2013). Biosurfactants. In *Sustainable Development in Chemical Engineering—Innovative Technologies* (pp. 199–240). Chichester: John Wiley & Sons.

Nor, F. H. M., Abdullah, S., Yuniarto, A., Ibrahim, Z., Nor, M. H. M., & Hadibarata, T. (2021). Production of lipopeptide biosurfactant by Kurthia gibsonii KH2 and their synergistic action in decolourisation of textile wastewater. *Environmental Technology & Innovation*, *22*, 101533.

Patil, S., & Athalye, A. (2023). Biosurfactants in textiles: Sustainable future. *Trends in Textile and Fashion Design*, *5*(3), 2023.

Rodrigues, L. R. (2015). Microbial surfactants: Fundamentals and applicability in the formulation of nano-sized drug delivery vectors. *Journal of Colloid and Interface Science*, *449*, 304–316.

Rosas-Galván, N. S., Martínez-Morales, F., Marquina-Bahena, S., Tinoco-Valencia, R., Serrano-Carreón, L., Bertrand, B., León Rodríguez, R., Guzmán-Aparicio, J., Alvaréz-Berber, L., & Trejo-Hernández, M. D. R. (2018). Improved production, purification, and characterization of biosurfactants produced by *Serratia marcescens* SM3 and its isogenic SMRG-5 strain. *Biotechnology and Applied Biochemistry*, *65*(6), 690–700.

Santos, D. K., Resende, A. H., de Almeida, D. G., Soares da Silva, R. D. C. F., Rufino, R. D., Luna, J. M., ... & Sarubbo, L. A. (2017). Candida lipolytica UCP0988 biosurfactant: potential as a bioremediation agent and in formulating a commercial-related product. *Frontiers in microbiology*, *8*, 767.

Shah, N., Nikam, R., Gaikwad, S., Sapre, V., & Kaur, J. (2016). Biosurfactant: Types, detection methods, importance, and applications. *Indian Journal of Microbiology Research*, *3*(1), 5-10.

Urum, K., Grigson, S., Pekdemir, T., & McMenamy, S. (2006). A comparison of the efficiency of different surfactants for removal of crude oil from contaminated soils. *Chemosphere*, *62*(9), 1403–1410.

Zuckerberg, A., Diver, A., Peeri, Z., Gutnick, D. L., & Rosenberg, E. (1979). Emulsifier of *Arthrobacter RAG-1*: Chemical and physical properties. *Applied and Environmental Microbiology*, *37*(2), 414–420.