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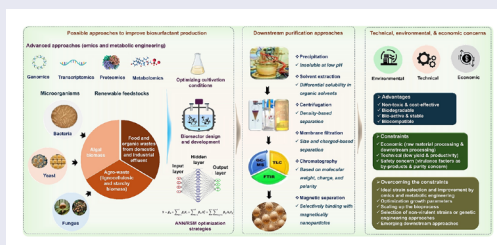
Technological advancement in sustainable production of biosurfactant using agro-industrial wastes: A review of enhanced bioprocessing and computational optimization techniques

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ABSTRACT

This review analyzes the literature from the last decade to evaluate advancements in biosurfactant production practices, highlighting their role in sustainable business and as a key contributor to the green circular economy worldwide. Biosurfactants show a stable chemical structure in various environmental conditions, low molecular weight, and surface-active reagents, which makes them important industrial molecules. The global biosurfactant market was valued at over USD 4.41 billion in 2023 and is expected to rise to USD 6.71 billion by 2032, reflecting a consistent rise in demand driven by the shift toward sustainable and eco-friendly surfactant alternatives. Advanced microbial strain development using omics approaches and metabolic engineering enables promising and economic biosurfactant production with tailored properties using renewable substrates, such as agro-industrial wastes and lipid-rich substrates (waste cooking oil and olive mill waste). Eco-friendly biosurfactant production from low-cost biomass resources can achieve yields ranging from 1.11 to 27.24 g/L, depending on the substrates, microbes, and target biosurfactants. Advances in biostatistical techniques for optimizing input parameters to maximize product output (~3-fold) and artificial neural networks for outcome prediction ($R^2 = 0.9998$) have enhanced predictive accuracy and industrial automation, enabling the saving of time, resources, and capital. Furthermore, integrated extraction techniques and foam fractionation in downstream processing have demonstrated considerable potential to achieve high product purity. Highlighting the current developments in biosurfactant production, this review exclusively illustrates a promising prospect toward enhanced sustainable biosurfactant production, confirming a high titer with quality by implementing mathematical modeling, biostatistical tools, and virtually simulated outcome predictions.



KEYWORDS Agro-industrial feedstocks; biostatistical optimization and prediction; biosurfactants; downstream processing; sustainable technology

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