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Hybrid RSM-AI Approaches for Enhanced Biodiesel Feedstock Production

Haram Sarfraz, and Zainab Mahmood*

Department of Bioengineering, Integral University Lucknow, Uttar Pradesh, India

*Corresponding author

ABSTRACT

The growing demand for sustainable energy has intensified interest in microbial lipids as an alternative biodiesel feedstock, particularly from lignocellulosic agro-residues such as sugarcane bagasse. Conventional statistical optimization tools like Response Surface Methodology (RSM) have been widely employed to enhance lipid production; however, their predictive capability is often limited when dealing with complex, nonlinear bioprocess systems. This study proposes a hybrid RSM-Artificial Intelligence (AI) framework to improve lipid yield and process efficiency in oleaginous microorganisms cultivated on biomass hydrolysates. Initially, RSM is employed to identify significant process variables, including substrate concentration, C/N ratio, pH, and incubation time. Subsequently, machine-learning models such as Artificial Neural Networks (ANN) and Random Forest algorithms are integrated to capture nonlinear interactions and predict optimal operational conditions with higher accuracy. The hybrid approach enhances model robustness, reduces experimental trials, and improves scalability potential. Validation studies demonstrate superior predictive performance and increased lipid accumulation compared to conventional RSM optimization alone. Furthermore, integration of AI-driven analytics with bioprocess monitoring enables intelligent decision-making for industrial-scale biodiesel production. The proposed strategy highlights the transformative role of AI in advancing sustainable biofuel technologies and supports the development of smart, data-driven biorefineries aligned with circular bioeconomy principles.

Keywords: *Artificial Intelligence, Response Surface Methodology, Machine Learning, Biodiesel Feedstock*

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