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Insights Into Biocatalysts: Applications And Advances

Vijay Swaroop Singh Gaddala
Department of Chemistry,
Sri DNR Government Degree College for Women, PALAKOL. 534260. India

Abstract

Their distinctive properties, unequaled to date in catalyzing reactions under mild conditions and of great specificity, have conferred a paramount status on biocatalysts—enzymes and whole cells—in sustainable industrial practice. Some recent advancements in this field of biocatalysis, ranging from pharmaceutical industries to environmental cleaning and food processing, are highlighted in this review article. Advanced techniques include protein engineering, immobilization techniques, and unconventional media, which have gained strength in increasing measure. Such techniques increase efficiency and stability. Besides, this review will cover the challenges and future perspectives of biocatalytic technologies as underlining their contribution to the global problems of sustainability.

Keywords: Biocatalysts, Enzymes, Whole Cells, Sustainability, Environmental Remediation, Protein Engineering.

Introduction

Biocatalysts are materials that occur naturally and catalyze biochemical reactions. The two main kinds of biocatalysts are enzymes and microbial cells. Enzymes have their specific activity, and catalyzing at mild conditions has made them suitable for various applications (Roostaei, 2023). On the other hand, whole cells can perform complex transformations and find wide application in fermentation processes (Nguyen et al., 2021).

Biocatalysts are gaining recognition for their potential in the revolution of industrial practices by providing eco-friendly alternatives to conventional chemical processes. Biological catalysts offer numerous benefits, including high specificity, mild reaction conditions, and minimal environmental impact, making them appropriate for diverse applications in the chemical, pharmaceutical, and food sectors. (Bell et al., 2021; Chapman et al., 2018; Alcántara et al., 2022).

Biocatalysts are essential for biodiesel and bioethanol generation. The utilization of biocatalysts obtained from natural sources in biodiesel manufacture is covered by Nguyen et al. (2021). These biocatalysts can reduce their environmental impact while increasing the yield and quality of biodiesel.The catalytic enhancement of bio-oil using enzymatic methods has demonstrated potential in augmenting the quality of biofuels. (Zhu et al., 2018).

The use of biocatalysts can significantly reduce energy consumption and environmental impact compared to conventional chemical processes (Nguyen et al., 2021).

Recent advancements in biocatalysis have been driven by innovations in protein engineering, genomic mining, and computational methods, which have collectively enhanced the performance and applicability of biocatalysts (Bell et al., 2021; Alcántara et al., 2022).

Applications of Biocatalysts

Biocatalysts have found extensive applications in the pharmaceutical industry, enabling the synthesis of complex molecules with high stereoselectivity. For instance, cytochrome P450 enzymes have been utilized for the biotransformation of xenobiotics, showcasing their potential in drug metabolism and environmental detoxification (Harris et al., 2022).

Additionally, whole-cell biocatalysis has been employed to produce fine chemicals, such as benzyl alcohol, demonstrating the efficiency of microbial systems in catalyzing specific reactions (Rodrigues & Carvalho, 2022).

In environmental applications, biocatalysts play a crucial role in bioremediation efforts. For example, laccases and peroxidases have been effectively used to degrade phenolic pollutants, highlighting their utility in wastewater treatment (Salehi et al., 2021; Bilal et al., 2021).

The ability of Rhodococcus species to metabolize a variety of environmental contaminants further underscores the versatility of biocatalysts in addressing pollution (Krivoruchko et al., 2019).

Biocatalysts are also widely employed in food industry.Papain, a proteolytic enzyme, is widely used for meat tenderization and in the production of protein hydrolysates for nutritional supplements. (Fernández-Lucas et al., 2017).Lipases are employed in dairy processing to enhance flavor and texture in products like cheese and butter (Sarmah et al., 2017; Daiha et al., 2015).

Biocatalysts have also been adopted by the cosmetics sector to manufacture products that need certain biological processes. When creating skin care products, enzymes such as lipases and proteases are utilized to aid in the creation of mild exfoliants and moisturizers. (Sarmah et al., 2017).

Advances in Biocatalysis

Recent advancements in biocatalysis have focused on enhancing the stability and efficiency of biocatalysts. Techniques such as enzyme immobilization have been pivotal in improving the operational stability of biocatalysts under industrial conditions (Polakovič et al., 2017; Sharma et al., 2022). For instance, immobilized lipases have been extensively studied for biodiesel production, demonstrating their effectiveness in catalyzing transesterification reactions (Abdulmalek & Yan, 2022).

Moreover, the development of CRISPR tools has opened new avenues for engineering whole-cell biocatalysts, allowing for tailored metabolic pathways to enhance productivity (Mulet, 2023).

In the context of waste management, demonstrated the use of engineered “Clostridium thermocellum” for the thermophilic degradation of polyethylene terephthalate (PET) (Yan et al., 2020).

The exploration of non-conventional media, such as ionic liquids, has also shown promise in expanding the operational range of biocatalysts, enabling reactions that were previously challenging under aqueous conditions (Aranda & Gonzalo, 2020; Vera et al., 2020). These innovations are critical for the scalability of biocatalytic processes, particularly in the context of sustainable industrial chemistry (Alcántara et al., 2022).

Genomic mining involves the in-silico analysis of genomic sequences to identify potential biocatalysts.The mining of metagenomic data has led to the identification of new nitrilases, which are valuable for various biocatalytic applications, including the synthesis of pharmaceuticals (Gong et al., 2013).

One notable example of genomic mining is the identification of a hyperthermophilic glucose isomerase from Thermoanaerobacter ethanolicus and successfully characterized this enzyme, demonstrating its potential for high fructose corn syrup production, which is crucial in the food industry (Liu et al., 2015).

The ability to mine genomic data for flavin-dependent halogenases (FDHs)has opened new avenues for the development of environmentally friendly halogenation processes in Synthetic Chemistry(Lewis, 2024).

Computational methods encompass a range of techniques, including molecular modeling, quantum mechanics/molecular mechanics (QM/MM) simulations, and machine learning to predict enzyme behavior, optimize reaction conditions, and design novel biocatalysts. One notable application of computational methods is the development of RetroBioCat, a tool that aids in the retrosynthetic analysis of biocatalytic processes (Rocha et al., 2022).

The increasing relevance of machine learning methods in managing large datasets related to enzyme properties and activitiescan identify patterns and predict enzyme performance, facilitating the discovery of new biocatalysts with desirable characteristics. (Sampaio & Fernandes, 2023).

Challenges and Future Directions

Despite the significant progress in biocatalysis, challenges remain in terms of enzyme stability, substrate specificity, and the economic feasibility of biocatalytic processes. The need for further research into the fundamental mechanisms of enzyme action and the development of robust biocatalysts is essential for overcoming these barriers (Chapman et al., 2018; Espina et al., 2022).

Future directions should focus on integrating biocatalysis with other green technologies, such as electrochemistry and photochemistry, to create synergistic effects that enhance overall process efficiency (Yamanaka et al., 2011; (Bell et al., 2021;)

Future research should focus on integrating genomic mining with other omics technologies, such as transcriptomics and proteomics, to gain a comprehensive understanding of enzyme function and regulation(Intasian et al., 2021; Jaiswal et al., 2019).

Conclusion

Biocatalysts represent a transformative approach to industrial chemistry, offering sustainable solutions to pressing environmental and economic challenges. The continuous advancements in biocatalytic technologies, coupled with a growing understanding of enzyme mechanisms and microbial metabolism, position biocatalysts as key players in the transition towards greener industrial practices.

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