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Editorial

Microbial Biocatalysis

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Biocatalysis, which can be performed by whole cells and isolated enzymes, has become a topic of public interest for its potential use in the chemical industry in manufacturing, monitoring, and waste management. Enzymes are proteins that organisms produce to catalyze the biochemical reactions needed for life. However, the isolation and purification of enzymes may be costly and time-consuming, and cofactors may need to be added or recovered. An alternative approach is to use whole cells as "Microbial Biocatalysts" to perform multiple enzyme reactions in a single strain and regenerate cofactors internally. Whole-cell biocatalysts can be used for different types of processes, such as biotransformation and fermentation. They involve one or more steps of biocatalysis to produce valuable chemicals through biosynthesis/biotransformation or degrade organic pollutants completely.

Fermentation is a whole-cell biosynthesis process that involves multiple enzymes and native pathways. α-Ketoglutaric acid (KGA) is a valuable compound that can be produced by *Yarrowia lipolytica* CBS146773 using a mixed carbon source of glycerol and rapeseed oil [1]. This strain requires thiamine for growth and overexpresses genes encoding glycerol kinase, citrate synthase, and the mitochondrial acid transporter. By optimizing the fermentation conditions, the KGA yield reached 82.4 g/L. In contrast to the pure compound KGA, extracellular polymers (EPS) are complex secondary metabolites produced by microorganisms. They consist of proteins, polysaccharides, humic acids, and nucleic acids. A Cordyceps strain C058 and its bioaugmented biofloc, named mycelium biofloc (MBF), have shown high water purification efficiency due to their high EPS production [2]. MBF was constructed by both fungi and bacteria, with C058 being the main contributor to EPS synthesis. Multifunctional enzymes (MFEs), including various synthetases and post-modification enzymes, are involved in the biosynthesis of such secondary metabolites [3]. The review summarized the research advances of MFEs such as polyketides, non-ribosomal peptides, terpenoids, and a wide range of cytochrome P450s that participate in secondary metabolite synthesis [3].

Whole-cell biocatalysis relies on finding suitable biocatalysts for specific conversion reactions. A team from Shenyang Pharmaceutical University reported three examples of whole-cell biotransformation reactions in three articles: the 7α- and 7β-hydroxylation of Dehydroepiandrosterone by *Gibberella* sp. CICC 2498 and *Absidia coerulea* CICC 41050 [4]; the O-demethylation of rabeprazole by *Cunninghamella blakesleeana* 3.970 [5]; and the non-oxidative deamination of L-phenylalanine and L-tyrosine by recombinant *Escherichia coli* BL21 [6]. These reactions are useful for the synthesis of important pharmaceutical intermediates. α-Amylase is an important industrial enzyme that has not been extensively studied in marine sources. The α-amylase from the symbiotic bacteria *Bacillus* sp. HR13 and HR16 isolated from the intestines of *Sillago sihamas* and *Rastrelliger Kanagurta* exhibited high thermostability at 60 °C [7]. This suggests that they have potential applications in food and detergent industries. Phenol-degrading bacteria have been widely reported, but little is known about phenol degradation by cold-tolerant strains in extreme environments

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such as Antarctica. Two cold-adapted Arthrobacter strains that only possessed catechol 1,2-dioxygenase were able to degrade phenol via an ortho-cleavage pathway at temperatures between 10 and 15 °C [8].

In order to improve the efficiency of whole-cell catalysis, the catalyst can be modified by mutation, directed evolution, and immobilization. Random mutagenesis was the first technology that enabled the efficient generation of large diversity and is still used in many laboratories. For example, UV mutagenesis of the nystatin-producing strain Streptomyces noursei D-3-14 resulted in the mutant strain 72-22-1, with a high yield of polyfungin B and high fungicidal activities [9]. The mutant strain showed a 1.58 and 1.91-fold increase in chemical and biological potency, respectively, and had stable genetic characteristics. However, random mutagenesis has some limitations, such as the incompleteness of the diversity introduced. This can be overcome by combining it with other technologies to achieve the directed evolution of catalysts. A case in point is the use of error-prone PCR for random mutagenesis and a suitable and efficient high-throughput screening method to enhance the acetophenone tolerance of short-chain dehydrogenase/reductase (SDR) from *Empedobacter brevis* ZJUY-1401 [10]. The mutant M190V exhibited a 74.8% activity improvement compared with the wild-type when using 200 mM acetophenone as the substrate. Another way to improve whole-cell catalysis efficiency is to immobilize cells to keep them alive, stabilize their catalytic efficiency, and enable their reuse. This also simplifies cell recycling and downstream processing. For instance, immobilized whole *E. coli* pRSF-AfNit2 cells were able to effectively catalyze the hydrolysis of 3-cyanopyridine to nicotinic acid in a semi-continuous packed-bed bioreactor (sPBR) using recombinant nitrilase [11]. The conversion rate remained at 100% after repeating the operation for 41 batches of sPBR. A review of diclofenac biodegradation by microorganisms and immobilized systems was presented [12]. It showed that immobilized fungal and bacterial systems can achieve complete degradation of diclofenac by a metabolic relay that avoids the accumulation of toxic intermediates.

Process intensification can be an effective way to improve the efficiency of microbial biocatalysis. For example, in the water-organic solvent two-phase system, hydrophobic *Mycolicibacterium* can act as emulsifiers to stabilize the Pickering emulsion. This can enhance the interfacial biotransformation of phytosterols by increasing the substrate concentration to cause phase inversion and overcome substrate inhibition [13]. However, this strategy may not work for all biocatalytic reactions. In the same water-organic solvent two-phase system, the biodegradation of atrazine was inhibited by the organic solvent [14]. This could be because the atrazine-degrading bacterium is hydrophilic and the organic solvent limits substrate transfer between oil and water. The biodegradation process of pollutants in natural environments is also influenced by various environmental factors. Bioplastics are a potential alternative to petroleum-based polymers that can be degraded in compost, soil, and aquatic environments [15]. The review focused on the intensification of bioplastic biodegradation through composting technology.

To conclude, this Special Issue on "Microbial Biocatalysis" provides a comprehensive overview of the recent developments in catalyst discovery, its modification, and process intensification for whole-cell catalysis in the fermentation, biotransformation, or biodegradation processes. We hope that this collection of key studies will inspire further research in this field.

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