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A Glance at the Engineering Aspects in Microbial Production of Organic Acids

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ABSTRACT

Organic acids, an essential part of life and with a growing market demand is required across diverse industries apart from biomedical research. Organic acid production by microbial fermentation gains importance over natural and chemical methods of production. However, it is of utmost importance to increase the cost-effectiveness and adapt metabolic engineering and process optimization apart from other parameters. The present work studies in brief the importance of metabolic engineering and process parameters that will help to achieve an increased organic acid production for a sustainable growing environment.

Introduction

Organic acids are the acids derived from organic compounds that are partially dissociable in water, whereas mineral acids (also called as strong acids) dissociate wholly in water. Industrial organic acids with example of citric acid, lactic acid are used across diverse industries, and produced by microbial fermentation process. They can be also produced by chemical synthesis and natural method, however microbial production is environment friendly, sustainable, needs low-cost substrate, and microbial based production constitutes bulk of the large-scale industrial produces (Ghai *et al.,* 2023). The global market for fermentation products has an increasing growth trend, and in 2009 the market value was USD 17.8 billion which rose from USD 14.1 billion in 2004.

Herein, organic acids represent the third largest category amongst the products, with an expected market value of USD 36.86 billion in 2026 (Soccol *et al.,* 2008; Liu *et al.,* 2023). However, it is of utmost importance to increase the cost-benefit ratio and adapt metabolic engineering and process optimization apart from other parameters. The present work studies in brief the importance of metabolic engineering and process parameters that will help to achieve an increased organic acid production for a sustainable developmental process. Novelty of this process lies in engineering approaches to enhance cost-effectiveness.

Microbial metabolism in production of organic acids

Organic acids derived from microbial sources are the products, by-products or co-products of different metabolic pathways (Lorenzo *et al.,* 2022). A combination choice of raw material and micro-organism acts as the key factor in boost up of large-scale productivity (Vishnu *et al.,* 2020). However, microbes must tolerate extreme conditions of pH, organic acids, and presence of lignocellulose inhibitors (Tran and Zhao, 2021). Solid state fermentation is used widely due to the choice of renewable feedstock as source and low- cost economics as well as availability (Vishnu *et al.,* 2020).

Engineering approaches

Metabolic engineering approach is the choice-able platform to enhance organic acid production. Integration of gene editing, pathway reconstruction, dynamic regulation, and choice based microbial platform has accelerated organic acid production exemplarily. Researchers have also used overexpression strategies, knock-out technology, enhanced carbon dioxide fixation to increase production efficiency (Wang *et al.,* 2025). Knowledge of strain genetics, physiology, strain engineering tools, high throughput screening techniques and other advanced technologies has helped to increase the strain performance and increase yield of organic acid production (Liu *et al.,* 2023).

In depth knowledge of strain genetics, physiology, strain engineering tools, synthetic biology, methods in metabolic engineering, omics-technology tools, and high throughput screening methods helps to understand on ways to improve production efficiency. And they are further applied to modify the cellular reaction networks of potential microbial hosts and improve the strain performance, which facilitated the commercialization of consumable organic acids.

Microbial engineering

Micro-organisms have been used as bio-refineries for short-chain organic acid production. The identified reason for low productivity of organic acids is the underlying regulatory metabolic machinery in carbon metabolism. To improve upon the situation, prime strategies adapted were pathway engineering to reduce by product formation and substrate utilization, strain optimization, as well as process optimization. Targets used also included use of less expensive substrate (Yadav *et al.,* 2022).

Strategies primarily focus on improving the catalytic enzymatic efficiency, enhanced rate of substrate conversion, improved metabolic flux to promote product biosynthesis, and increased substrate spectrum (Singh *et al.,* 2025; Li *et al.,* 2021).

Fermentation metabolism and kinetics

In organic acid production, the process parameters in fermentation like pH, nutrients, dO_2, products of microbial metabolism affect the microbial physiology and metabolism (González-Figueredo, 2019). In an experiment with production and consumption for malic acid production, production was seen to be dependent upon the process parameters (Ramon-Portugal, 1999). Additionally, large-scale fermentative production of organic acids with microbial strain modification has become a choice over the regular chemical-based method of production (Liu *et al.,* 2023). Derman *et al.,* (2024) observed in a comparative study with different carbon source combination that simultaneous use of two different carbon sources, glycerol and lactic acid in fermentative production of propionic acid speeded up the fermentation by almost fifty percent. Furthermore, carbon source concentration influences upon the rate of fermentation, with an increase in osmotic pressure followed by reduced μmax. Additionally, addition of vitamin combinations also influenced upon the rate of fermentation (Derman *et al.,* 2024). Mathematical modelling and predictive approaches are also been used to optimize the fermentation conditions (Biase *et al.,* 2022). Production scale up can be based on artificial intelligence and computational fluid dynamics apart from mathematical modelling parameters. Scalability of the process also helps in sampling and application research (Fraunhofer, 2025).

Utility of organic acids

Organic acids, widely found in nature has been found to be essential not only for biological systems but also for industry including food industry. These are highly important in metabolism and physiological functions apart from bioprocess optimization (Li *et al.,* 2020). Organic acid metabolic disorder lead also to inherited metabolic disorders.

Organic acids are also used in biomedical research to study heterogenous nature of gut microflora and their impact on nutrition and metabolism (Dibner and Buttin, 2002). Herein, microorganisms play prime role in conversion of renewable feedstocks in production of organic acids. However, it is a necessity to emphasize on engineering design for an increased cost-benefit ratio and achieve sustainability as well as adapt advanced technology for industrial production of organic acids (Wang *et al.,* 2025).

Organic acid, an essential part for life and living of human-beings constitutes a growing industrial demand. Though these could be produced by chemical and natural process, but preferred opted way is microbial production process. However, challenges remain in utilizing non-food biomass sources to meet sustainability goals. Thus, it is essential to look at the process parameters, utilize the engineering approaches to increase the cost effectiveness of organic acid production.

Author Contributions

Susinjan Bhattacharya: Investigation, formal analysis, writing—original draft.

Data Availability

No statistically presentable data has been generated.

Declarations

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