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SUSTAINABLE EARTH RESOURCES ENGINEERING

Sustainable bioethanol production by solid-state fermentation: a systematic review

Nur Fathin Ruslan[1] · Noormazlinah Ahmad[1] · Azlan Abas[2] · Antonio Sanfilippo[3] · Khaled Mahmoud[3] · Mimi Sakinah Abdul Munaim[1] · Abdurahman Hamid Nour[1]

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Abstract
The escalation of the global population has accelerated the demand for sustainable energy sources such as bioethanol. Traditionally, bioethanol was obtained by the fermentation of sugar from agricultural crops and grains. However, this technique creates serious threats on the global food supplies, thus hindering the commercial production of bioethanol. Therefore, there is a need to develop new technologies and low-cost raw materials in order to ensure that bioethanol is economically comparable to the first generation of bioethanol. Solid-state fermentation (SSF) has been in the limelight within the scientific community because of its efficiency, cost-effectiveness, and promising technology to produce bioethanol. SSF involves the cultivation of microorganisms on a solid substrate in the absence of free-flowing water, which eliminates the need for sugar extraction and reduces wastewater production. This systematic review provides an overview of the applications of SSF in bioethanol production while presenting recent studies and advancements of this technology for producing sustainable and cost-effective bioethanol.

Keywords Bioethanol · Solid-state fermentation · Systematic literature review · Microorganism · Lignocellulosic wastes · *Saccharomyces cerevisiae*

Introduction

In contemporary times, the demand for energy sources has risen tremendously due to rapid economic development and the growing world population. As estimated, 85% of current energy demands are fulfilled by unsustainable fossil fuels, which are currently depleted at an alarming level and brought harmful impacts such as environmental pollution and global warming caused by uncontrolled carbon dioxide emissions (Kiran et al. 2014; Liew et al. 2014). This scenario has led to the urge to discover alternative energy sources that are renewable, sustainable, and eco-friendly (Demirbas 2009). Renewable energy, such as biofuels, not only acts as an alternative to depleting petroleum sources, but it also hinders high carbon dioxide emissions from fossil fuel combustion (Zhao et al. 2015).

Bioethanol, one of the emerging proposed biofuels, displays great potential for substituting fossil fuel dependence and is currently applied in the various energy sectors, especially in the transportation sector (Zhang 2023). The incorporation of bioethanol in diesel engines enhances the complete burning of diesel due to the presence of oxygen and produces a cleaner by-product (Dibazar et al. 2023). In 2023, total production of bioethanol recorded about 29,590 million gallons, with the USA as a major contributor (58%), followed by Brazil (28%), the EU (5%), and India (5%). Figure 1 depicts the projected global bioethanol production and consumption for 2024 (FAO & OECD, 2015).

Biofuels that are produced from renewable substrates, which include food crops such as corn, sugarcane, and sweet sorghum, are known as first-generation biofuels, and

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✉ Nur Fathin Ruslan
nurfathin2112@gmail.com

[1] Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuhraya Tun Razak, 26300 Kuantan, Pahang, Malaysia

[2] Centre for Research in Development, Social and Environment (SEEDS), Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, UKM, 43600 Bangi, Selangor, Malaysia

[3] Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University–Qatar Foundation, Doha, Qatar

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