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Microbial Electrochemical Technology: An Emerging Technique for Household Food Waste Valorisation

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Abstract

Nutrition is a fundamental element for sustaining and preserving life. As our lifestyles evolve and urbanization accelerates across the world, there is a growing accumulation of food waste origination from diverse industrial, agricultural, and household outlets. Kitchen waste, a form of human-generated organic waste, encompasses items such as fruits, vegetables, leftover cooked meals, meat, as well as used fats, oils, and greases. The conventional methods of landfill disposal and incineration carry the potential to pose significant environmental and human health risks, as they result in the emission of harmful gases and chemicals into the surroundings. The traditional approaches of land-filling and incineration could cause severe environmental and human health hazards by generating toxic gases and chemicals into the environment. Thus, employing the biological technologies for the treatment of such waste offers a sustainable way for valorization. Microbial electrochemical technology (MET) is an emerging technology which uses unique group of microbes called electrochemically active bacteria which includes *Geobacter sulfurreducens*, *Shewanella oneidensis*, *Pseudomonas sp.*, exhibits extracellular electron transfer via different mechanisms like, formation of nanowires, by forming conducive layer at the cell wall, by naturally secreted mediators and by electron redox shuttles from biodegradable organic substances and explore the interaction between microbes and surface of electrodes to produce different value added products *viz*., bioelectricity, bio-hydrogen, biogas, algal lipids, value added chemicals *etc.*

Introduction

Food is an essential component for the survival and existence of life. Every organism on earth rely on food sources at various trophic levels and consume them in diverse forms. A significant issue arises when this vital resource is mishandled or mismanaged at any point of food life cycle, resulting in severe social, economic, and environmental repercussions. As

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global lifestyles evolve and urbanization of global population accelerates, the production of food waste from multiple origins, including industrial, agricultural, and household sectors also increases. This results in great concern as this not only represent a loss of valuable resources, but also the disposal of this waste in the environment raises significant environmental consequences. Food waste (FW) refers to the organic waste resulting from leftover or pre-cooked food, which is biodegradable in nature (Tsang *et al.*, 2019). According to Food and Agriculture Organisation (FAO), FW is the "food losses of quality and quantity through the process of the supply chain taking place at production, post-harvest, and processing stages". As per FAO's data, 1.3 billion tonnes of food is wasted annually on a global scale. According to UN Report, 2019, Out of the total waste generated globally, Asia contributes to highest FW 278 million tonnes. India wasted 68 million tonnes of food in 2019 (Sharma *et al*., 2020).

Kitchen waste (KW) is a type of human-generated organic waste typically originating from public catering establishments, restaurants, households, school and factory cafeterias, and various other sources (Liu *et al*., 2019). KW includes items such as leftover cooked food wastes, vegetables, fruits, used fat, meat, oil and greases. Chemically, KW consist of carbohydrate polymers (includes celllose, hemicellulose, pectin, and starch), proteins, lignin, fats, organic acids, inorganic salts and other components. This waste is generated throughout various stages of food processing, encompassing handling, preparation, production, storage, transportation, and consumption. Conventional methods for managing kitchen waste, such as landfill disposal, composting, incineration, and the direct or indirect discharge of wastewater into the environment, have adverse effects on both ecosystems and human health (Chen *et al.*, 2019). Kitchen waste is composed of biodegradable biomass with higher moisture content and a rich nutrient composition that encourages the rapid growth of pathogenic microorganisms, leading to decay and proliferation of flies and mosquitoes in a relatively short timeframe. These processes result in the emission of toxic substances, greenhouse gases, substantial leachate entering water bodies, and the release of unpleasant odors, including ammonia and hydrothion. The ammonia produced during kitchen waste decomposition has a potent and pungent odor, which can lead to respiratory tract irritation, eye and skin redness, while hydrothion is highly toxic to humans (Sharma *et al*., 2020)

FW contains a large amount of biodegradable organics that can be converted to clean energy, which can potentially minimize the utilization of fossil fuels. Conventional biowaste valorization technologies, such as anaerobic digestion and composting, have been adopted for FW management for recovering useful biogas and compost. However, they are often limited by high capital and operation costs, low recovery efficiency, slow process kinetics, and system instability. On the other hand, microbial electrochemical technologies (METs) have been highly promising for efficiently harvesting bioenergy and high value-added products from FW (Chung *et al*., 2021).

Microbial electrochemical technology (MET) for food waste valorisation

Microbial electrochemical technology is a promising technology that integrates microbial system, electrochemistry and material science to achieve effective conversion of chemical energy stored in organic materials into other forms of energy like electrical energy, bio-hydrogen, biogas, organic acids *etc*. MES exploits the biocatalytic activity of living microbes to harvest electrons from the biodegradable organic substances and therefore explore the interaction between living microbial cells (electron donor) and surface of electrodes (electron acceptor) (Hassan *et al.,* 2021).

Exoelectrogens are microorganisms, primarily bacteria which are capable of producing electrical energy through the oxidation of organic substances and then transfer electrons to an external electron acceptor, hence the term 'Exo'. Typically, these exoelectrogens can be isolated from anerobic sludge from industrial or domestic wastewater treatment plants, anerobic sediments, primary effluents from industrial or municipal wastes, and even from agricultural soils. These can be isolated either as pure cultures or mixed cultures, and can be further harnessed for use in Microbial Electrochemical Technologies (MET). They exhibit the ability to generate electrical energy from a variety of sources, including organic or chemical substances such as simple carbohydrates like glucose, as well as waste materials from municipal, domestic, and industrial wastewater treatment plants (Guang *et al*., 2020).

These exoelectrogens include

A. Nitrate-reducing bacteria (denitrifying bacteria) such as *Pseudomonas* and *Ochrobactrum*
B. Dissimilatory metal-reducing bacteria, such as *Geobacter, Shewanella, Geopsychrobacter* and *Geothrix*
C. Sulfate-reducing bacteria including *Desulfuromonas* and *Desulfobulbus*

Working Principle of Met

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Microorganisms gain energy by respiration, catalyze redox reactions or breakdown reduced organic/inorganic compounds. Electrons are transferred from a donor (reduced substrate) to a terminal electron acceptor, making the donor oxidized and acceptor reduced. The energy released by breakdown of reduced substrate will be captured by nicotinamide adenine dinucleotide (NAD), flavin adenine dinucleotide (FAD), *etc*. Bacteria can extracellularly transport electrons by outer membrane cytochromes, nanowires and endogenous mediators, while algae and yeast can transport electrons extracellularly by direct and mediated electron transport. When NAD and FAD transfer electrons to final electron acceptors such as oxygen and nitrates, electron transport chain (ETC) conserves a portion of the energy while transferring electrons to the final electron acceptor. These electrons can be harvested by using bioelectrochemical systems and can be conserved in several forms like bioelectricity, biohydrogen, *etc*. Electron transfer from reduced substrate to final electron acceptor will be used to transport protons across the inner membrane, thus generating an electrochemical proton gradient which is finally used for generating energy (Hassan *et al.*, 2021).The Microbial electrochemical systems are of different types, they are microbial fuel cells, microbial electrocatalysis cell, microbial desalination cell, or the combination of these systems. *etc*. Depending on the target value-added products from FW, METs can be either utilized as a standalone or a part of a hybrid process of multiple systems. However, the majority of studies have primarily focused on applying microbial electrochemical systems as a standalone process (Chung *et al*., 2021). These can be used for the production of different value added products *viz*., bioelectricity, bio-hydrogen, biogas, algal lipids, value added chemicals *etc*. Therefore, MET provides a novel alternative approach with multifaceted application for household food waste valorization and proved to be a sustainable and eco-friendly food waste management system.

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