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Influence and strategies for enhanced biohydrogen production from food waste

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ABSTRACT

The growing of food waste generation is gradually becoming a global problem due to the improper management of it. According to the Food and Agriculture Organization (FAO), United Nation, more than 1.3 million tonnes of food is being wasted. Food waste and food processing waste are abundant - which are rich in organic acids and nutrients. These acids and nutrients can be utilized for attractive and efficient generation of renewable and sustainable fuels such as biohydrogen through fermentation process. Many investigations have revealed a significant biohydrogen generation using food wastes from restaurant, dining hall and food processing industries. During the hydrogen generation through fermentation, several parameters influence the yield of hydrogen. Some of them are method of pre-treatment, feed composition, fermentation temperature, culture and substrate, solution pH, etc. Also, the presence of inert intermediates produced during the reaction in fermentation process reduces the process efficiency. Few studies have shown that the use of nanoparticles in fermentation process along with the application of short & cyclic ultrasound is beneficial to increase the process efficiency. The augmentation in ultrasound-assisted process is due to the physical and chemical effects of ultrasound in the medium through the phenomenon of cavitation. During the transient collapse of cavitation bubbles, several reactive species are produced which further participate in the thermochemical and biochemical reactions. Thus, enhances the rate of reaction by annihilation the complex sugars in food wastes. Additionally, the cavitational effect helps to reduce the growth of hydrogen inhibiting microorganism in the feed. This review demonstrates the potentiality of food waste for production of biohydrogen through fermentation process including a brief overview of process parameters that affect the fermentation process. Additionally, an overview of integrated fermentative process coupled with nanoparticles and ultrasound is also discussed for enhanced biohydrogen generation from food waste.

1. Introduction

The depletion of fossil fuels and the apparent pollution problem due to the emission of greenhouse gases made a significant impact on climate change. To avoid such tragedy, alternative/renewable energy attracted the researchers' attention for production of clean fuel such as biohydrogen and biodiesel through thermal or biochemical conversion [1–4]. Interestingly, biological technique is more realistic for hydrogen production since it uses feedstock of sustainable and renewable wastes (such as agricultural waste, food waste etc.) without greenhouse gas emissions or environmental pollution. Also, the biological method has been found to be inexpensive and effective process for hydrogen production due to its applicability at the ambient temperature and pressure [5]. These practical advances have attracted the researchers for biohydrogen production. The biomass stands out to be the major feedstock for biohydrogen production and the availability of this feedstock may be a major source of energy in the near future. The transformation of biomass into hydrogen occurs through the following mechanism as shown in Eq. (1).

$$\text{Biomass} + O_2 \rightarrow CO + H_2 + CO_2 + \text{Energy} \tag{1}$$

In biochemical conversion of biomass using micro-organisms, the hydrogen-producing enzymes (*viz. hydrogenase* and *nitrogenase*) are synthesized to produce hydrogen from complex molecules. The mixed cultures of microbes such as algae and bacteria are reported to be beneficial for high yield of hydrogen production from carbohydrates and starch [6]. Among the biomasses, food waste constitutes approximately one-third of the total global food consumption which is discharged directly into the landfills. The food wastes are rich in proteins, lipids, carbohydrates, metal ions, nitrogen, complex polysaccharides, and phosphate. These food wastes can be utilized as raw material for hydrogen production through fermentation process and to increase the

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Notations

1,3-PDO	1,3-Propanediol
1,3 PG	1,3-bisphosphoglycerate
2PG	2-phosphoglycerate
3-HPA	3-Hydroxypropionaldehyde
3PG	3-phosphoglycerate
AC	Acetate
ACCOA	AcetylcoenzymeA
BA	Butyrate
DHAP	Dihydroxyacetone phosphate
E4P	Erythrose4–phosphate
F6P	Fructose6-phosphate
Fd	Ferredoxin
FdH2	ReducedFerredoxin
FW	Food waste
G6P	Glucose6-phosphate
GAP	Glyceraldehyde3-phosphate
H_2	Hydrogen
KG	α-Ketoglutarate
LAC	Lactate
NADH	Nicotinamide adenine dinucleotide
NADPH	Nicotinamide adenine dinucleotide phosphate
OAA	Oxaloacetate
PEP	Phosphoenolpyruvate
PYR	Pyruvate
R5P	Ribose5-phosphate
Ru5P	Ribulose5-phosphate
S7P	Sedoheptulose7-phosphate
SUCC	Succinate
X5P	Xylulose5-phosphate

hydrogen economy [7,8]. Fermentation process is very effective for enhancing the generation of hydrogen energy by 2.75 fold (122 kJ/g) compared to the conventional methods from fossil fuels [9]. In fermentation methods, the fermentable sugars rich with organic acids are extracted from the food waste and used for generation of biohydrogen by breaking the sugar complexes. However, the organic acids-based biohydrogen process also has some limitations; for example, (i) it requires energy for separation of organic acid, (ii) maintenance of inorganic anions which are responsible for variation of solution pH at high concentration leading to low biohydrogen production, and (iii) the cost for liquefaction to produce soluble fermentable sugars [10]. The other challenges in the fermentative process include low hydrogen production efficiency from biomass and the stability of the synthesized hydrogen [11].

In fermentation process, the feedstock must be hydrolyzed for converting it into suitable substrates. The hydrolysis process is usually performed using chemicals, enzymes and hydrothermal method [12–14]. Among these, the hydrothermal method is considered to be an environmental friendly technique as it requires only water. While in enzymatic or chemical hydrolysis, the selection of enzymes or chemicals for the substrates is very difficult. Further, these processes also require optimization technique to estimate the process parameters and their appropriate combination. Generally, the feedstock is maintained at a moderate temperature (200 – 260 °C) and ambient pressure to make the substrate pathogens free which inhibits the biohydrogen production by affecting the intracellular redox balance of the feedstock and reduces the growth of hydrogen producing microbes [15]. Therefore, due to the instability of complex organic substrates, the efficacy of the fermentation process is relatively less even the food wastes are rich in carbohydrate, protein and lipid substrates [16].

Moreover, several studies reported that the pre-treatment of the feedstock and addition of catalysts increases the formation of more fermentable sugars which are easily accessible by the microorganisms to produce hydrogen [17–20]. Recent studies have revealed that biohydrogen production can be enhanced through proper technology development and further improvement in the processes such as fermentation coupled with ultrasound irradiation technique and fermentation in the presence of nanocatalyst [21,22]. The nanocatalysts are found to be very useful for enhancing the rate of reaction by producing radicals which attack the complex compounds. One of the major advantages of nanocatalyst is that it possesses high surface area and provides a large number of available active sites where proton formation occurs; thus accelerates the fermentation process [23]. The hydrogen production can be increased 1.2–1.5 fold with the addition of hematite and Ni-oxide nanoparticles during the fermentation process [24]. Another study has shown that the metal-free catalysts like graphene oxide (GO) with high porosity and surface area can increase the biohydrogen production by increasing the reaction kinetics and the fermentative activity of *ferredoxin oxidoreductase* enzyme [25]. While the metal-doped catalysts with GO act as a promoter and increase the enzymatic activity in wastewater fermentation process [26]. The doping of metal components on the organic catalysts substantially increases the fermentative hydrogen production due to high solubility and increases the bioactivity of enzymes which are responsible for hydrogen production

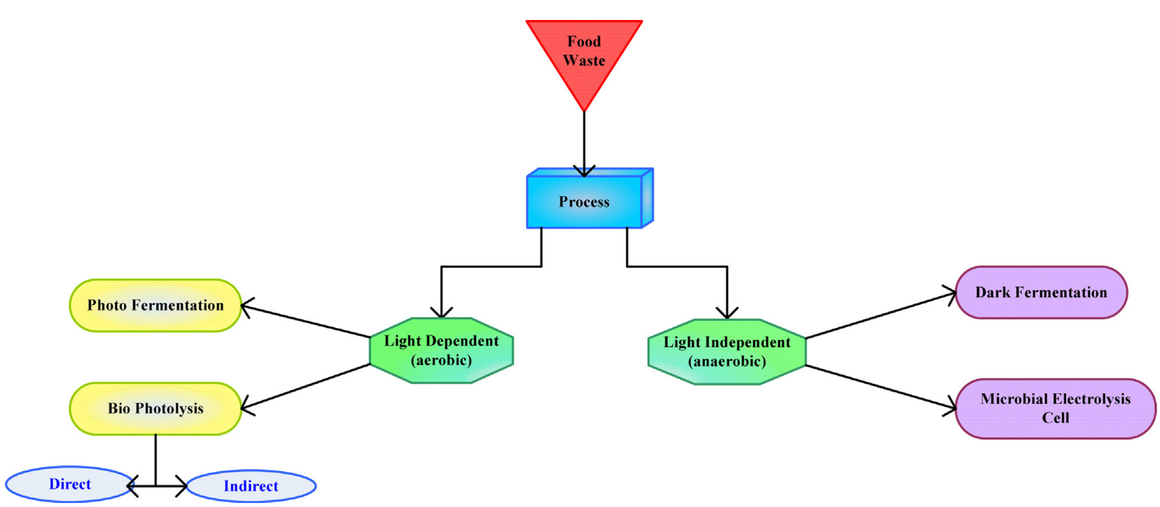

Fig. 1. Classification of fermentation process for biohydrogen production from food waste.