Biohydrogen Production Using Fruit Waste as The Potential Substrate: A Sustainable Approach

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ABSTRACT

This review investigates the viability of utilising fruit wastes as an efficient substrate for anaerobic fermentation-based biohydrogen production in a sustainable manner. Under anaerobic conditions, microbial fermentation of organic matter is presently the most prevalent method for biohydrogen production. The review examined the potential of fruit waste for biohydrogen production pathway, emphasising the need for suitable pretreatments to improve the efficiency of complex organic waste. Finally, the benefits, and drawbacks of the biohydrogen production process utilising fruit wastes as a substrate have been evaluated.

Keywords: Fruit waste, pretreatment, biohydrogen, dark fermentation, biohydrogen pathways.

1. INTRODUCTION

Constraints regarding the environment and economy deem the continuous and rapid consumption of fossil fuels impracticable on account of their contribution to global warming issues [1]. To meet global needs, the search for alternative energy sources is necessary because fossil fuels are increasing pollution and energy demand [2].

Biohydrogen, which is obtained from organic matter like fruit waste, exhibits promise as a viable substitute for carbon-intensive fuels [3]. Hydrogen exhibits a significantly greater energy yield (122 kJ/kg of biomass) in comparison to fossil fuels. Dark fermentation is becoming increasingly popular for producing hydrogen as a result of its lower energy requirement, higher yield, and higher production rate [4].

The production of biohydrogen through fermentation using fruit waste has been documented in numerous investigations [5]–[9]. The fruit waste was chosen for biohydrogen production because it meets the main selection criteria, which are that it is cheap and easy to get, has a lot of carbohydrates, and breaks down quickly [8]. Additionally, many different pretreatment methods for source materials are being used on fruit waste right now to speed up the degradation process by a large amount [10].

The purpose of this article is to provide an overview of the hydrogen production pathway. Additionally, the pretreatment procedure for biohydrogen production from fruit waste as substrate is assessed in this review. In addition, the benefits and drawbacks of using fruit refuse as a raw material in the production of hydrogen are evaluated.

2. GENERAL APPROACHES FOR DARK FERMENTATIVE BIOHYDROGEN PRODUCTION

Anaerobic microorganisms that produce hydrogen turn organic and inorganic substances into biohydrogen when there is no light [3]. This is called dark fermentation. Dark fermentation is a highly promising process due to its distinctive characteristics, as stated by Słupek *et al.* (2019) [11]: a high rate of production and the capacity to utilise a variety of substrates, including organic wastes.

Throughout the biohydrogen production process, microorganisms, primarily bacteria, perform a crucial function by utilising various types of organic wastes in metabolic reactions to generate biohydrogen as cellular energy [1]. The excess cellular reductant is eliminated through fermentation via the formation of reduced metabolic byproducts, including acids and alcohol [12]. Carbohydrate-rich organic and inorganic substrates are crucial in the production of biohydrogen via dark fermentation. Regardless, carbohydrates, including glucose, are among the most preferred carbon sources during fermentation [13]. The conversion of glucose produces various microbial products such as hydrogen, carbon dioxide, volatile fatty acids, and alcohol [3].

Theoretically, acidogenic bacteria were primarily responsible for facilitating the formation of volatile fatty acids (VFAs), specifically acetic and butyric acids [14]. Table 1 shows the dark fermentation pathways for acetic and butyric acids [15].

Table 1 The dark fermentation pathways for acetic and butyric production

VFA pathways	Carbon Mass Balance
Acetic acid	$C_6H_{12}O_6 + 2H_2O \rightarrow 4H_2 + 2CO_2 + 2C_2H_4O_2$
Butyric acid	$C_6H_{12}O_6 \rightarrow 2H_2 + 2CO_2 + C_48O_2$

3. PRETREATMENT OF FRUIT WASTE AS THE SOURCE FOR BIOHYDROGEN PRODUCTION

Fruit waste refers to non-edible fruit components that are disposed of throughout the various phases of fruit processing, transportation, collection, and handling [3]. Despite the fact that fruit waste is typically discarded, it can serve as a feedstock for renewable energy sources and value-added products, including hydrogen gas. Fruit waste has emerged as a potentially viable carbon source for the biohydrogen production substrate, overtaking glucose as the primary carbon source. Fruit waste is rich in protein and sugar, both of which are able to undergo biological conversion into hydrogen gas [7]. Figure 1 shows the biohydrogen production using fruit waste via dark fermentation.

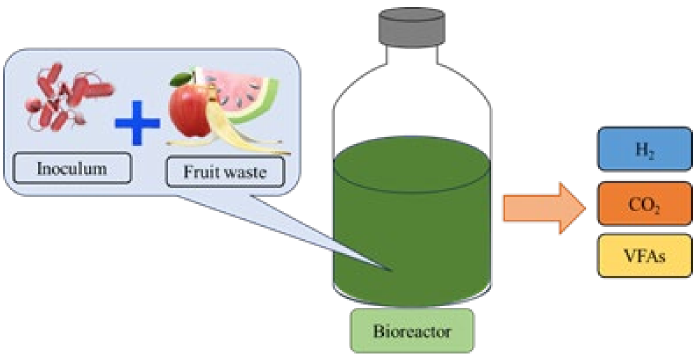

Figure 1. Dark fermentation process for biohydrogen production.

However, due to the complexity of the structure, the biodegradable substrate is less accessible in some fruit waste, which thereby leads to low biohydrogen yield [16]. In addition to increasing the production of fermentable sugars that are readily assimilated by hydrogen-producing bacteria for biohydrogen production, pretreatment is required to degrade lignin, hemicellulose, and cellulose crystallinity, as well as to facilitate the conversion of fruit waste into soluble sugar and increase the production of fermentable sugars. [17], [18]

Blending or grinding fruit waste is a common method used to generate suspension-soluble sugar for biohydrogen production. Martínez-Mendoza *et al*. (2022) [6] used this pretreatment method and produced 73 mL of H_2/g VS of hydrogen yield (HY) and 535.7 mL/L/h hydrogen production rate (HPR). In addition, Dwivedi *et al*. (2020) [7] used a similar blending method with an additional sieving process to separate the soluble sugar from the solid residue and produced HY of 125 mL/g COD. This process will enhance sugar consumption efficiency through mixed culture for hydrogen production.

Combination pretreatment can also enhance the hydrogen yield. Thermal pretreatment is one of the suitable processes to increase the soluble sugar concentration in suspension fruit waste. Heating the fruit waste after the blending process can deactivate non-hydrogen-producing bacteria present in the fruit waste that reduce biohydrogen production during dark fermentation. Weronika et al. (2020) had conducted the experiment using combination pretreatment blending and heating (80 °C) process of fruit waste. The researchers found that hydrogen yield was 52.1 mL/g VS. In addition, Mahato *et al*. (2020) had found that by implementing combination pretreatment of fruit waste produced 2.43 mol/mol hexose for the HY. Meanwhile, Pascualone *et al*. (2019) [8] conducted an experiment based on a dark fermentation of fruit waste with vermicompost mixed culture and studied the impact of pretreatment without and with heating (63 ^{o}C) on fruit waste. The result shows that untreated fruit waste produced low HY (86.6 mL/g VS), whereas thermal pretreatment increased the HY (129.2 mL/g VS). To conclude, a combination of blending and heating processes becomes a preferable pretreatment to enhance biohydrogen production. Table 2 shows the summary of the pretreatment types used in biohydrogen production.

Table 2 The summarise of pretreatment type used in biohydrogen production

Substrate with pretreatment	HPR and HY	Reference
Fruit and vegetable waste + grinding and sieving	4.5 mL/h (HPR) 125 mL/g COD (HY)	[7]
Fruit and vegetable waste + blending	535.7 mL/L/h (HPR) 73 mL H_2 /g VS (HY)	[6]
Fruit and vegetable waste + grinding and heating	n/a (HPR) 52.1 mL/g VS (HY)	[5]
Fruit waste + blending and heating	105.25 mL/L/h (HPR) 2.43 mol/mol hexose (HY)	[9]
Fruit and vegetable waste + blending, and heating	146.5 mL/L/d (HPR) 129.2 mL/g VS (HY)	[8]

4. ADVANTAGES AND LIMITATIONS

Dark fermentation is one of the most promising procedures to produce biohydrogen. Biohydrogen can be classified as clean energy and helpful approaches to prevent the greenhouse effect (water vapour as the byproduct) [8]. In addition, the utilisation of fruit waste, in dark fermentation biohydrogen production can be applied as a strong alternative to energy biofuels that are 2.75 times higher than fossil fuels with a low capital cost and a sustainable source [1]. Pretreatment of fruit waste via blending process reduce the particle size, homogenise the fruit waste slurry [6]. In addition, heating process gave a few positive impacts towards biohydrogen production which are enhances the anaerobic digestion process and induces fruit waste liquification by converting complex molecular carbohydrate onto simple soluble sugar [2].

Nonetheless, there are some constraints that prevent the conversion of fruit waste into biohydrogen gas. Identifying a proper pretreatment, in addition to the substrate, is a crucial concern [19]. To enable optimal product recovery, fruit waste particles must be reduced in size, which can be accomplished through pretreatment. Hence, a definitive effective particle size for higher biohydrogen production is currently unclear and thus needs further investigation. Furthermore, in order to obtain a high yield of biohydrogen gas from fruit waste, an adequate deployment of prospective bacteria mixed culture, as well as operational optimisation, should be improved [18].

5. CONCLUSION

This review discussed the potential of fruit waste as an effective and low-cost substrate for improved biohydrogen production. Fruit waste is being produced in daily life in a significant amount, which can be used for biohydrogen production by bacteria. The biohydrogen pathway was predominant acetic acid pathway or butyric acid pathway. Moreover, the solubilization of fruit waste through various pretreatment methods before biohydrogen production is an innovative approach. The choice of pretreatment method is usually based on the composition of the fruit waste. In conclusion, the existing pretreatment methods can be restructured to increase their overall performance, leading to higher production rates of biohydrogen.

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