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Integrated Pretreatment Strategies for Enhanced Carbohydrate Release and Solubility in Palm Oil Mill Effluent

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KEYWORDS

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Pretreatment
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Substrate
Dark fermentation

ABSTRACT

Palm oil mill effluent (POME) is a high-strength wastewater rich in organic matter and carbohydrates, making it a potential substrate for biohydrogen production. However, its complex structure requires pretreatment to improve carbohydrate solubility and availability. This study examined ultrasonic, thermal, alkaline, acidic, and combined pretreatments to enhance carbohydrate release and reduce inhibitory compounds. Results showed that heat shock achieved the highest total carbohydrate concentration (5.25 g/L), followed by autoclave (5.24 g/L), indicating effective hydrolysis of complex organics. The lowest volatile suspended solids (VSS) were observed in alkali + autoclave and acid + autoclave pretreatments, confirming better solid breakdown. All treatments maintained slightly acidic pH, with alkali methods showing minor neutralization. Overall, heat shock was identified as the most effective and simple pretreatment for improving carbohydrate availability and POME quality as a feedstock for biohydrogen production.

1. INTRODUCTION

Palm oil mill effluent (POME) is a waste product produced in large amounts during palm oil processing. It contains high levels of organic matter and carbohydrates such as glucose, lactose, and sucrose, making it a good source for hydrogen production [1]. However, POME needs pretreatment to make carbohydrates more soluble and easier for microorganisms to use [2]. Different pretreatment methods such as biological, chemical, and physical can be applied to improve hydrogen production efficiency. In this study, physical and chemical pretreatments were chosen because they are faster and more effective in breaking down complex organic compounds compared to biological pretreatment [1].

Physical pretreatment is simple and does not require chemicals, enzymes, or fungi [2]. It includes thermal methods such as heat shock and autoclaving, as well as ultrasonic methods [3]. Thermal pretreatment helps break complex carbohydrates into simpler forms for easier microbial use. For example, heating POME at 70°C produced the highest amount of reducing sugar and reduced hydrogen-consuming bacteria [4]. Ultrasonication was also found to increase soluble carbohydrates by 16.10% by breaking down compounds like cellulose and lignin , while autoclaving, which uses high temperature and pressure, also improves the solubility of organic compounds autoclaving at 90°C for 90 minutes increased and sterilized POME .

Chemical pretreatment involves the use of alkali or acid to break down the cell wall structure in POME. Sodium hydroxide (NaOH) is an effective alkaline agent that increased soluble organic mixture by 39.8% in activated sludge. Acid pretreatment, on the other hand, uses strong acids such as sulfuric or hydrochloric acid to convert complex carbohydrates into simple sugars. Sulfuric acid is commonly used because it effectively breaks down lignocellulosic materials. Combined pretreatment methods, such as using both thermal and alkaline treatments, have also been shown to enhance digestibility, with one study reporting a 22.5% improvement in biogas production [2].

In this study, it was aimed to increase the POME carbohydrates, by applying different pretreatments to the substrate mixture [5]. For this study, the effects of ultrasonic, thermal, alkaline, and acidic pretreatments on the disintegration of the feedstock and the solubility of organic matter were investigated.

2. EXPERIMENTAL PROCEDURE

Raw POME was collected from a palm oil mill operated in Pulau Pinang, Malaysia and was subjected to a series of pretreatments to enhance carbohydrate release and control microbial activity. Untreated samples stored at 4 °C were used as the control. Heat shock treatments were performed using a water bath at 80 °C for 60 min to reduce non-spore-forming microbes [6]. Physical disruption was tested by a sonication process (20–40 kHz,20 min, 10 s on/off pulses),

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while complete sterilization was achieved by autoclaving at 121 °C for 20 min [7]. Combined chemical–thermal pretreatments included alkali (1% NaOH) followed by heat shock or autoclaving, as well as dilute acid (0.5% H_2SO_4) with heat shock or autoclaving to promote sugar release [8]. Sequential physical–thermal approaches were also evaluated, including sonication followed by heat shock, sonication followed by autoclaving, and a combined sonication-acid-autoclave treatment to maximize solubilization and microbial inactivation. The working volume for all pretreatments was set 50 mL. Table 1 shows the list of pretreatments used for enhancing concentration of carbohydrates from POME. After pretreatments, the samples were filtered to collect the suspension substrate for undergoing characterization such as total carbohydrate (TC) using phenol-sulfuric acid method [9]. while pH (4500–H^+), volatile suspended solid (VSS) (2540–E) were determined by American Public Health Association method [10]

Table 1 List of pretreatments of POME for enhanced carbohydrate concentration

Label	Pretreatment
A	Control
B	Heat Shock
C	Sonicator
D	Autoclave
E	Alkali + Heat Shock
F	Acid + Heat Shock
G	Alkali + Autoclave
H	Acid + Autoclave
I	Sonicator + Heat Shock
J	Sonicator + Autoclave
K	Sonicator + Acid + Autoclave

3. RESULTS AND DISCUSSION

Figure 1(a) shows the effect of different pretreatments on the dissolution of organic matter in the mixture of POME. All pretreatments increased the total carbohydrate (TC) concentration compared to the control (A) and the highest dissolved TC concentrations of the mixtures increased from 4.76 g/L and 5.25 g/L at heat shock (B) pretreatment. The second-best TC dissolution was obtained with the autoclave (D) pretreatment 5.24 g/L. This was followed by G, H, F, E, K, J, I, C pretreatments. The similar result with [5] where the heat shock or thermal pretreatment resulting increasing of TC concentration of food waste from 6.41 g/L to 6.45 g/L at temperature 70°C. This situation can be explained by the transformation of complex organic matter into more soluble simple sugar [5].

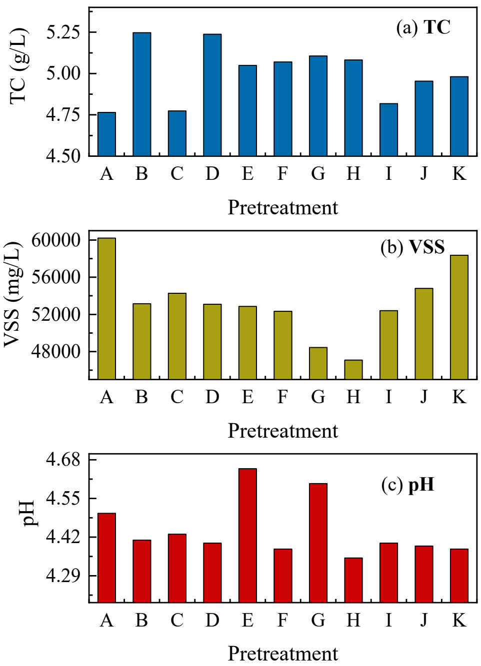

Figure 1. Effect of different pretreatments on the dissolution of POME.

The VSS values showed a larger difference among pretreatments in Figure 1(b). The VSS in POME after pretreatment J (54793 mg/L) and K(58360 mg/L) had highest VSS values, meaning that much of the solid organic matter remained undigested [11]. On the other hand, the lowest VSS values were found in the G and H samples, suggesting that these pretreatments were the most effective in breaking down or disintegrating solid particles into soluble form[8]. This reduction in VSS indicates that stronger or combined treatments can enhance organic matter solubilization in POME.

The pH values have remained within a narrow range for all samples, showing that in Figure 1(c) pretreatment did not cause major changes in acidity or alkalinity. However, POME samples with pretreatment E and F showed slightly higher pH values of 4.65 and 4.6, respectively, due to alkali-based pretreatment with NaOH that neutralized some acidic compounds. On the other hand, except for pretreatments E and F, the POME samples showed lower pH values (4.35–4.50), indicating that microbial aggregation was disrupted by protonation of the medium, which released acidic intermediates during organic breakdown [5].

4. CONCLUSION

This study revealed that different pretreatments and their parameters have a significant effect on the organic matter disintegration of feedstock consisting in POME. The thermal pretreatment which is heat shock was selected as the best pretreatment for POME to become potential feedstock where the carbohydrate value was 5.25 g/L. For the VSS biomass value was 53153.33 mg/L. Lastly, the pH value after heat shock pretreatment was 4.41.

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