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Effect of steam pretreatment on oil palm empty fruit bunch for the production of sugars

Saleha Shamsudin^{a,b}, Umi Kalsom Md Shah^{c,*}, Huzairi Zainudin^c, Suraini Abd-Aziz^c, Siti Mazlina Mustapa Kamal^b, Yoshihito Shirai^d, Mohd Ali Hassan^{b,c}

^a School of Bioprocess Engineering, Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia

^b Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Malaysia

^c Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, 43400 Serdang, Malaysia

^d Graduate School of Life Science and Systems Engineering, Kyushu Institute of Technology, Hibikino, Wakamatsu-ku, Kitakyushu-shi, 808-0196 Fukuoka, Japan

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ABSTRACT

Lignocellulose into fuel ethanol is the most feasible conversion route strategy in terms of sustainability. Oil palm empty fruit bunch (EFB) generated from palm oil production is a huge source of cellulosic material and represents a cheap renewable feedstock which awaits further commercial exploitation. The purpose of this study was to investigate the feasibility of using steam at 0.28 MPa and 140 °C generated from the palm oil mill boiler as a pretreatment to enhance the digestibility of EFB for sugars production. The effects of steam pretreatment or autohydrolysis on chemical composition changes, polysaccharide conversion, sugar production and morphology alterations of four different types of EFB namely fresh EFB (EFB1), sterilized EFB (EFB2), shredded EFB (EFB3) and ground EFB (EFB4) were evaluated. In this study, the effects of steam pretreatment showed major alterations in the morphology of EFB as observed under the scanning electron microscope. Steam pretreated EFB2 was found to have the highest total conversion of 30% to sugars with 209 g kg⁻¹ EFB. This production was 10.5 fold higher than for EFB1 and 1.6 fold and 1.7 fold higher than EFB3 and EFB4, respectively. The results suggested that pretreatment of EFB by autohydrolysis using steam from the mill boiler could be considered as being a suitable pretreatment process for the production of sugars. These sugars can be utilized as potential substrates for the production of various products such as fuel ethanol.

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1. Introduction

Currently more than 46 900 km² of oil palm are cultivated in Malaysia, the world's largest exporter of palm oil [1]. As one of the biggest exporters of palm oil and palm oil products, the palm oil industry in Malaysia generates huge quantities of biomass in the form of oil palm empty fruit bunch (EFB), oil palm shell (OPS) and oil palm fibers (OPF). The potentials of these biomasses are yet to be exploited. Out of these

biomasses, EFB generated during the processing of palm oil, can be considered as a primary feedstock for the production of sugars which can be further used as carbon source for ethanol production by yeast. Ethanol production from biomass consists of four basic steps namely pretreatment, hydrolysis, fermentation and distillation. Pretreatment is the crucial step in which the biomass can be broken down into sugars through enzymatic hydrolysis enhancing the yield of saccharification.

* Corresponding author. Tel.: +60 3 8946 8478; fax: +60 3 8946 7593.

E-mail addresses: umi@biotech.upm.edu.my, umiaris@yahoo.com (U.K. Md Shah).
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Investigations on the potential utilization of EFB as a substrate for ethanol production require detailed knowledge of pretreatment. There are variations in major components of EFB such as cellulose, hemicellulose and lignin, as reported by others [2–4]. The structure of EFB needs to be examined to facilitate optimal utilization of this bioresource for biofuel production. The major obstacles for sugar production are the recalcitrant nature of the raw biomass and therefore it required an additional pretreatment step to facilitate the enzymatic hydrolysis for the enhancement of sugar yield.

Steam power has the potential to degrade (thereby pretreat) the complex structure of lignocellulosic biomass. In steam pretreatment, the biomass is simultaneously treated with high pressure and high temperature steam of 140 °C–260 °C, for a few minutes to several minutes. Steam pretreatment has been reported to be efficient in partially hydrolyzing hemicelluloses, modifying the lignin, increasing access to surface area, decreasing the crystallinity of cellulose and its degree of polymerization [5]. Steam or moist heat pretreatment on lignocellulosic materials has been used by many researchers for ethanol production [6–9].

Steam pretreatment of EFB for ethanol production could be the most economical option to be implemented in the palm oil mill. During oil palm processing, steam is continuously being generated in the mill for electricity generation and for sterilizing the fruits. The boilers produce superheated steam which is used to generate electricity through a turbine generator. Low-pressure steam (140 °C, 0.28 MPa) is used for heating purposes in the factory. Every year, palm oil mills produce 50 Tg of OPS and OPF; only 60% of which are used as solid fuel for steam boilers [10]. This amount is sufficient to support the application of steam for the pretreatment of EFB in the palm oil mill. Overall, this pretreatment is attractive to be practiced in the palm oil mill as it includes renewable resources (water, OPS and OPF) and all these could be considered as inexpensive resources which are readily available in the mill.

Biomass pretreatment for ethanol production based on enzymatic hydrolysis has been described as the second most expensive unit cost [11]. Therefore, in this study a cost-effective pretreatment method strategy had been developed using the excess steam from the mill and applied to the different types of EFB (fresh EFB, sterilized EFB, shredded EFB and ground EFB) as an autohydrolysis steam pretreatment. Autohydrolysis is the process of converting lignocelluloses into sugars by exposure to high temperature steam with no addition of external catalysts. Chemical composition, sugar concentration and structural changes were determined in order to assess the effects of steam pretreatment on the different types of EFB biomass.

2. Materials and methods

2.1. Biomass collection and preparation

Four different EFB namely fresh EFB (EFB1), sterilized EFB (EFB2), shredded EFB (EFB3) and ground EFB (EFB4) were used in this experiment.

2.1.1. Fresh EFB (EFB1) and sterilized EFB (EFB2)

EFB1 and EFB2 were obtained from the FELDA Seriting Hilir Palm Oil Mill, Negeri Sembilan, Malaysia. The standard grade of oil palm fruits for production of palm oil were collected from oil palm plantations (N2°48', E102°22') borne on bunches termed as fresh fruit bunch (FFB) which varied in weight from 10 kg to 40 kg. The FFB for palm oil processing was harvested daily in the plantations from trees aged 30 months of field planting which continue to be productive for the next 30 years. The standard quality achieved is initially dependent on the quality of the bunches arriving at the mill. For ensuring good quality of oil, the harvested bunches were loaded into lorries and rapidly transported to the factory before being transferred to sterilizer cages. In this experiment, EFB1 was an expert selection from matured quality FFB after manual cutting and threshing with chopper to detach the fruits from the bunch. Usually, the EFB constitutes about 20%–25% of FFB [12]. The EFB2 samples were obtained from the palm oil mill after the FFB was steam-sterilized with saturated steam (140 °C, 0.28 MPa) at flow rate of 5219 kg h⁻¹ for 90 min using cylindrical horizontal autoclaves of approximately 1.83 m (diameter) to 3.05 m (length) with up to 3.5 Mg FFB capacity as the first step in the sequence of the processes to extract the oil [4]. There was an estimated 50 m distance from the steam pretreatment equipment to the output EFB within the factory. The sterilized EFB (EFB2) after being mechanically threshed to loosen the fruits was directly used as EFB2 starting samples. EFB1 and EFB2 were manually cut into 2.5 cm pieces, 0.25 kg each and stored in sealed plastic bags for immediate use in the pretreatment. The initial moisture content (MC) of all samples was measured.

2.1.2. Shredded EFB (EFB3) and ground EFB (EFB4)

Shredded EFB was provided by the Seri Ulu Langat Palm Oil Mill, Selangor, available from plantations (N2°51', E101°39') nearest to the palm oil mill. The freshly collected sample on 28 January 2008 was fibrous and wet. To prevent fungal contamination, it was soaked in detergent overnight before being washed and rinsed with water to remove the dirt and oil. The loose fibrous materials were then air-dried and stored at 4 °C before use. The EFB3 was clean shredded EFB with an average length of 5 cm. EFB4 was prepared by grinding EFB3 samples to average particle sizes of 2 mm. There were no visible signs of microbial contamination during the preparation of EFB3 and EFB4 samples and the handling of the biomass process for steam pretreatment. Samples of EFB3 and EFB4 were weighed, 0.1 kg each and stored in sealed plastic bags for use in the pretreatment. The initial moisture content (MC) of each sample was measured.

2.2. Steam pretreatment (autohydrolysis)

Steam pretreatment of EFB was carried out in a batch equipment fitted with a high pressure container, steam line from the boiler in the palm oil mill, valve, pressure and temperature gauge and blow down line to stand an operating pressure/temperature of 0.28 MPa/140 °C at FELDA Seriting Hilir Palm Oil Mill as illustrated in Fig. 1. Steam was applied to 0.25 kg EFB1, 0.25 kg EFB2, 0.1 kg EFB3 and 0.1 kg EFB4 with

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