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Synergistic effects on process parameters to enhance enzymatic hydrolysis of alkaline oil palm fronds

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ABSTRACT

Due to an increasing demand for more sustainable and renewable resources, there has been strong interest in utilizing biomass as a source for cleaner production of energy and chemicals. In this work, the lignocellulosic elements of oil palm frond (OPF) biomass were assessed as an alternate sugar feedstock for biofuel and bio-products production. At present, long hydrolysis times and high enzymatic loadings hinder commercialisation and large-scale utilisation of enzymatic hydrolysis of lignocellulosic biomass. Thus, various process parameters of enzymatic hydrolysis of alkaline OPF fibre were investigated in an attempt to improve process performance. In this study, OPF biomass was pretreated with 4.42% NaOH at 100 °C for 58.31 min, resulting in significant disruption as characterised by Fourier transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD) analysis, and scanning electron microscopy (SEM). Alkaline pretreatment of OPF biomass improved enzymatic biodegradability, and glucan recovery by the Cellic Ctec2 enzyme was more effective than the conventional Celluclast 1.5 L cellulase enzyme. Synergistic effects of stirring speed, surfactant Triton X-100 loading, and β-glucosidase supplement on enzymatic hydrolysis were assessed using statistical experimental design. Under optimal conditions (450 rpm, 1.31%, and 0.14 pNPGU/FPU), 88% conversion of glucan was obtained from alkaline OPF, which is equivalent to the conversion from commercial cellulose (microcrystalline cellulose, MCC). Enzymatic hydrolysis of pretreated OPF was further improved at high agitation speeds. Synergy between agitation speed and surfactant loading interactions with β-glucosidase supplement enhanced glucose production due to the efficient mixing and availability of cellulose to be adsorbed by cellulase.

1. Introduction

An increasing demand for renewable energy and a scarcity of fossil fuel reserves have stimulated great interest in finding non-conventional renewable and natural energy sources. Lignocellulosic materials, which include agricultural residues, agricultural by-products, and woody biomass are produced in abundance by photosynthesis. These materials have the potential to serve as sustainable supplies of fuels and chemicals, in addition to offering other advantages such as availability, reduced dependence on crude oil, low carbon dioxide emissions, and no competition with the food chain (García et al., 2016; Pryor et al., 2017).

The palm oil industry in Malaysia has generated 8% from 11% of Malaysia's Gross National Income (GNI) (Aljuboori, 2013). This industry is steadily growing and is now producing more biomass than any other industry in Malaysia. The lignocellulosic biomass residue produced from oil palm industries can be categorised into six class: oil palm fronds (OPF) and oil palm trunks (OPT) at the plantation site, empty fruit bunches (EFB), palm kernel shells, mesocarp fibre, and palm oil mill effluent (POME) produced at mill site. OPF is the largest Malaysian biomass source at 48 million tonnes per year and has high polysaccharide quantity along with lower lignin content (Sohni et al., 2018; Tan et al., 2016). It is recommended as valuable feedstock, and therefore important to efficiently convert this biomass into other valuable products.

Lignocellulose like OPF are complex structures that are resistant to chemical and/or biological degradation. Various biomass disintegration and pretreatment methods are therefore important to reduce lignocellulosic biomass recalcitrance using thermochemical platforms and sugar platforms (Carroll and Somerville, 2009). Cellulose must be converted chemically or enzymatically into glucose before being fermented into biofuel. However, pretreatment is required prior to enzymatic hydrolysis to break down the crystalline structure of cellulose and

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Table 1
Design of experiment by RSM.

Design factor level			Microcrystalline cellulose		Alkaline pretreated OPF	
Impeller Agitation Speed (rpm)	Surfactant Triton X-100 (%)	β glucosidase (ratio)	Glucose (g/L)	% of theoretical	Glucose (g/L)	% of theoretical
200	1.71	0.86	20.89	62.73	22.00	66.07
325	2.00	0.5	23.04	69.19	26.00	78.08
325	1.00	1.00	25.97	77.99	25.00	75.08
450	1.71	0.14	32.81	98.53	31.30	93.99
450	0.29	0.14	29.88	89.73	25.70	77.18
325	1.00	0.50	23.83	71.56	27.68	83.12
500	1.00	0.50	29.79	89.46	26.40	79.28
200	0.29	0.14	20.14	60.48	21.00	63.06
200	1.71	0.14	22.50	67.57	22.10	66.37
325	1.00	0.50	23.25	69.82	28.57	85.80
325	1.00	0.50	22.92	68.81	27.47	82.49
325	1.00	0.00	27.12	81.44	24.80	74.47
450	1.71	0.86	28.96	86.97	25.00	75.08
325	0.00	0.50	20.89	62.73	25.20	75.68
150	1.00	0.50	19.01	57.09	19.60	58.86
450	0.29	0.86	26.11	78.41	26.00	78.08
200	0.29	0.86	20.20	60.66	24.10	72.37

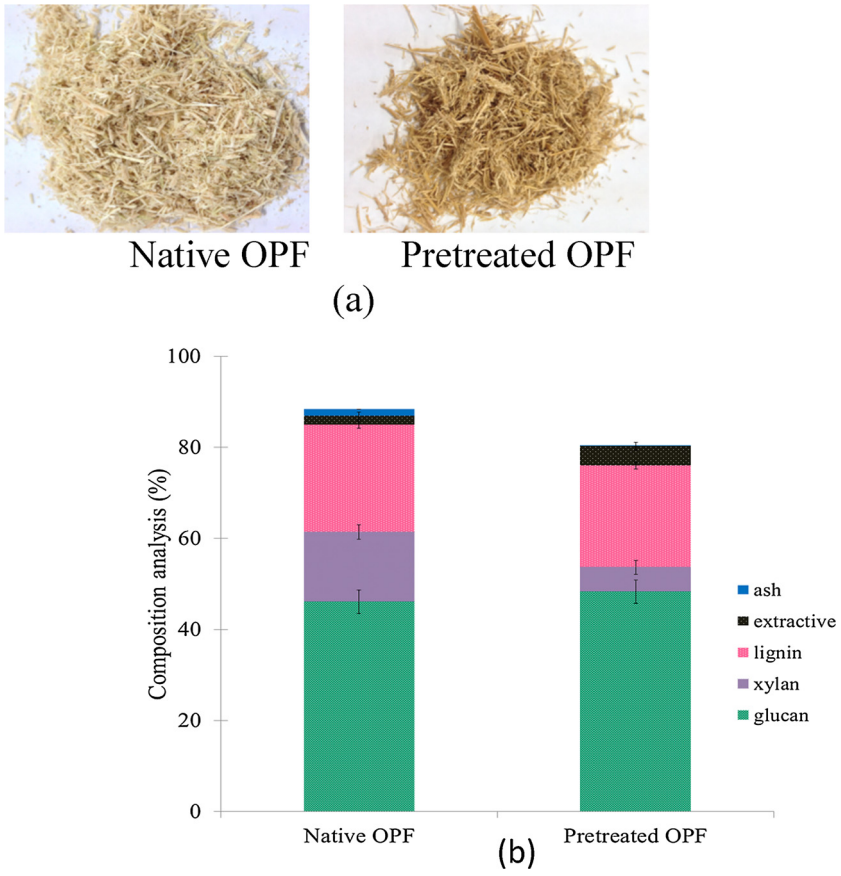

Fig. 1. The physical appearance (a) and composition (b) of native untreated OPF and alkaline pretreated OPF.

increase the penetration of enzymes into cellulose (Chen et al., 2017; Sindhu et al., 2016).

Enzymatic hydrolysis is environmentally friendly and thus another means for cleaner production of chemicals. It utilises milder operating condition with lower energy consumption and higher yields and selectivity than acid hydrolysis (Ekman et al., 2013). Three important factors during enzymatic hydrolysis are: low and high glucan loading, cost of the enzymatic complex, and mixing energy consumption (Karimi and Taherzadeh, 2016). Techno-economical studies indicate that the ability to process biomass at high-solid loadings of 7% to 15% will be important for these biorefineries, due to the high concentration of glucose liquor produced from high solid glucan content. Moreover, using high substrate concentrations in enzymatic hydrolysis offers several advantages including improving overall productivity, reducing equipment sizes, and reducing energy usage for heating and cooling (Modenbach and Nokes, 2013).

However, use of high solid contents in enzymatic hydrolysis presents several technical problems. For example, mass transfer limitations and in homogeneous distributions of enzymes and biomass of high solid content material can affect sugar recovery. High initial viscosities lead