Production of xylose, glucose, and other products from tropical lignocellulose biomass by using maleic acid pretreatment

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Abstract. Efforts to utilize hemicellulose in the biorefinery of bioethanol has been continuously grown in recent years. The utilization of hemicellulosic hydrolysate after pre-treatment was still limited due to its complex composition of sugars (xylose, glucose, arabinose), sugar degradation products (HMF and furfural), lignin degradation products (phenolic compounds), and organic acids (acetic acid also formic acid). Thus, characterization of hemicellulosic hydrolysate components after pre-treatment became important. In this study, the effect of maleic acid concentrations on the production of sugars and by-products from three tropical lignocellulosic biomass: sugarcane trash, corn cob, and sweet sorghum bagasse, has been investigated. The biomass was pre-treated using various concentrations of maleic acid (1, 1.5, 2, 2.5, and 3% v/v) at 121°C for 60 minutes. The results showed the presence of xylose, glucose, acetic acid, lactic acid, HMF and furfural in all biomass hydrolysates after pretreatment with maleic acid. SEM analysis was also conducted to identify the morphological changes of the biomass caused by maleic acid hydrolysis.

1. Introduction

Lignocellulosic biomass including agro-industrial and forest residues, grasses and woody materials, kitchen and paper waste has been considered as a promising feedstock for bioethanol and other chemical products [1,2]. Lignocellulosic biomass is composed of cellulose, hemicellulose, and lignin, as well as water and other minor components. These components have specific properties to be converted into different products [3,4]. Similar with cellulose, hemicellulose can be broken down into monosaccharides, such as xylose, glucose, and arabinose, through acid or enzymatic hydrolysis [5]. However, utilization of hemicellulosic hydrolysate was still limited due to its complex by-products, such as weak organic acids, phenolic compounds, and sugar degradation compounds, which produced during hemicellulose hydrolysis.

There are mainly four processes involved in the conversion of lignocellulosic biomass to ethanol, which are pretreatment, hydrolysis by chemical or enzymatic, fermentation of monosaccharides, and purification of products [6]. To release fermentable sugars from lignocellulosic biomass, that can be
converted into ethanol and other chemical products, various pretreatment methods have been investigated. Physical treatment by milling and grinding [7], chemical treatment using acids [8,9], alkali [10–12], or organic solvents [13], physio-chemical treatment using liquid hot water [14] or steam explosion [15], and biological treatment using fungi [16–18], have been reported along with their advantages and disadvantages.

Sulfuric acid was the common and superior catalyst to hydrolyze hemicellulosic fraction of lignocellulosic biomass. However, pretreatment with sulfuric acid generates additional lignocellulose-derived compounds such as sugar degradation compounds and phenolic compounds, which are toxic to microorganisms. These by-products have inhibitory effects on the fermentation process by decreasing yeast performance [2]. In order to solve this problem, an organic acid catalyst such as maleic acid, oxalic acid, and formic acid, was used in the pretreatment process. As reported by many researchers, maleic acid produces fewer inhibitors in hydrolysate than sulfuric acid [19]. Thus, in this study, maleic acid was used to hydrolyze lignocellulose components of three tropical biomass, sugarcane trash, corn cob, and sweet sorghum bagasse. The main objective of this study was to investigate sugars production and the formation of degradation products in the hydrolysates obtained after maleic acid pretreatment. Morphological examination of the original and pretreated biomass was also conducted through Scanning Electron Microscopy (SEM) to support the analysis.

2. Experimental

2.1. Materials

Sugarcane (Saccharum officinarum L.) trash used in this study was collected from Sugarcane Factory Rajawali II, Subang, West Java, Indonesia. Corn cob and sweet sorghum bagasse were obtained from a local farm in Sukabumi and Cibinong, West Java, Indonesia, respectively. Prior to use, the raw materials were ground into small particles using a drum chipper, ring flaker, and hammer mill, then sieved to obtain particle size (powder) smaller than 80 mesh. The moisture content (MC) of sugarcane trash (ST) was 7.7%, while the MC of corn cob (CC) and sorghum bagasse (SB) was 5.7% and 5.9%. The materials were stored in sealed plastic bags at room temperature. Maleic acid (Wako Pure Chemical Industries, Ltd., Osaka, Japan) and other chemicals (from Merck) used in this study were analytical grade and used without further purification.

2.2. Methods

2.2.1 Maleic Acid Pretreatment of Raw Materials.

Pretreatment was done with the OFAT method to evaluate the effect of maleic acid concentration. Three grams (oven-dry weight) of biomass were immersed in various concentrations (1; 1.5; 2; 2.5 and 3%; v/v) of MA in laboratory glass bottles (Duran) with solid to liquid ratio of 1:10, then were heated in an autoclave at 121°C for 60 min. The slurries were filtered with an Advantec filter paper (Toyo Roshi Kaisha, Ltd., Japan) using vacuum filtration (GAST DOA-P504-BN, Cole-Parmer, Vernon Hills, IL, USA). The liquid fractions were separated and kept in a refrigerator until further analysis of glucose, xylose, acetic acid, 5-HMF, and furfural using HPLC. The pH of the liquid fractions was also measured using pH meter. The residual solid fractions (pulp) were separated, washed with distilled water until the pH was neutral, and stored in sealed plastic bags in the refrigerator for further experiments.

2.2.2. Chemical components analyses of liquid fraction.

Xylose, glucose, glycerol, acetic acid, 5-HMF, and furfural in the liquid fraction of the pre-treated biomass were analyzed by high performance liquid chromatography/HPLC (Shimadzu LC-20AB, Kyoto, Japan) equipped with a refractive index detector and Bio-Rad (Hercules, CA) Aminex HPX-87H column (300-7.8 mm) at 60 °C; 0.01 N H₂SO₄ as eluent, at a flow rate of 0.6 mL/min and injection volume of 10 μL. The samples were centrifugated and filtered through the 0.22 μm membrane prior to injection.
2.2.3. **Scanning electron microscopy (SEM) analysis.**
In order to support the analysis, the surface morphology of the original and pre-treated sugarcane trash was characterized using scanning electron microscopy (SEM) JEOL JSM-5310LV (Jeol Ltd., Japan). Dried samples were placed on a specimen stub (10 mm in diameter). The surfaces of the samples then were coated with a thin layer (approximately 400-500 Å thick) of gold using coating unit Ion Coater iB2. SEM images of the samples were recorded using an accelerating voltage of 20 kV at 500-1500 magnification.

3. **Results and Discussions**

3.1. **Sugars in the hydrolysate of maleic acid-pretreated biomass**

Pre-treatment is an essential step to achieve effective hydrolysis of substrates into simple sugars, which can be used directly or fermented by microorganisms [20]. To investigate the effects of maleic acid (MA) pre-treatment on the formation of sugars and by-products in the hydrolysates, experiments were performed at MA concentrations ranging from 1 up to 3%. Results showed that xylose and glucose were formed in the hydrolysates during pre-treatment, while other monosaccharides, such as arabinose and mannose, were not detected in the hydrolysates. Figure 1 showed the effects of MA concentrations on xylose and glucose concentrations in the hydrolysates after pre-treatment. For all biomass, the concentration of xylose was increased with increasing of maleic acid concentrations up to 2.5%, and it was decreased when the hydrolysis was conducted at 3% concentration of MA.

Among all biomass, corn cob produced the highest xylose concentration (14.2 g/L) when treated by 2.5% of MA at 121 °C for 60 minutes. The previous study on MA-pretreatment of corn cob reported by Lee and Jeffries [9] showed that 50 g/L of xylose was achieved when corn cob was hydrolyzed with 15.33 g/L of MA at 170 °C for 18 minutes. Xylose concentration achieved in our study was higher than xylose concentration obtained by Mardawati et al. [21], which was only 5.5 g/L after the corn cob was treated by 6% sulfuric acid at 120 °C for 15 minutes. However, xylose concentration obtained in our study was still lower than other results reported by Hatano et al. [22], which showed that 29.7 g/L of xylose was obtained when corn cob was treated by 2% (w/v) sulfuric acid at 121 °C for 60 minutes. Another study by Misra et al. [23] also showed that 25 g/L of xylose was successfully obtained from corn cob after treatment with 1% sulfuric acid at 121 °C for 30 minutes.

Industrially, sugarcane trash, which consists of sugarcane tops and leaves, was left on the field or burnt [24]. Unlike sugarcane bagasse, utilization of sugarcane trash as an alternative energy source was still limited. As reported, sugarcane leaves consist of 40-44% cellulose, 23-29% hemicellulose, and 10% lignin [25,26]. Therefore, the utilization of sugarcane trash to produce value-added products becomes important. In this research, besides corn cob and sweet sorghum bagasse, we used sugarcane trash and hydrolyzed it using MA. As much as 11.2 g/L of xylose was produced in sugarcane trash hydrolysate during pre-treatment with 2.5% MA for 60 minutes. This xylose concentration was higher than xylose concentration reported by Jutakanoke [26], which was only 9.7 g/L after the sugarcane trash was treated by 1.5% of sulfuric acid at 121 °C for 30 minutes.

Glucose was another mono-sugar obtained in the hydrolysate during acid pre-treatment. For all biomass, the concentrations of glucose were increased with increasing of maleic acid concentrations. Maleic acid concentration of 3% gave the highest glucose concentration. Among the three biomass investigated, sweet sorghum bagasse produced the highest glucose concentration (24.7 g/L) in the hydrolysate, while the lowest concentration of glucose was obtained in sugarcane trash hydrolysate (22.5 g/L). Okur and Eken [27] reported that xylose and arabinose released in the hydrolysate were obtained from hemicellulose, while glucose and cellobiose were obtained from hydrolysis of cellulose. Moreover, Aguilar et al. [28] noted that the presence of glucose in the hydrolysate during acid pre-treatment might also come from heteropolymers of hemicellulose fraction. In addition, according to Li et al. [29], glucose obtained in corn cob hydrolysate during pretreatment may come from glucuronoxarabinofuransyls and xyloglucans.
The interesting part of this study was the glucose concentration in the hydrolysate. Particle size reduction caused by milling and grinding probably has a positive influence in high glucose released in the hydrolysate. In this study, we used the biomass particle which is smaller than 80 mesh. Banerji et al. [30] reported that the reduction of particle size decreased the cellulose crystallinity of sweet sorghum bagasse. Besides the physical disruption, another possibility was the reaction time. This study used a longer reaction time (60 minutes) to hydrolyze hemicellulose compared to another study. However, a study by Mardawati et al. [21] also reported that both glucose (4.07 g/L) and xylose (5.5 g/L) were also produced in corn cob hydrolysate after treated by 6% sulfuric acid at 121 °C for 15 minutes. Therefore, comprehensive research is necessary to assess these phenomena.

3.2 Formation of degradation compounds in the hydrolysate

During acid hydrolysis, degradation compounds including sugar degradation compounds (HMF and furfural), lignin degradation products (phenolic compounds), and organic acid (acetic acid, formic acid, were produced in the hydrolysates. Figure 2 showed the final pH of hydrolysates after treated with MA. The pH of all biomass decreased as the concentration of maleic acid rose. The changes in the pH of the hydrolysates after treated with maleic acid was related to utilization of some hydrogen ions from the acid for hydrolysis process, which increased the pH of the hydrolysates. Moreover, some hydrogen ions were also formed during pretreatment as degradation products of the carbohydrates, such as acetic acid or formic acid [3]. In addition, some authors noted that during acid pretreatment, a part of the acetyl groups in the hemicellulose was cleaved and produced acetic acid [29,31]. As expected, HPLC results showed that acetic acid, ranging from 0.33 to 2.23 g/L, were formed in all of the biomass hydrolysates (Table 2).

As shown in Table 2, acetic acid and lactic acid were organic acids formed in hydrolysates during pretreatment. The other organic acids, such as levulinic, malonic, and formic acids, were not detected in hydrolysates. The concentrations of acetic acid in hydrolysates were steadily increased with increasing acid concentrations. The highest concentration of acetic acid was found in the corn cob pretreated with 2.5% MA. As was mentioned before, the formation of organic acids in the hydrolysate can inhibit the performance of fermenting microorganisms, although some microorganisms also have tolerance mechanism to avoid an inhibitory effect of the toxic hydrolysates. Weak organic acid in the hydrolysates, such as acetic and lactic acids, can lead to an influx into cytosol of the microorganisms. It caused improper ion transportation and finally inhibit the growth and productivity of the microorganisms [2]. Moreover, microorganism tolerance toward toxic degradation products in hydrolysates was strongly dependant on the physiology and nature of the microorganism itself [32]. Oberoi et al. [33] reported that 1% of acetic acid formed in rice straw hydrolysate could inhibit the growth of *Pichia kudriavzevii*. Another study by Delgenes et al. [32] showed that the growth of
Zymomonas mobilis was inhibited by the presence of 5 g/L acetic acid. The growth of Saccharomyces cerevisiae was also inhibited with the presence of 10.2 g/L acetic acid in hydrolysate liquor [34].

Lactic acid was also formed in all biomass hydrolysates due to acid pretreatment (Table 1). The formation of lactic acid was related to depolymerization of hemicellulose or xylan to xylose by an acid catalyst. The xylose then was converted to glycolaldehyde and glyceraldehyde through a retro-aldol condensation reaction, thus released lactic acid as a final product [35]. In this study, the highest concentration of lactic acid was produced in sugarcane trash hydrolysate (99 mg/L) after treated by 1.5% MA. However, this concentration was still low. The study by Favaro et al. [36] reported that S. cerevisiae fm17 have a tolerance to the presence of lactic acid, ranging from 1-5 g/L, in the fermentation hydrolysate.

Table 1. Acetic and lactic acid concentrations in hydrolysates after maleic acid (MA) pretreatment of sugarcane trash (ST), corn cob (CC) and sorghum bagasse (SB)

| MA Conc. (%) | Acetic acid (g/L) | Lactic Acid (mg/L) |
|--------------|------------------|--------------------|
|              | ST | CC | SB | ST | CC | SB |
| 1            | 0.33 ± 0.07 | 1.09 ± 0.04 | 0.58 ± 0.49 | 21 ± 0.2 | 8 ± 0.6 | 20.7 ± 0.0 |
| 1.5          | 0.65 ± 0.17 | 1.35 ± 0.01 | 1.61 ± 0.45 | 99 ± 0.7 | 15 ± 0.2 | 21.4 ± 0.0 |
| 2            | 0.84 ± 0.11 | 1.95 ± 0.09 | 1.47 ± 0.39 | 48 ± 0.2 | 39 ± 0.3 | 21.5 ± 0.0 |
| 2.5          | 1.11 ± 0.15 | 2.23 ± 0.14 | 1.14 ± 0.24 | 25 ± 0.2 | 19 ± 0.02 | 21.4 ± 0.0 |
| 3            | 1.22 ± 0.14 | 2.04 ± 0.11 | 2.08 ± 0.42 | 48 ± 0.2 | 18 ± 0.003 | 20.9 ± 0.0 |

In this study, we used maleic acid in order to avoid degradation compounds production in the hydrolysates that can inhibit the fermenting microorganisms. Pretreatment with organic acids, such as maleic acid, produces fewer inhibitors compared with sulfuric acid [19]. Table 2 shows the formation of hydroxymethylfurfural (HMF) and furfural in pretreated hydrolysates, respectively. For all biomass, the concentration of HMF and furfural were smaller than 0.01 g/L. The highest concentration of HMF (7.3 mg/L) was produced in sorghum bagasse hydrolysate after treated with 2.5% MA. Meanwhile, the highest concentration of furfural (13.1 mg/L) was produced in corn cob hydrolysate after treated with 3% MA. These concentrations were lower than those resulted by a study on pretreatment of sweet sorghum bagasse by 0.5-5% sulfuric acid conducted by Banerji et. al. [30] at analogous process, which produced 3.1-3.4 g/L of acetic acid, 1.1 g/L of furfural, and 2.95 g/L of levulinic acid (degradation of HMF). Misra et al. [23] also reported that 1.31 g/L of acetic acid and 0.21 g/L of furfural were formed in corn cob hydrolysate after treated with 1% sulfuric acid at 121 °C for 30 minutes.
Table 2. Hydroxymethylfurfural (HMF) and furfural concentrations in the hydrolysates during maleic acid (MA) pretreatment of sugarcane trash (ST), corn cob (CC) and sorghum bagasse (SB)

| MA Conc. (%) | HMF (mg/L) ST | HMF (mg/L) CC | HMF (mg/L) SB | Furfural (mg/L) ST | Furfural (mg/L) CC | Furfural (mg/L) SB |
|-------------|---------------|---------------|---------------|-------------------|-------------------|-------------------|
| 1           | 0.9 ± 0.3     | 1.1 ± 0.1     | 0.6 ± 0.1     | 4.7 ± 0.8         | 4.4 ± 0.0         | 5.7 ± 0.0         |
| 1.5         | 0.5 ± 0.3     | 0.5 ± 0.1     | n.d.          | 4.8 ± 0.6         | 5.4 ± 0.1         | n.d.              |
| 2           | 0.4 ± 0.1     | 0.7 ± 0.0     | 4.6 ± 0.4     | 5.3 ± 0.8         | 10.3 ± 0.2        | 4.6 ± 0.0         |
| 2.5         | 0.7 ± 0.0     | 5.2 ± 0.6     | 7.3 ± 0.0     | 9.9 ± 0.6         | 8.2 ± 0.3         | 7.3 ± 0.0         |
| 3           | n.d.          | 1.6 ± 0.1     | 5.3 ± 0.5     | 5.9 ± 1.6         | 13.1 ± 0.2        | 5.3 ± 0.5         |

* n.d. = not detected

3.3. Scanning Electron Microscopy (SEM)

Figure 3. Scanning electron micrographs of the untreated and pretreated sugarcane trash: (A) untreated, (B) pretreated with 1% MA, (C) pretreated with 1.5% MA, (D) pretreated with 2% MA, (E) pretreated with 2.5% MA, and (F) pretreated with 3% MA. Magnification: 500x (B), 1000x (A, D), 1500x (C, E, F)
Scanning electron microscopy was carried out to compare the morphology of the untreated, and maleic acid pretreated biomass. Figure 3A is an image of the untreated sugarcane trash. Figure 3B, 3C, 3D, 3E, and 3F are images of sugarcane trash pretreated with 1, 1.5, 2, 2.5, and 3% MA, respectively. As shown in Figure 3A, the structure of untreated sugarcane trash is compact and rigid, but the surface was clearly degraded probably due to physical treatment. The sugarcane trash became more degraded as increasing of acid concentrations. Numerous porous and holes became clearly apparent as shown in Figure 3C-3F. According to Chen et al. [37], this disruption was probably caused by the removal of reactive amorphous cellulose on the biomass surface. This disruption changes the morphology of the biomass, then increases its porosity and surface area.

4. Conclusions
This study showed the quantitative and qualitative characteristics of sugarcane trash, corn cob, and sweet sorghum bagasse hydrolysates during maleic acid pretreatment. The disruption effect of acid pretreatment was also explored. Xylose and glucose were the main simple sugars produced in the hydrolysates. Among all biomass, corn cob produced the highest xylose concentration (14.2 g/L) after treated by 2.5% of MA at 121 °C for 60 minutes. The highest glucose concentration (24.7 g/L) was produced by sweet sorghum bagasse after treated by 3% of MA at 121 °C for 60 minutes. Acetic acid, lactic acid, HMF, and furfural were also produced as degradation compounds in hydrolysates.

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6. References
[1] Wang L, Yang M, Fan X, Zhu X, Xu T and Yuan Q 2011 An environmentally friendly and efficient method for xylitol bioconversion with high-temperature-steaming corncob hydrolysate by adapted Candida tropicalis Process Biochemistry 46 1619–26
[2] Kim D 2018 Physico-Chemical Conversion of Lignocellulose: Inhibitor Effects and Detoxification Strategies: A Mini Review Molecules 23 (2) 309
[3] Harmesen P, Huijgen W, López L and Bakker R 2010 Literature review of physical and chemical pretreatment processes for lignocellulosic biomass (No. 1184) Wageningen UR-Food & Biobased Research
[4] Deng A, Ren J, Wang W, Li H, Lin Q, Yan Y, Sun R and Liu G 2016 Production of xylo-sugars from corncob by oxalic acid-assisted ball milling and microwave-induced hydrothermal treatments Industrial Crops and Products 79 137–45
[5] Brodeur G, Yao E, Badal K, Collier J, Ramachandran K B and Ramakrishnan S 2011 Chemical and Physicochemical Pretreatment of Lignocellulosic Biomass: A Review 2011
[6] Taherzadeh M J and Karimi K 2008 Pretreatment of lignocellulosic wastes to improve ethanol and biogas production: A review International journal of molecular sciences 9 (9) 1621-1651
[7] Norsyarahah S, Kamarludin C, Jainal M S, Azizan A, Sharliza N and Safaai M 2015 Mechanical Pretreatment of Lignocellulosic Biomass for Biofuel Production Mechanical Pretreatment of Lignocellulosic Biomass For Biofuel Production Applied Mechanics and Materials 625 838–41
[8] Sindhu R, Kuttiraja M, Binod P, Sukumaran R K and Pandey A 2014 Bioethanol production from dilute acid pretreated Indian bamboo variety (Dendrocalamus sp.) by separate hydrolysis and fermentation Industrial Crops and Products 52 169–76
[9] Lee J-W and Jeffries T W 2011 Efficiencies of acid catalysts in the hydrolysis of lignocellulosic biomass over a range of combined severity factors Bioresource Technology 102 5884–90
[10] Akhtar N, Goyal D and Goyal A 2016 Characterization of microwave-alkali-acid pre-treated rice straw for optimization of ethanol production via simultaneous saccharification and fermentation (SSF) Energy Conversion and Management 141 133-144
[11] Khuong L D, Kondo R, De Leon R, Kim Anh T, Shimizu K and Kamei I 2014 Bioethanol
production from alkaline-pretreated sugarcane bagasse by consolidated bioprocessing using Phlebia sp. MG-60 International Biodeterioration and Biodegradation 88 62–8

[12] Krishnan C, Sousa C, Jin M, Chang L, Dale B E and Balan V 2010 Alkali-Based AFEX Pretreatment for the Conversion of Sugarcane Bagasse and Cane Leaf residues to Ethanol Biotechnology and Bioengineering 107 (3) 441-450

[13] Zhao X, Cheng K and Liu D 2009 Organosolv pretreatment of lignocellulosic biomass for enzymatic hydrolysis Applied Microbiology and Biotechnology 82 815–27

[14] Wang W, Zhuang X, Yuan Z, Yu Q, Qi W, Wang Q and Tan X 2012 Effect of structural changes on enzymatic hydrolysis of eucalyptus, sweet sorghum bagasse, and sugarcane bagasse after liquid hot water pretreatment BioResources 7 2469–82

[15] Ballesteros M, Oliva J M, Negro M J, Manzanares P and Ballesteros I 2004 Ethanol from lignocellulosic materials by a simultaneous saccharification and fermentation process (SFS) with Kluyveromyces marxianus CECT 10875 Process Biochemistry 39 1843–8

[16] Ishola M M, Isroi and Taherzadeh M J 2014 Effect of fungal and phosphoric acid pretreatment on ethanol production from oil palm empty fruit bunches (OPEFB) Bioresource Technology 165 9–12

[17] Fatriasari W, Syafii W, Wistara N J, Syamsu K and Prasetya B 2014 Digestibility of Betung Bamboo Fiber Following Fungal Pretreatment Makara Journal of Technology 18 51–8

[18] Kamat S, Khot M, Zinjarde S, RaviKumar A and Gade W N 2013 Coupled production of single cell oil as biodiesel feedstock, xylitol and xylanase from sugarcane bagasse in a biorefinery concept using fungi from the tropical mangrove wetlands Bioresource Technology 135 246–53

[19] Kim S, Park J M, Seo J W and Kim C H 2012 Sequential acid-/alkali-pretreatment of empty palm fruit bunch fiber Bioresource Technology 109 229–33

[20] Triwahyuni E, Muryanto, Sudiyani Y and Abimanyu H 2015 The effect of substrate loading on simultaneous saccharification and fermentation process for bioethanol production from oil palm empty fruit bunches Energy Procedia 68 138–46

[21] Mardawati E, Andoyo R, Syukra K A, Kresnowati M T A P and Bindar Y 2018 Production of xylitol from corn cob hydrolysate through acid and enzymatic hydrolysis by yeast Production of xylitol from corn cob hydrolysate through acid and enzymatic hydrolysis by yeast IOP Conf. Ser.: Earth Environ. Sci 141 012019 pp 1–19

[22] Hatano K ichi, Aoyagi N, Miyakawa T, Tanokura M and Kubota K 2013 Evaluation of nonionic adsorbent resins for removal of inhibitory compounds from corncob hydrolysates for ethanol fermentation Bioresource Technology 149 541–6

[23] Misra S, Raghuwanshi S and Saxena R K 2013 Evaluation of corncob hemicellulosic hydrolysate for xylitol production by adapted strain of Candida tropicalis Carbohydrate Polymers 92 1596–601

[24] Misran E 2005 Industri Tebu Menuju Zero Waste Industry Jurnal Teknologi Proses 4 6–10

[25] Moodley P and Kana E B G 2015 Optimization of xylose and glucose production from sugarcane leaves (Saccharum officinarum) using hybrid pretreatment techniques and assessment for hydrogen generation at semi-pilot scale International Journal of Hydrogen Energy 40 3859–67

[26] Jutakanoke R, Tolieng V, Tanasupawat S and Akaracharanya A 2017 Ethanol Production from Sugarcane Leaves by Kluyveromyces marxianus S1.17, a Genome-Shuffling Mediated Transformant BioResources 12 1636–46

[27] Telli-Okur M and Eken-Saraçoğlu N 2008 Fermentation of sunflower seed hull hydrolysate to ethanol by Pichia stipitis Bioresource Technology 99 2162–9

[28] Aguilar-Reynosa A, Romani A, Ma. Rodríguez-Jasso R, Aguilar C N, Garrote G and Ruiz H A 2017 Microwave heating processing as alternative of pretreatment in second-generation biorefinery: An overview Energy Conversion and Management 136 50–65

[29] Li H, Chen X, Ren J, Deng H, Peng F and Sun R 2015 Functional relationship of furfural yields and the hemicellulose - derived sugars in the hydrolysates from corncob by microwave -
assisted hydrothermal pretreatment Biotechnology for Biofuels 1–12

[30] Banerji A, Balakrishnan M and Kishore V V N 2013 Low severity dilute-acid hydrolysis of sweet sorghum bagasse Applied Energy 104 197–206

[31] Hsu T C, Guo G L, Chen W H and Hwang W S 2010 Effect of dilute acid pretreatment of rice straw on structural properties and enzymatic hydrolysis Bioresource Technology 101 4907–13

[32] Delgenes J P, Moletta R and Navarro J M 1996 Effects of lignocellulose degradation products on ethanol fermentations of glucose and xylose by Saccharomyces cerevisiae, Zymomonas mobilis, Pichia stipitis, and Candida shehatae Enzyme and Microbial Technology 19 220–5

[33] Oberoi H S, Babbar N, Sandhu S K, Dhaliwal S S, Kaur U, Chadha B S and Bhargav V K 2012 Ethanol production from alkali-treated rice straw via simultaneous saccharification and fermentation using newly isolated thermotolerant Pichia kudriavzevii HOP-1 Journal of Industrial Microbiology and Biotechnology 39 557–66

[34] Nielsen F, Tomás-Pejó E, Olsson L and Wallberg O 2015 Short-term adaptation during propagation improves the performance of xylose-fermenting Saccharomyces cerevisiae in simultaneous saccharification and co-fermentation Biotechnology for Biofuels 8 1–15

[35] He T, Jiang Z, Wu P, Yi J, Li J and Hu C 2016 Fractionation for further conversion: From raw corn stover to lactic acid Scientific Reports 6 1–11

[36] Favaro L, Basaglia M, Trento A, Van Rensburg E, García-Aparicio M, Van Zyl W H and Casella S 2013 Exploring grape marc as trove for new thermotolerant and inhibitor-tolerant Saccharomyces cerevisiae strains for second-generation bioethanol production Biotechnology for Biofuels 6 1–14

[37] Chen W H, Tu Y J and Sheen H K 2011 Disruption of sugarcane bagasse lignocellulosic structure by means of dilute sulfuric acid pretreatment with microwave-assisted heating Applied Energy 88 2726–34