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SYNTHESIS OF LEVULINIC ACID FROM OIL PALM MESOCARP FIBER BY ACID HYDROLYSIS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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SYNTHESIS OF LEVULINIC ACID FROM OIL PALM MESOCARP FIBER BY ACID HYDROLYSIS

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Chair : Prof Robiah Yunus, PhD
Faculty : Engineering

Levulinic acid (LA) can be produced from both C6 and C5 carbohydrates via dehydration and hydrolysis processes of biomass. This study focuses on the production of LA from oil palm mesocarp fiber (OPMF). From proximate and thermogravimetric analysis (TGA), it was found that OPMF has 21.16 - 29.73% of cellulose, hemicellulose 21.81 – 27.61%, lignin 10.39 – 30.80%, ash 6.39% and extractive 25.23%. It is difficult to produce high yield of LA from the biomass due to generation of humins during hydrolysis reaction. Moreover, the high content of silica bodies on OPMF surface also causes lower sugar production which affects the formation of LA. Thus, pretreatment is needed to improve the yield of LA.

This study aimed to investigate the effect of several pretreatments on the synthesis of LA. Four pretreatments were conducted; acid pretreatment, ultrasonic-assisted acid pretreatment, alkali pretreatment and ultrasonic-assisted alkali pretreatment. Sulfuric acid (H_2SO_4) and sodium hydroxide (NaOH) were used as catalysts in pretreatment. For acid and alkaline pretreatments, samples were pretreated with different temperatures (60 °C, 80 °C and 100 °C). The parameter for ultrasonic-assisted pretreatment was sonication power (40%, 60% and 80%). The highest content of HMF produced after pretreatment from all pretreatments was 1.71% pretreated by 6% (v/v) sulphuric acid pretreatment without ultrasonic at 100 ºC. Direct hydrolysis of biomass was proposed after it was discovered that most of the sugars after pretreatment were present in the liquor. The maximum yield of LA was 20.54% obtained from direct acid hydrolysis of sample which was pretreated at 100 ºC using 6% (v/v) H_2SO_4 solution. The results on morphological structure of treated OPMF fiber after SEM analysis showed the evidence of silica bodies removal from the surface of OPMF fiber thus allowed for a direct exposure of acid pretreatment and acid

hydrolysis. FTIR analysis suggested that the formation of carbonyl groups indicates the formation of LA in hydrolysis samples. TGA results indicated that the sample which produced highest amount of levulinic acid had lowest activation energy in the reaction.

The second objective is to the study effect of process conditions on the hydrolysis of OPMF into LA using Response Surface Methodology (RSM). The pretreatment method chosen in this step was based on the results obtained from the first objective. The pretreated samples were hydrolyzed in acid hydrolysis reactor. Three parameters were investigated; reaction time (2 – 4 hours), acid concentration (1 - 3% (v/v) H_2SO_4) and temperature of reaction (120 – 160 °C). The highest content of LA 17.88% was produced at the temperature 160 ºC, using 3% sulphuric acid concentration for 4 hours. Since these are the highest conditions for each parameter, the optimized condition could not be determined due to the limitation of reactor specification for acid hydrolysis reaction.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

SINTESIS ASID LEVULINIK DARIPADA SERAT MESOKARP KELAPA SAWIT MELALUI KAEDAH HIDROLISIS ASID

Oleh

NOR AKHLISAH BINTI ZULKIPLI

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Asid levulinik (LA) boleh diperolehi daripada kedua-dua C5 dan C6 karbohidrat melalui tindak balas dehidrasi dan hidrolisis. Kajian ini mengfokuskan kepada penghasilan asid levulinik daripada serat mesokarp kelapa sawit (OPMF). Melalui analisis penganggaran dan termogravimetri (TGA), OPMF mempunyai selulosa sebanyak 21.16 – 29.73%, hemiselulosa sebanyak 21.81 – 27.61%, lignin sebanyak 10.39 – 30.80 %, 6.39% abu dan 25.23% hasil ekstraktif. Didapati bahawa kandungan asid levulik yang tinggi sukar diperolehi disebabkan oleh penghasilan humin semasa tindak balas hidrolisi. Tambahan pula, banyak jasad silika yang terdapat pada OPMF juga menyebabkan penghasilan gula menjadi rendah dan memberi kesan kepada penghasilan asid levulinik.

Kajian ini bertujuan untuk mengkaji kesan empat prarawatan ke atas penghasilan asid levulinik (LA) iaitu prarawatan asid, prarawatan asid dengan bantuan ultrasonik, prarawatan alkali, dan prarawatan alkali dengan bantuan ultrasonic. Asid sulfurik (H_2SO_4) and natrium hidroksida (NaOH) telah digunakan sebagai pemangkin dalam prarawatan. Untuk prarawatan asid dan alkali, sampel diprarawat dengan menggunakan suhu yang berbeza (60 °C, 80 °C dan 100 °C). Parameter untuk prarawatan ultrasonik adalah kuasa ultrasonik (40%, 60% dan 80%). Kandungan HMF yang paling tinggi adalah 1.71% diprarawat menggunakan 6% asid sulfurik pada suhu 100 ºC melalui kaedah prarawatan asid tanpa ultrasonik. Hidrolisis secara langsung ke atas biojisim telah disarankan selepas menemukan kebanyakan gula selepas prarawatan telah dialihkan ke dalam cairan prarawatan. Kadar kandungan maksimum asid levulinik yang dihasilkan adalah 20.54% diperoleh daripada hidrolisis asid secara langsung ke atas sampel yang diprarawat pada suhu 100 ºC menggunakan 6% (v/v) asid sulfurik. Hasil pada struktur morfologi

terhadap serat OPMF selepas analisis SEM menunjukkan bukti bahawa jasad silica telah dibuang daripada permukaan serat OPMF dan membenarkan pendedahan langsung prarawatan dan hidrolisis asid. FTIR mengesahkan pembentukan asid levulinik dalam sampel hidrolisis melalui ikatan karbonil. Hasil TGA pula menunjukkan bahawa sampel yang menghasilkan asid levulinik yang tinggi mempunyai tenaga pengaktifan yang rendah dalam tindak balas.

Objektif kedua adalah untuk mengkaji kesan keadaan hidrolisis ke atas OPMF terhadap asid levulinik dengan menggunakan Response Surface Methodology (RSM). Kaedah prarawatan yang dipilih dalam langkah ini adalah berdasarkan hasil yang diperoleh daripada objektif pertama. Sampel yang telah diprarawat, dihidrolisis dalam reaktor hidrolisis asid. Tiga parameter telah dikaji; masa tindakbalas (2 – 4 jam), kepekatan asid (1 – 3% (v/v) H_2SO_4) dan suhu tindakbalas (120 – 160 °C). Kandungan asid levulinik tertinggi adalah 17.89% diperoleh pada suhu 160 °C menggunakan 3% kepekatan asid sulfurik selama 4 jam. Asid levulinik paling tinggi terhasil pada keadaan parameter yang paling ekstrem maka keadaan yang optimum tidak dapat ditentukan disebabkan oleh keterbatasan kebolehan reaktor yang digunakan untuk tindak balas hidrolisis asid.

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“*Rabbi Yassir Wa La Tuassir*
– O Allah, make it easy and do not make it difficult”

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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LIST OF ABBREVIATIONS

ADL	Acid Detergent Lignin
ADF	Acid Detergent Fiber
ANOVA	Analysis of Variance
CCD	Central Composite Design
CNF	Cellulose Nanofiber
CrI	Crystallinity Index
DALA	Delta Aminolevulinic Acid
DPA	Diphenolic Acid
E_a	Activation Energy
FAME	Fatty Acid Methyl Esters
FFB	Fresh Fruit Bunch
FTIR	Fourier Transform Infrared Spectroscopy
HBI	Hydrogen Bonding Index
HMF	Hydroxymethylfurfural
HPLC	High Performance Liquid Chromatography
ITMA	Institute of Advance Technology
LA	Levulinic Acid
LHW	Liquid Hot Water
LOI	Lateral Order Index
L/S	Liquid per Solid Ratio
M	Molar
MARDI	Malaysian Agriculture Research and Development Institute
MTHF	Methyl Tetrahydrofuran
NDF	Neutral Detergent Fiber
OPEFB	Oil Palm Empty Fruit Bunch
OPF	Oil Palm Frond
OPMF	Oil Palm Mesocarp Fiber
OPT	Oil Palm Trunk
PKS	Palm Kernel Shell
POME	Palm Oil Milling Effluent
PTSA	P-Toluenesulfonic Acid
RID	Refractive Index Detector
RSM	Response Surface Methodology
SEM	Scanning Electron Microscopy
TCI	Total Crystallinity Index
TGA	Thermogravimetric Analysis
TFA	2,2,2-Trifluoroacetic Acid
THF	Tetrahydrofuran
WDM	Wet Disk Milling
XOS	Xylo-Ologomers

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Energy Generation and Chemical Production from Biomass

In the past years, unstable fuel price has affected the economy of many countries. Moreover, the use of fossil fuel which yields more carbon and sulphur leads to major environmental concerns including the global warming and acid rain (Hossain *et al.,* 2016). These two mentioned issues are considered as challenges and need to be resolved by developing new technologies especially the development of alternative fuel resources (Chiesa and Gnansounou, 2014). These concerns have escalated the development and application of alternative energies such as wind, biomass, hydro, and solar (Hossain *et al.,* 2016). Moreover, the research on the use of biomass as alternative energy sources has also increased lately due to its abundant supply. Generally, most of energy sources are used in two ways which are as a source of fuel or energy and second as raw materials in the production of chemicals.

Biomass, is one of the renewable resources which is widely available and can be considered as one of the promising affordable options for energy. Forestry, agriculture, waste and industry are known to be the sources of biomass (Sadhukhan *et al.,* 2018). They have their own potential to be converted into energy, chemical and other bio-products in various applications. Many types of waste biomass can be explored for examples; agricultural crops, food residuals, municipal solid wastes and animal waste. Agricultural wastes are by-products generated from agricultural industry. Embedded carbon released from combustion of biomass is seized during the growth of biomass thus alleviate the negative impact of using fossil fuels.

In addition, lignocellulosic biomass, a renewable source of carbon, has the potential to be converted into many chemicals such as levulinic acid (LA), furfural, ethanol and 5-hydroxymethylfurfural (HMF) (Alonso *et al.,* 2013b). Three main components of lignocellulosic biomass are cellulose, hemicellulose and lignin, which can be converted into monomer sugars such as glucose, fructose and xylose and then be converted into chemicals by process such as enzymatic or chemical hydrolysis (Alonso *et al.,* 2013b). Basically, biomass needs to be converted into reducing sugars at the first place before it is to be converted into bio-based chemicals and biofuels as shown in Figure 1.1 below. Levulinic acid (LA) is one of chemicals produced from biomass. The simultaneous degradation of both hemicellulose and cellulose is one of the main challenges in utilizing liqnocellulosic biomass. One of the most common thermochemical methods used to accomplish this process is acid hydrolysis (Sweygers *et al.,* 2017; Wettstein *et al.,* 2012). The process is carried out in the presence of acid catalyst. Routes for LA synthesis by acid hydrolysis are shown in Figure 1.2.

However, the presence of lignin slows down the reaction of acid hydrolysis. Thus, pretreatment was needed to improve the hydrolysis reaction. The examples of pretreatment are chemical pretreatment, physical pretreatment and biological pretreatment. Chemical pretreatments such as acid and alkali pretreatment are the most commonly applied techniques to remove lignin from lignocellulosic materials (Sun *et al.,* 2016). During both pretreatments, the ester linkages in lignin and hemicellulose are easily broken down under alkaline and acidic condition (Palamae *et al.,* 2014). Aqueous pretreatments such as dilute sulfuric acid and dilute alkali for example dilute sodium hydroxide have the advantages that they do not use organic solvents which can be expensive and can be carried out in batch reactors in laboratory studies (Bhagia *et al.,* 2016). Ultrasonic pretreatment is also widely used for biomass conversion. It should remove hemicellulose and disrupt the barrier of lignin (He *et al.*, 2017). Previous study found that ultrasonic waves can escalate the chemical reaction such as hydrolysis, resulted from the thermal effects, mechanical and cavitation of the ultrasound (Yu *et al.,* 2018).

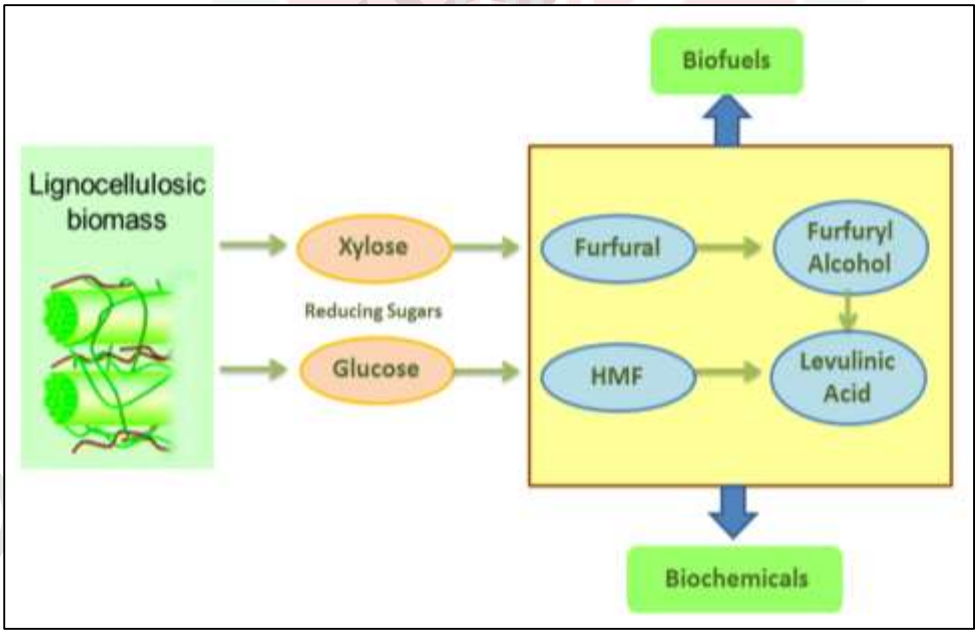

Figure 1.1: Flow of biomass conversion into biofuels and bio-chemicals (Alonso *et al.,* 2013b)**.**

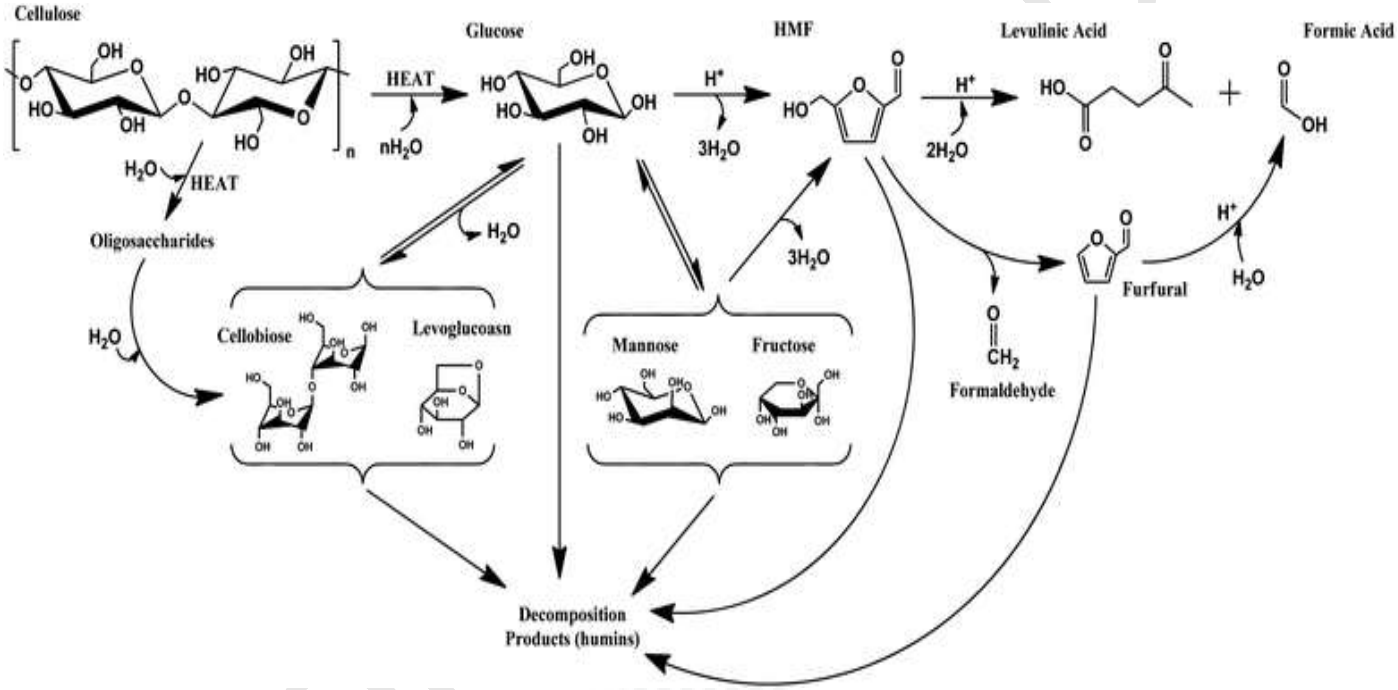

Figure 1.2: Acid hydrolysis reaction mechanism for LA synthesis. (Weingarten et al., 2012)

1.1.2 Oil Palm Biomass

Oil palm is known to be one of the potential sources of biomass. According to Ul Islam *et al. (*2016), Malaysia is stated as one of the foremost trading countries for oil palm plantation as well as in industrial productions. In 2011, 5 million hectares of land in Malaysia was utilized for palm oil plantation (Ul Islam *et al.,* 2016). Oil palm industry has significantly contributed to the Malaysia's economy especially in the plantation and manufacturing industry. Malaysia is also recognized as world's leading exporter of palm oil (Mumtaz *et al.,* 2010). Oil palm is often regarded as the most economic and productive oil crop (Ohimain and Izah, 2017). This is because oil palm can be extracted to produce edible oil known as palm oil and palm oil can be used as fuel via direct combustion (Nipattummakul *et al.,* 2012). Among 17 major oils traded in edible oil and fat market worldwide, palm oil is one of the main edible oils while palm kernel oil is used mainly in the oleo chemical industry (Zainudin *et al.,* 2009).

Palm oil is produced from the mesocarp (fiber) of the palm fruit while palm kernel oil is produced from the nut (kernel) of the fruit. In terms of chemical characteristics, palm oil contains mainly palmitic acid and oleic acid while lauric acid is the main fatty acid in palm kernel oil. Both palm oil and palm kernel oil can be utilized in many applications such as food, soaps, biodiesel and oleo chemicals either with or without any pretreatment.

Over the years, Malaysian palm oil industry has produced around 53 million tons of waste annually. However, a recent research shows a significant increase of oil palm solid residues at 80 million tons of dry residues in 2010, and estimated at 100 million by the year 2020 (Umar *et al.*, 2014). Oil palm biomass can be categorized into several types such as oil palm trunks, oil palm empty fruit bunches (OPEFB), oil palm fronds (OPF), oil palm leaves, palm kernel shells (PKS) and oil palm mesocarp fibers (OPMF) and palm oil milling effluent (POME) (Ahmad *et al.,* 2016; Mohammad *et al.,* 2012). Products and by products of oil palm is shown in Figure 1.3.

Basically, large quantities of oil palm biomass ended as wastes from the palm oil industry after oils (crude palm kernel oil and crude palm oil) were extracted from Fresh Fruit Bunch (FFB) as we can see in Figure 1.3.The production rates of the oil palm biomass with respect to the production rate of FFB are shown in Table 1.1. Recently, these biomasses present as readily available supply of raw materials for the production of green chemicals to curb the environmental issues.

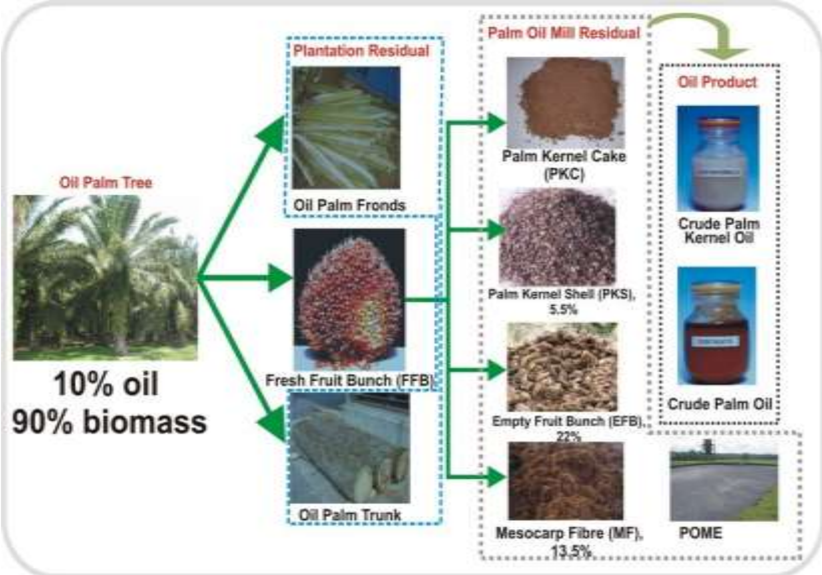

Figure 1.3: Products and by-products from oil palm biomass (Zafar, 2018)

Table 1.1: Production Rates of Oil Palm Biomass with Respect to FFB (Malaysia Energy Statistics Handbook, 2016).

Biomass available from Palm Oil Industry	% from FFB Quantity	Quantity million tonnes
OPEFB	23	21.24
OPMF	13	12.00
PKS	6	5.54
POME	60	55.40

1.2 Problem Statement

The commercially available LA is produced from carbohydrates and has limited success due to its high cost of raw materials for production. However, there are still many unexploited options of raw materials such as lignocellulosic biomass containing other carbohydrates and high starch that can be explored as an alternative raw material. Through many researches, they found that oil palm biomass including Oil Palm Mesocarp Fibre (OPMF) are considered as lignocellulosic biomass because their main components comprise of cellulose, hemicellulose and lignin. These lignocellulose biomasses can be converted into carbohydrates and be used to produce arrays of green chemicals including LA. The conversion of oil palm biomass from cellulose into levulinic acid can be seen in Figure 1.4 below. Unfortunately, most of OPMF are used as fuel in boilers and lack of research using OPMF available in literature for production of LA. This is because, previous research only utilized OPMF to produce sugars such as glucose and xylose. It is expected that OPMF can produced high amount of levulinic acid via hydrolysis reaction.

OPMF is recalcitrant in nature due to the highly crystalline nature of the cellulose and the lignin content. The successful conversion of lignocellulosic biomass needs an effective pretreatment as an important step to optimize the process of conversion into reducing sugar before production of LA. Various pretreatment techniques have been explored to improve the efficiency of hydrolysis reaction and it was found that acid pretreatment and alkaline pretreatment are the common pretreatment applied. Ultrasonic pretreatment also has been proved to enhance the production of sugar. Lack of studies carried out the combination of acid or alkaline pretreatment with ultrasonic technology. Combination of pretreatment methods, for example, ultrasonic-assisted acid pretreatment and ultrasonic-assisted alkaline pretreatment would improve the efficiency of biomass conversion in the overall process.

Previous works have only reported on pretreatments of OPMF for production of sugars, not on the effect of pretreatment on the production of LA. Through pretreatment, OPMF is expected to produced high amount of sugars which can be attributed to high yield of HMF and LA. Characterization studies are important to establish the morphological and structural changes due to pretreatment methods and acid hydrolysis reaction. However, only limited studies are reported on characterization of OPMF after hydrolysis and related to the changes with respect to levulinic acid synthesis.

Furthermore, no attempt has been done to study the optimization of LA production from OPMF via acid hydrolysis reaction in order to improve LA content and productivity. If the parameters affecting acid hydrolysis reaction conditions are optimized, the production of LA by this reaction is expected to be more efficient and higher yield of LA can be obtained.

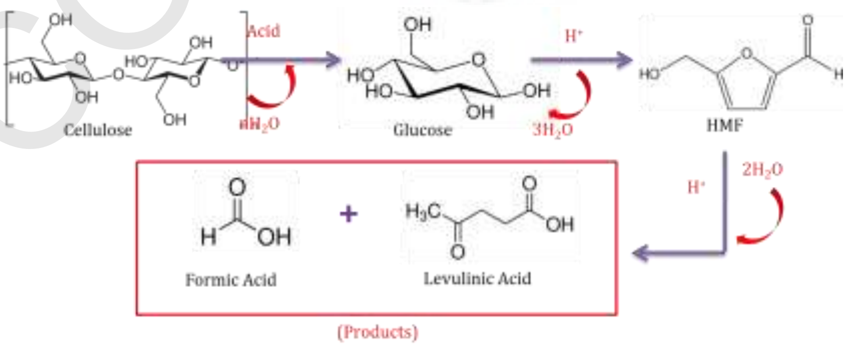

Figure 1.4: Chemical routes of biomass conversion into levulinic acid

1.3 Objectives

The objectives of this research are as follows:

1. To evaluate the effects of different pretreatment methods on formation of levulinic acid (LA) via acid hydrolysis of oil palm mesocarp fiber (OPMF)and characterization of OPMF.

2. To study the effects of process conditions on conversion of OPMF into LA via acid hydrolysis using Response Surface Methodology (RSM).
3.

1.4 Scope of Work

The scope of work for this research is primarily on the acid hydrolysis of OPMF for LA production. The research began by comparing several methods of pretreatment which were ultrasonic pretreatment, acid pretreatment and alkali pretreatment. For all pretreatments, effect of acid or alkali concentrations were investigated. Other parameter for ultrasonic pretreatments was on ultrasonic power while for acid and alkali pretreatments, both were investigated on effect of temperature. Effects of process conditions on conversion of LA were studied using Response Surface Methodology (RSM). Parameters involved in this study were effect of acid concentration, effect of temperature and effect of reaction time. The characterization of OPMF was also carried out. The properties investigated include moisture, lignin, cellulose and hemicellulose content.

1.5 Thesis Outline

This reports comprises of five chapters. Chapter 1, the introductory chapter, provides the background of study, the problem statement, objectives and scope of work. Chapter 2 gives detailed analysis of literature review which includes review on lignocellulosic materials, application of oil palm biomass, various pretreatment methods used, LA production and parameters that affected the hydrolysis reaction. All materials and methods are discussed in Chapter 3. Chapter 4 comprises the results and discussions namely on characterization of OPMF using proximate analysis, moisture analysis, TGA analysis, FTIR analysis, effects of several pretreatments on acid hydrolysis and Response Surface Methodology study on effects of process conditions on LA contents. Finally, chapter 5 concludes the present research work and provides the recommendations for future works.

REFERENCES

Abdel-Rahman, M.A., Tashiro, Y., Sonomoto, K., 2010. Lactic acid production from lignocellulose-derived sugars using lactic acid bacteria: Overview and limits. J. Biotechnol. 156, 286–301. https://doi.org/10.1016/j.jbiotec.2011.06.017

Abdullah, M.A., Nazir, M.S., Raza, M.R., Wahjoedi, B.A., Yussof, A.W., 2016. Autoclave and ultra-sonication treatments of oil palm empty fruit bunch fibers for cellulose extraction and its polypropylene composite properties. J. Clean. Prod. 126, 686–697. https://doi.org/10.1016/j.jclepro.2016.03.107

Abnisa, F., Daud W.M.A. Wan, W.M.A.W., Husin, W.N.W., Sahu, J.N., 2011. Utilization possibilities of palm shell as a source of biomass energy in Malaysia by producing bio-oil in pyrolysis process. Biomass and Bioenergy 35, 1863–1872. https://doi.org/10.1016/j.biombioe.2011.01.033

Adel, A.M., El-wahab, Z.H.A., Ibrahim, A.A., Al-shemy, M.T., 2011. Characterization of microcrystalline cellulose prepared from lignocellulosic materials . Part II: Physicochemical properties. Carbohydr. Polym. 83, 676–687. https://doi.org/10.1016/j.carbpol.2010.08.039

Ahmad, A., Buang, A., Bhat, A.H., 2016. Renewable and sustainable bioenergy production from microalgal co-cultivation with palm oil mill effluent (POME): A review. Renew. Sustain. Energy Rev. 65, 214–234. https://doi.org/10.1016/j.rser.2016.06.084

Ahmad Rizal, N.F.A., Ibrahim, M.F., Zakaria, M.R., Kamal Bahrin, E., Abd-Aziz, S., Hassan, M.., 2018. Combination of Superheated Steam with Laccase Pretreatment Together with Size Reduction to Enhance Enzymatic Hydrolysis of Oil Palm Biomass. Molecules 23(4), 811. https://doi.org/10.3390/molecules23040811

Alonso, D.M., Gallo, M.R., Mellmer, M.A., Wettstein, S.G., Dumesic, J.A., 2013a. Direct conversion of cellulose to levulinic acid and gamma-valerolactone using solid acid catalysts. Catal. Sci. Technol. 3, 927–931. https://doi.org/10.1039/c2cy20689g

Alonso, D.M., Wettstein, S.G., Dumesic, J.A., 2013b. Gamma-valerolactone, a sustainable platform molecule derived from lignocellulosic biomass. Green Chem. 15, 584–595. https://doi.org/10.1039/c3gc37065h

Alonso, D.M., Wettstein, S.G., Mellmer, M.A., Gurbuz, I., Dumesic, J.A., 2013c. Integrated conversion of hemicellulose and cellulose from lignocellulosic biomass. Energy Environ. Sci. 6, 76–80. https://doi.org/10.1039/c2ee23617f

Alvira, P., Tomás-Pejó, E., Ballesteros, M., Negro, M.J., 2010. Pretreatment technologies for an efficient bioethanol production process based on enzymatic hydrolysis: A review. Bioresour. Technol. 101, 4851–4861. https://doi.org/10.1016/j.biortech.2009.11.093

Amarasekara, A.S., Wiredu, B., 2012. A comparison of dilute aqueous p - toluenesulfonic and sulfuric acid pretreatments and saccharification of corn stover at moderate temperatures and pressures. Bioresour. Technol. 125, 114–118. https://doi.org/10.1016/j.biortech.2012.08.112

Ang, S.K., Shaza, E.M., Adibah, Y.A., Suraini, A.A., Madihah, M.S., 2013. Production of cellulases and xylanase by Aspergillus fumigatus SK1 using untreated oil palm trunk through solid state fermentation. Process Biochem. 48, 1293–1302. https://doi.org/10.1016/j.procbio.2013.06.019

Antal, M.J., Mok, W.S.L., Richards, G.N., 1990. Mechanism of formation of S (hydroxymethyl) -2-furalde- hyde from D-fructose and sucrose *. Carbohydr. Res. 199, 91–109.

Arantes, V., Saddler, J.N., 2011. Cellulose accessibility limits the effectiveness of minimum cellulase loading on the efficient hydrolysis of pretreated lignocellulosic substrates. Biotechnol. Biofuels 4. https://doi.org/10.1186/1754-6834-4-3

Ariffin, H., Hassan, M., Umi Kalsom, M., Abdullah, N., Shirai, Y., Ariffin, H., Ali Hassan, M., Kalsom Md Shah, U., Abdullah, N., Shirai, Y., 2008. Effect of physical, chemical and thermal pretreatments on the enzymatic hydrolysis of oil palm empty fruit bunch (OPEFB) (Kesan prarawatan fizikal, kimia dan termal terhadap hidrolisis enzimitik tandan kosong kelapa sawit). J. Trop. Agric. Fd. Sc 36, 0–0. https://doi.org/10.1007/s13205-015-0279-4

Asadieraghi, M., Wan Daud, W.M.A., 2014. Characterization of lignocellulosic biomass thermal degradation and physiochemical structure: Effects of demineralization by diverse acid solutions. Energy Convers. Manag. 82, 71–82. https://doi.org/10.1016/j.enconman.2014.03.007

Asakura, Y., Nishida, T., Matsuoka, T., Koda, S., 2008. Effects of ultrasonic frequency and liquid height on sonochemical efficiency of large-scale sonochemical reactors. Ultrason. Sonochem. 15, 244–250. https://doi.org/10.1016/j.ultsonch.2007.03.012

Asghari, F.S., Yoshida, H., 2006. Acid-Catalyzed Production of 5-Hydroxymethyl Furfural from D -Fructose in Subcritical Water. Ind. Eng. Chem. Res. 45, 2163–2173.

Assary, R.S., Redfern, P.C., Hammond, J.R., Greeley, J., Curtiss, L.A., 2010. Computational studies of the thermochemistry for conversion of glucose to levulinic acid. J. Phys. Chem. B 114, 9002–9009. https://doi.org/10.1021/jp101418f

Azubuike, C.P., Rodríguez, H., Okhamafe, A.O., Rogers, R.D., 2012. Physicochemical properties of maize cob cellulose powders reconstituted from ionic liquid solution. Cellulose 19, 425–433. https://doi.org/10.1007/s10570-011-9631-y

Bhagia, S., Li, H., Gao, X., Kumar, R., Wyman, C.E., 2016. Biotechnology for Biofuels Flowthrough pretreatment with very dilute acid provides insights into high lignin contribution to biomass recalcitrance. Biotechnol. Biofuels 1–15. https://doi.org/10.1186/s13068-016-0660-5

Bond, J.Q., Upadhye, A.A., Olcay, H., Tompsett, G.A., Jae, J., Xing, R., Alonso, D.M., Wang, D., Zhang, T., Kumar, R., Foster, A., Sen, S.M., Maravelias, C.T., Malina, R., Barrett, S.R.H., Lobo, R., Wyman, C.E., Dumesic, J.A., Huber, G.W., 2014. Production of renewable jet fuel

range alkanes and commodity chemicals from integrated catalytic processing of biomass. Energy Environ. Sci. 7, 1500–1523. https://doi.org/10.1039/C3EE43846E
Bozell, J.J. and Petersen, G.R., 2010. Technology development for the production of biobased products from biorefinery carbohydrates — the US Department of Energy ' s " Top 10 " revisited. Green Chem. 12. https://doi.org/10.1039/b922014c
Bozell, J.J., Moens, L., Elliott, D.C., Wang, Y., Neuenscwander, G.G., Fitzpatrick, S.W., Bilski, R.J., Jarnefeld, J.L., 2000. Production of levulinic acid and use as a platform chemical for derived products. Resour. Conserv. Recycl. 28, 227–239. https://doi.org/10.1016/S0921-3449(99)00047-6
Braga, R.M., Costa, T.R., Freitas, J.C.O., Barros, J.M.F., Melo, D.M.A., Melo, M.A.F., 2014. Pyrolysis kinetics of elephant grass pretreated biomasses. J. Therm. Anal. Calorim. 117, 1341–1348. https://doi.org/10.1007/s10973-014-3884-2
Brasholz, M., Von Kaenel, K., Hornung, C.H., Saubern, S., Tsanaktsidis, J., 2011. Highly efficient dehydration of carbohydrates to 5-(chloromethyl)furfural (CMF), 5-(hydroxymethyl)furfural (HMF) and levulinic acid by biphasic continuous flow processing. Green Chem. 13, 1114–1117. https://doi.org/10.1039/c1gc15107j
Broido, A., Forest, P.S., Station, R.E., 1969. A Simple , Sensitive Graphical Method of Treating Thermogravimetric Analysis Data * 1773, 1761–1773.
Çetinkol, Ö.P., Dibble, D.C., Cheng, G., Kent, M.S., Knierim, B., Auer, M., Wemmer, D.E., Pelton, J.G., Melnichenko, Y.B., Ralph, J., Simmons, B.A., Holmes, B.M., 2010. Understanding the impact of ionic liquid pretreatment on eucalyptus 1, 33–46.
Chang, C., Cen, P., Ma, X., 2007. Levulinic acid production from wheat straw. Bioresour. Technol. 98, 1448–1453. https://doi.org/10.1016/j.biortech.2006.03.031
Chang, C., Ma, X., Cen, P., 2006. Kinetics of Levulinic Acid Formation from Glucose Decomposition at High Temperature. Chinese J. Chem. Eng. 14, 708–712. https://doi.org/10.1016/S1004-9541(06)60139-0
Chen, B., Zhao, B., Li, M., Liu, Q., Sun, R., 2017. Bioresource Technology Fractionation of rapeseed straw by hydrothermal / dilute acid pretreatment combined with alkali post-treatment for improving its enzymatic hydrolysis. Bioresour. Technol. 225, 127–133. https://doi.org/10.1016/j.biortech.2016.11.062
Chen, C., Boldor, D., Aita, G., Walker, M., 2012. Ethanol production from sorghum by a microwave-assisted dilute ammonia pretreatment. Bioresour. Technol. 110, 190–197. https://doi.org/10.1016/j.biortech.2012.01.021
Chen, S.S., Wang, L., Yu, I.K.M., Tsang, D.C.W., Hunt, A.J., 2018. Valorization of lignocellulosic fi bres of paper waste into levulinic acid using solid and aqueous Brønsted acid. Bioresour. Technol. 247, 387–394. https://doi.org/10.1016/j.biortech.2017.09.110
Chen, S.S., Yu, I.K.M., Tsang, D.C.W., Yip, A.C.K., Khan, E., Wang, L., Sik, Y., Sun, C., 2017. Valorization of cellulosic food waste into levulinic acid catalyzed by heterogeneous Brønsted acids :

Temperature and solvent effects. Chem. Eng. J. 327, 328–335. https://doi.org/10.1016/j.cej.2017.06.108
Chen, W.H., Tu, Y.-J., Sheen, H.-K., 2010. Impact of dilute acid pretreatment on the structure of bagasse for bioethanol production. Int. J. energy Res. 31, 265–274. https://doi.org/10.1002/er.1566
Cheng, F., Brewer, C.E., 2017. Producing jet fuel from biomass lignin : Potential pathways to alkyl- benzenes and cycloalkanes. Renew. Sustain. Energy Rev. 72, 673–722. https://doi.org/10.1016/j.rser.2017.01.030
Chiesa, S., Gnansounou, E., 2014. Use of empty fruit bunches from the oil palm for bioethanol production: A thorough comparison between dilute acid and dilute alkali pretreatment. Bioresour. Technol. 159, 355–364. https://doi.org/10.1016/j.biortech.2014.02.122
Chin, S.X., Chia, C.H., Zakaria, S., Fang, Z., Ahmad, S., 2015. Ball milling pretreatment and diluted acid hydrolysis of oil palm empty fruit bunch (EFB) fibres for the production of levulinic acid. J. Taiwan Inst. Chem. Eng. 52, 85–92. https://doi.org/10.1016/j.jtice.2015.01.028
Chong, P.S., Jahim, J.M., Harun, S., Lim, S.S., Mutalib, S.A., Hassan, O., Nor, M.T.M., 2013. Enhancement of batch biohydrogen production from prehydrolysate of acid treated oil palm empty fruit bunch. Int. J. Hydrogen Energy 38, 9592–9599. https://doi.org/10.1016/j.ijhydene.2013.01.154
Choudhary, V., Mushrif, S.H., Ho, C., Anderko, A., Nikolakis, V., Marinkovic, N.S., Frenkel, A.I., Sandler, S.I., Vlachos, D.G., 2013. Insights into the Interplay of Lewis and Brønsted Acid Catalysts in Glucose and Fructose Conversion to 5 - (Hydroxymethyl)furfural and Levulinic Acid in Aqueous Media. J. Am. Chem. Soc. 135, 3997–4006.
Christia, A., Setiowati, A.D., Millati, R., Karimi, K., Cahyanto, M.N., Niklasson, C., Taherzadeh, M.J., 2016. Ethanol production from alkali-pretreated oil palm empty fruit bunch by simultaneous saccharification and fermentation with *mucor indicus*. Int. J. Green Energy 13, 566–572. https://doi.org/10.1080/15435075.2014.978004
Chundawat, S.P.S., Bellesia, G., Uppugundla, N., Da Costa Sousa, L., Gao, D., Cheh, A.M., Agarwal, U.P., Bianchetti, C.M., Phillips, G.N., Langan, P., Balan, V., Gnanakaran, S., Dale, B.E., 2011. Restructuring the crystalline cellulose hydrogen bond network enhances its depolymerization rate. J. Am. Chem. Soc. 133, 11163–11174. https://doi.org/10.1021/ja2011115
Climent, M.J., Corma, A., Iborra, S., 2014. Conversion of biomass platform molecules into fuel additives and liquid hydrocarbon fuels. Green Chem. 516–547. https://doi.org/10.1039/c3gc41492b
Conde-Mejía, C., Jiménez-Gutiérrez, A. and El-Halwagi, M., 2012. A comparison of pretreatment methods for bioethanol production from lignocellulosic materials. Process Saf. Environ. Prot. 90, 189–202. https://doi.org/10.1016/j.psep.2011.08.004
Costa, A.G., Pinheiro, G.C., Pinheiro, F.G.C., Dos Santos, A.B., Santaella, S.T., Leit??o, R.C., 2013. Pretreatment strategies to improve anaerobic biodegradability and methane production potential of the palm oil mesocarp fibre. Chem. Eng. J. 230, 158–165. https://doi.org/10.1016/j.cej.2013.06.070

Costa, A.G., Pinheiro, G.C., Pinheiro, F.G.C., Dos Santos, A.B., Santaella, S.T., Leitão, R.C., 2013. Pretreatment strategies to improve anaerobic biodegradability and methane production potential of the palm oil mesocarp fibre. Chem. Eng. J. 230, 158–165. https://doi.org/10.1016/j.cej.2013.06.070
Da Silva, A.S.A., Inoue, H., Endo, T., Yano, S., Bon, E.P.S., 2010. Milling pretreatment of sugarcane bagasse and straw for enzymatic hydrolysis and ethanol fermentation. Bioresour. Technol. 101, 7402–7409. https://doi.org/10.1016/j.biortech.2010.05.008
Demirbas, A., 2011. Competitive liquid biofuels from biomass. Appl. Energy 88, 17–28. https://doi.org/10.1016/j.apenergy.2010.07.016
Demirbaş, A., 2005. Bioethanol from cellulosic materials: A renewable motor fuel from biomass. Energy Sources 27, 327–337. https://doi.org/10.1080/00908310390266643
Ding, D., Wang, J., Xi, J., Liu, X., Lu, G., Wang, Y., 2014. High-yield production of levulinic acid from cellulose and its upgrading to γ-valerolactone. Green Chem. 16, 3846–3853. https://doi.org/10.1039/c4gc00737a
Efremov, A.A., Pervyshina, G.G., Kuznetsov, B.N., 1998. Production of levulinic acid from wood raw material in the presence of sulfuric acid and its salts. Chem. Nat. Compd. 34, 0–1.
Efremov, A.A., Pervyshina, G.G., Kuznetsov, B.N., 1997. Thermocatalytic transformations of wood and cellulose in the presence of HCl, HBr, and H2SO4. Chem. Nat. Compd. 33, 84–85.
Elumalai, S., Agarwal, B., Sangwan, R.S., 2016. Thermo-chemical pretreatment of rice straw for further processing for levulinic acid production. Bioresour. Technol. 218, 232–246. https://doi.org/10.1016/j.biortech.2016.06.037
Environ, E., Gonz, G.M., Assary, R.S., Curtiss, L.A., 2012. Experimental and theoretical studies of the acid-catalyzed conversion of furfuryl alcohol to levulinic acid in aqueous solution. Energy Environ. Sci. 5, 6981–6989. https://doi.org/10.1039/c2ee03465d
Fachri, B.A., Abdilla, R.M., Bovenkamp, H.H. Van De, Rasrendra, C.B., Heeres, H.J., 2015. Experimental and Kinetic Modeling Studies on the Sulfuric Acid Catalyzed Conversion of d -Fructose to 5-Hydroxymethylfurfural and Levulinic Acid in Water. ACS Sustain. Chem. Eng. 3, 3024–3034. https://doi.org/10.1021/acssuschemeng.5b00023
Fang, Q., Hanna, M.A., 2002. Experimental studies for levulinic acid production from whole kernel grain sorghum. Bioresour. Technol. 81, 187–192. https://doi.org/10.1016/S0960-8524(01)00144-4
Galletti, A.M.., Antonetti, C., De Luise, V., Licursi, D., Nassi, N., 2012. Levulinic Acid Production From Waste Biomass. BioResources 7, 1824–1835. https://doi.org/10.15376/biores.7.2.1824-1835
Gandarias, I., Arias, P.L., 2014. Heterogeneous acid-catalysts for the production of furan-derived compounds (furfural and hydroxymethylfurfural) from renewable carbohydrates : A review. Catal. Today 234, 42–58. https://doi.org/10.1016/j.cattod.2013.11.027
Girisuta, B., 2007. Levulinic Acid from Lignocellulosic Biomass.
Girisuta, B., Danon, B., Manurung, R., Janssen, L.P.B.M., Heeres, H.J.,

2008. Experimental and kinetic modelling studies on the acid-catalysed hydrolysis of the water hyacinth plant to levulinic acid. Bioresour. Technol. 99, 8367–8375. https://doi.org/10.1016/j.biortech.2008.02.045
Girisuta, B., Dussan, K., Haverty, D., Leahy, J.J., Hayes, M.H.B., 2013. A kinetic study of acid catalysed hydrolysis of sugar cane bagasse to levulinic acid. Chem. Eng. J. 217, 61–70. https://doi.org/10.1016/j.cej.2012.11.094
Girisuta, B., Janssen, L.P.B.M., Heeres, H.J., 2007. Kinetic study on the acid-catalyzed hydrolysis of cellulose to levulinic acid. Ind. Eng. Chem. Res. 46, 1696–1708. https://doi.org/10.1021/ie061186z
Girisuta, B., Janssen, L.P.B.M., Heeres, H.J., 2006. A Kinetic Study on the Conversion of Glucose to Levulinic Acid. Chem. Eng. Res. Des. 84, 339–349. https://doi.org/10.1205/cherd05038
Grote, A.F.V., Tollens, B., 1875. Untersuchungen über Kohlenhydrate. I. Ueber die bei Einwirkung von Schwefelsäure auf Zucker entstehende Säure (Levulinsäure). European J. Org. Chem. 175, 181–204.
Guo, Y., Li, K., Yu, X., Clark, J.H., 2008. Mesoporous H 3 PW 12 O 40 -silica composite : Efficient and reusable solid acid catalyst for the synthesis of diphenolic acid from levulinic acid 81, 182–191. https://doi.org/10.1016/j.apcatb.2007.12.020
Gupta, V.K., Tuohy, M.G., 2014. Biofuel technologies: Recent developments, Biofuel Technologies: Recent Developments. https://doi.org/10.1007/978-3-642-34519-7
Gürbüz, E.I., 2012. Strategies for the Catalytic Conversion of Lignocellulose-Derived Carbohydrates to Chemicals and Fuels. Univ. WISCONSIN-MADISON.
Hashim, R., Said, N., Lamaming, J., Baskaran, M., Sulaiman, O., Sato, M., Hiziroglu, S., Sugimoto, T., 2011. Influence of press temperature on the properties of binderless particleboard made from oil palm trunk. Mater. Des. 32, 2520–2525. https://doi.org/10.1016/j.matdes.2011.01.053
Hayes, D.J., 2009. An examination of biorefining processes, catalysts and challenges. Catal. Today 145, 138–151. https://doi.org/10.1016/j.cattod.2008.04.017
Hayes, D.J., Ross, P.J., Hayes, P.M.H.B., Fitzpatrick, P.S., 1999. The Biofine Process : Production of Levulinic Acid , Furfural and Formic Acid from Lignocellulosic Feedstocks.
He, Z., Wang, Z., Zhao, Z., Yi, S., Mu, J., Wang, X., 2017. Ultrasonics Sonochemistry Influence of ultrasound pretreatment on wood physiochemical structure. Ultrason. - Sonochemistry 34, 136–141. https://doi.org/10.1016/j.ultsonch.2016.05.035
Heeres, H., Handana, R., Chunai, D., Rasrendra, C.B., Girisuta, B., Heeres, H.J., 2009. Combined dehydration /(transfer) -hydrogenation of C6-sugars (D-glucose and D-fructose) to c -valerolactone using ruthenium catalysts. Green Chem. 11, 1247–1255. https://doi.org/10.1039/b904693c
Hendriks, A.T.W.M., Zeeman, G., 2009. Bioresource Technology Pretreatments to enhance the digestibility of lignocellulosic biomass 100, 10–18. https://doi.org/10.1016/j.biortech.2008.05.027
Hooi, K.K., Alauddin, Z.A.Z., Ong, L.K., 2009. Laboratory-scale pyrolysis of

oil palm pressed fruit fibres. J. Oil Palm Res. 21, 577–587.
Horvat, J., Klaić, B., Metelko, B., Šunjić, V., 1985. Mechanism of levulinic acid formation. Tetrahedron Lett. 26, 2111–2114.
Hossain, A., Jewaratnam, J., Ganesan, P., 2016. Prospect of hydrogen production from oil palm biomass by thermochemical process e A review. Int. J. Hydrogen Energy 41, 16637–16655. https://doi.org/10.1016/j.ijhydene.2016.07.104
Hsu, T., Guo, G., Chen, W., Hwang, W., 2010. Bioresource Technology Effect of dilute acid pretreatment of rice straw on structural properties and enzymatic hydrolysis. Bioresour. Technol. 101, 4907–4913. https://doi.org/10.1016/j.biortech.2009.10.009
Hu, X., Kadarwati, S., Wang, S., Song, Y., Hasan, M.D.M., Li, C.Z., 2015. Biomass-derived sugars and furans: Which polymerize more during their hydrolysis? Fuel Process. Technol. 137, 212–219. https://doi.org/10.1016/j.fuproc.2015.04.024
Huber, G.W., Iborra, S., Corma, A., 2006. Synthesis of Transportation Fuels from Biomass : Chemistry, Catalysts and Engineering. Chem. Rev. 106, 4044–4098.
Iberahim, N.I., Jahim, J.M., Harun, S., Nor, M.T.M., Hassan, O., 2013. Sodium Hydroxide Pretreatment and Enzymatic Hydrolysis of Oil Palm Mesocarp Fiber. Int. J. Chem. Eng. Apl. 4, 101–105. https://doi.org/10.7763/IJCEA.2013.V4.272
Ibraheem, O., Ndimba, B.K., 2013. Molecular adaptation mechanisms employed by ethanologenic bacteria in response to lignocellulose-derived inhibitory compounds. Int. J. Biol. Sci. 9, 598–612. https://doi.org/10.7150/ijbs.6091
Idris, S.S., Rahman, N.A., Ismail, K., 2012. Combustion characteristics of Malaysian oil palm biomass, sub-bituminous coal and their respective blends via thermogravimetric analysis (TGA). Bioresour. Technol. 123, 581–591. https://doi.org/10.1016/j.biortech.2012.07.065
Jamaludin, J., Adam, F., Rasid, R.A., Hassan, Z., 2017. Thermal studies on polysaccharides film Arabic gum. Chem. Eng. Res. Bull. 19, 0379-7678. https://doi.org/10.3329/cerb.v19i0.33800
Jeong, H., Jang, S., Hong, C., Kim, S., Lee, S., Min, S., Weon, J., Choi, I., 2017. Levulinic acid production by two-step acid-catalyzed treatment of Quercus mongolica using dilute sulfuric acid. Bioresour. Technol. 225, 183–190. https://doi.org/10.1016/j.biortech.2016.11.063
Jeong, H., Park, S., Ryu, G., Choi, J., Kim, J., Choi, W., Lee, S.M., Choi, J.W., Choi, G., 2018. Catalytic conversion of hemicellulosic sugars derived from biomass to levulinic acid. Catal. Commun. 117, 19–25. https://doi.org/10.1016/j.catcom.2018.04.016
Jiang, D., Ge, X., Zhang, Q., Li, Y., 2016. Comparison of liquid hot water and alkaline pretreatments of giant reed for improved enzymatic digestibility and biogas energy production. Bioresour. Technol. 216, 60–68. https://doi.org/10.1016/j.biortech.2016.05.052
Joshi, S.S., Zodge, A.D., Pandare, K.V., Kulkarni, B.D., 2014. Efficient conversion of cellulose to levulinic acid by hydrothermal treatment using Zirconium dioxide as a recyclable solid acid catalyst. Ind. Eng. Chem. Res. 53, 18796–18805. https://doi.org/10.1021/ie5011838
Jow, J., Rorrer, G.L., Hawley, M.C., Lamport, D.T.A., 1987. Dehydration of D-Fructose to Levulinic Acid over LZY Zeolite Catalyst. Biomass 14,

185–194.
Jung, S.J., Kim, S.H., Chung, I.M., 2015. Comparison of lignin, cellulose, and hemicellulose contents for biofuels utilization among 4 types of lignocellulosic crops. Biomass and Bioenergy 83, 322–327. https://doi.org/10.1016/j.biombioe.2015.10.007
Kabir, G., Din, A.T.M., Hameed, B.H., 2017. Bioresource Technology Pyrolysis of oil palm mesocarp fiber and palm frond in a slow-heating fixed-bed reactor : A comparative study. Bioresour. Technol. 241, 563–572. https://doi.org/10.1016/j.biortech.2017.05.180
Katinonkul, W., Lee, J.S., Ha, S.H., Park, J.Y., 2012. Enhancement of enzymatic digestibility of oil palm empty fruit bunch by ionic-liquid pretreatment. Energy 47, 11–16. https://doi.org/10.1016/j.energy.2012.06.050
Kelly-Yong, T.L., Lee, K.T., Mohamed, A.R., Bhatia, S., 2007. Potential of hydrogen from oil palm biomass as a source of renewable energy worldwide. Energy Policy 35, 5692–5701. https://doi.org/10.1016/j.enpol.2007.06.017
Khalil, H.P.S.A., Alwani, M.S., Ridzuan, R., Kamarudin, H., Khairul, A., 2008. Chemical composition, morphological characteristics, and cell wall structure of Malaysian oil palm fibers. Polym. - Plast. Technol. Eng. 47, 273–280. https://doi.org/10.1080/03602550701866840
Kim, J.S., Lee, Y.Y., Kim, T.H., 2016. A review on alkaline pretreatment technology for bioconversion of lignocellulosic biomass. Bioresour. Technol. 199, 42–48. https://doi.org/10.1016/j.biortech.2015.08.085
Kong, S.H., Loh, S.K., Bachmann, R.T., Rahim, S.A., Salimon, J., 2014. Biochar from oil palm biomass: A review of its potential and challenges. Renew. Sustain. Energy Rev. 39, 729–739. https://doi.org/10.1016/j.rser.2014.07.107
Kricheldorf, H.R., Hobzova, R., Schwarz, G., 2003. Cyclic hyperbranched polyesters derived from 4,4-bis(4′ -hydroxyphenyl)valeric acid. Polymer (Guildf). 44, 7361–7368. https://doi.org/10.1016/j.polymer.2003.09.041
Kuglarz, M., Gunnarsson, I.B., Svensson, S., Prade, T., Johansson, E., Angelidaki, I., 2014. Ethanol production from industrial hemp : Effect of combined dilute acid / steam pretreatment and economic aspects. Bioresour. Technol. 163, 236–243. https://doi.org/10.1016/j.biortech.2014.04.049
Kumar, P., Barrett, D.M., Delwiche, M.J., Stroeve, P., 2009. Methods for Pretreatment of Lignocellulosic Biomass for Efficient Hydrolysis and Biofuel Production. Bioresour. Technol. 42–48. https://doi.org/10.1016/j.psep.2011.08.004
Lahijani, P., Zainal, Z.A., Mohamed, A.R., 2012. Catalytic effect of iron species on CO2gasification reactivity of oil palm shell char. Thermochim. Acta 546, 24–31. https://doi.org/10.1016/j.tca.2012.07.023
Lai, H., Peng, J., Liao, B., Xian, J., Zhang, Z., Guo, J., Cui, Y., 2011. Experimental studies for levulinic acid production from water hyacinth plant. 2011 Int. Conf. Mater. Renew. Energy Environ. 1, 373–376. https://doi.org/10.1109/ICMREE.2011.5930833
Lamaming, J., Hashim, R., Sulaiman, O., Sugimoto, T., Sato, M., Hiziroglu, S., 2014. Measurement of some properties of binderless

particleboards made from young and old oil palm trunks. Meas. J. Int. Meas. Confed. 47, 813–819. https://doi.org/10.1016/j.measurement.2013.10.007
Lange, J.P., 2007. Lignocellulose conversion: an introduction to chemistry, process and economics. Biofuels, Bioprod. biorefining 1, 39–48. https://doi.org/10.1002/bbb
Lee, J., Jeffries, T.W., 2011. Bioresource Technology Efficiencies of acid catalysts in the hydrolysis of lignocellulosic biomass over a range of combined severity factors. Bioresour. Technol. 102, 5884–5890. https://doi.org/10.1016/j.biortech.2011.02.048
Leonard, R.H., 1956. Levulinic Acid as a Basic Chemical Raw Material. Ind. Eng. Chem. 48, 1330–1341. https://doi.org/10.1021/ie50560a033
Li, B., Filpponen, I., Argyropoulos, D.S., 2010. Acidolysis of Wood in Ionic Liquids. Ind. Eng. Chem. Res. 49, 3126–3136.
Li, J., Jiang, Z., Hu, L., Hu, C., 2014. Selective conversion of cellulose in corncob residue to levulinic acid in an aluminum trichloride-sodium chloride system. ChemSusChem 610064, 2482–2488. https://doi.org/10.1002/cssc.201402384
Li, K., Hu, J., Li, W., Ma, F., Xu, L., Guo, Y., 2009. Design of mesostructured H 3 PW 12 O 40 -silica materials with controllable ordered and disordered pore geometries and their application for the synthesis of diphenolic acid †. J. Mater. Chem. 19, 8628–8638. https://doi.org/10.1039/b910416j
Li, S., Yang, X., Zhang, Y., Ma, H., Qu, W., Ye, X., Muatasim, R., 2016. Enzymolysis kinetics and structural characteristics of rice protein with energy-gathered ultrasound and ultrasound assisted alkali pretreatments. Ultrason. Sonochem. 31, 85–92. https://doi.org/10.1016/j.ultsonch.2015.12.005
Liao, Z., Huang, Z., Hu, H., Zhang, Y., Tan, Y., 2011. Microscopic structure and properties changes of cassava stillage residue pretreated by mechanical activation. Bioresour. Technol. 102, 7953–7958. https://doi.org/10.1016/j.biortech.2011.05.067
Lilja, J., Murzin, D.Y., Salmi, T., Aumo, J., Mäki-arvela, P., Sundell, M., 2002. Esterification of different acids over heterogeneous and homogeneous catalysts and correlation with the Taft equation. J. Mol. Catal. 183, 555–563.
Lima, M.A., Lavorente, G.B., Kp, H., Bragatto, J., Rezende, C.A., Bernardinelli, O.D., Eduardo, R., Gomez, L.D., Mcqueen-mason, S.J., Labate, C.A., Polikarpov, I., 2013. Effects of pretreatment on morphology , chemical composition and enzymatic digestibility of eucalyptus bark : a potentially valuable source of fermentable sugars for biofuel production – part 1. Biotechnol. Biofuels 6, 1–17.
Liu, G., Bao, J., 2017. Bioresource Technology Evaluation of electricity generation from lignin residue and biogas in cellulosic ethanol production. Bioresour. Technol. https://doi.org/10.1016/j.biortech.2017.07.022
Liu, Y., Lotero, E., Jr, J.G.G., 2006. A comparison of the esterification of acetic acid with methanol using heterogeneous versus homogeneous acid catalysis. J. Catal. 242, 278–286. https://doi.org/10.1016/j.jcat.2006.05.026
Loh, S.K., 2017. The potential of the Malaysian oil palm biomass as a

renewable energy source. Energy Convers. Manag. 141, 285–298. https://doi.org/10.1016/j.enconman.2016.08.081
Loow, Y., Wu, T.Y., Tan, K.A., Lim, Y.S., Fong, L., 2015. Recent Advances in Application of Inorganic Salt Pretreatment for Transforming Lignocellulosic Biomass into Reducing Sugars. J. Agric. Food Chem. 1–48. https://doi.org/10.1021/acs.jafc.5b01813
Madani, M., 2011. Structure , optical and thermal decomposition characters of LDPE graft copolymers synthesized by gamma irradiation. Curr. Appl. Phys. 11, 70–76. https://doi.org/10.1016/j.cap.2010.06.021
Mahmud, N.A.N., Baharuddin, A.S., Bahrin, E.K., Sulaiman, A., Naim, M.N., Zakaria, R., Hassan, M.A., Nishida, H., Shirai, Y., 2013. Enzymatic saccharification of oil palm mesocarp fiber (OPMF) treated with superheated steam. BioResources 8, 1320–1331. https://doi.org/10.15376/biores.8.1.1320-1331
Mäki-Arvela, P., Anugwom, I., Virtanen, P., Sjöholm, R., Mikkola, J.P., 2010. Dissolution of lignocellulosic materials and its constituents using ionic liquids-A review. Ind. Crops Prod. 32, 175–201. https://doi.org/10.1016/j.indcrop.2010.04.005
Manimaran, P., Senthamaraikannan, P., Sanjay, M.R., Marichelvam, M.K., 2018. Study on characterization of Furcraea foetida new natural fi ber as composite reinforcement for lightweight applications. Carbohydr. Polym. 181, 650–658. https://doi.org/10.1016/j.carbpol.2017.11.099
Mascal, M., Nikitin, E.B., 2008. Direct , High-Yield Conversion of Cellulose into Biofuel. Angew. Chemie 8042–8044. https://doi.org/10.1002/ange.200801594
Matsumura, S., Hlil, A.R., Lepiller, C., Gaudet, J., Guay, D., Shi, Z., Holdcroft, S., Hay, A.S., 2008. Ionomers for proton exchange membrane fuel cells with sulfonic acid groups on the end-groups: Novel branched poly(ether-ketone)s. Am. Chem. Soc. Polym. Prepr. Div. Polym. Chem. 49, 511–512. https://doi.org/10.1002/pola
Mazaheri, H., Lee, K.T., Mohamed, A.R., 2013. Influence of temperature on liquid products yield of oil palm shell via subcritical water liquefaction in the presence of alkali catalyst. Fuel Process. Technol. 110, 197–205. https://doi.org/10.1016/j.fuproc.2012.12.015
Md Yunos, N.S.H., Baharuddin, A.S., Md Yunos, K.F., Naim, N., Nishida, H., 2012. Physicochemical property changes of oil palm mesocarp fibers treated with high-pressure steam. BioResources 7, 5983–5994. https://doi.org/10.15376/biores.7.4.5983-5994
Medina, J.D.C., Woiciechowski, A., Filho, A.Z., Nigam, P.S., Ramos, L.P., Soccol, C.R., 2016. Steam explosion pretreatment of oil palm empty fruit bunches (EFB) using autocatalytic hydrolysis: A biorefinery approach. Bioresour. Technol. 199, 173–180. https://doi.org/10.1016/j.biortech.2015.08.126
Meinita, M.D.N., Marhaeni, B., Winanto, T., Setyaningsih, D., Hong, Y.K., 2015. Catalytic efficiency of sulfuric and hydrochloric acids for the hydrolysis of Gelidium latifolium (Gelidiales, Rhodophyta) in bioethanol production. J. Ind. Eng. Chem. 27, 108–114. https://doi.org/10.1016/j.jiec.2014.12.024
Mir, J.M., Maurya, R.C., Vishwakarma, P.K., 2017. Corrosion resistance and thermal behavior of acetylacetonato- oxoperoxomolybdenum (VI

) complex of maltol : Experimental and DFT studies ScienceDirect Corrosion resistance and thermal behavior of acetylacetonato-oxoperoxomolybdenum (VI) complex of malt. Karbala Int. J. Mod. Sci. 3, 212–223. https://doi.org/10.1016/j.kijoms.2017.08.006

Misson, M., Haron, R., Kamaroddin, M.F.A., Amin, N.A.S., 2009. Pretreatment of empty palm fruit bunch for production of chemicals via catalytic pyrolysis. Bioresour. Technol. 100, 2867–2873. https://doi.org/10.1016/j.biortech.2008.12.060

Mohamed, P., Jahim, J., Harun, S., Markom, M., Aminah, N., Hassan, O., Balan, V., Dale, B.E., Tusirin, M., Nor, M., 2016. Effects of changes in chemical and structural characteristic of ammonia fibre expansion (AFEX) pretreated oil palm empty fruit bunch fibre on enzymatic saccharification and fermentability for biohydrogen. Bioresour. Technol. 211, 200–208. https://doi.org/10.1016/j.biortech.2016.02.135

Mohammad, N., Alam, M.Z., Kabbashi, N.A., Ahsan, A., 2012. Effective composting of oil palm industrial waste by filamentous fungi: A review. Resour. Conserv. Recycl. 58, 69–78. https://doi.org/10.1016/j.resconrec.2011.10.009

Moodley, P., Kana, E.B.G., 2017. Comparison of a two-stage and a combined single stage salt-acid based lignocellulosic pretreatment for enhancing enzymatic sacchari fi cation. Ind. Crop. Prod. 108, 219–224. https://doi.org/10.1016/j.indcrop.2017.06.048

Morales-delaRosa, S., Campos-Martin, J.M., Fierro, J.L.G., 2014. Optimization of the process of chemical hydrolysis of cellulose to glucose. Cellulose 21, 2397–2407. https://doi.org/10.1007/s10570-014-0280-9

Moreau, C., Durand, R., Razigade, S., Duhamet, J., Faugeras, P., Rivalier, P., Ros, P., Avignon, G., 1996. Dehydration of fructose to 5-hydroxymethylfurfural over H-mordenites. Appl. Catal. A Gen. 145, 211–224.

Morone, A., Apte, M., Pandey, R.A., 2015. Levulinic acid production from renewable waste resources: Bottlenecks, potential remedies, advancements and applications. Renew. Sustain. Energy Rev. 51, 548–565. https://doi.org/10.1016/j.rser.2015.06.032

Mumtaz, T., Yahaya, N.A., Abd-Aziz, S., Abdul Rahman, N., Yee, P.L., Shirai, Y., Hassan, M.A., 2010. Turning waste to wealth-biodegradable plastics polyhydroxyalkanoates from palm oil mill effluent-a Malaysian perspective. J. Clean. Prod. 18, 1393–1402. https://doi.org/10.1016/j.jclepro.2010.05.016

Muranaka, Y., Suzuki, T., Sawanishi, H., Hasegawa, I., Mae, K., 2014. Effective production of levulinic acid from biomass through pretreatment using phosphoric acid, hydrochloric acid, or ionic liquid. Ind. Eng. Chem. Res. 53, 11611–11621. https://doi.org/10.1021/ie501811x

Nabilah-jansar, K., Muhaimin, A., Ali, M., 2018. Review Article : Appropriate Hydrothermal Pretreatment of Oil Palm Biomass in Palm Oil Mill 4, 31–40.

Nguyen, C. Van, Lewis, D., Chen, W., Huang, H., Abdullah, Z., Yamauchi, Y., Wu, K.C., 2016. Combined treatments for producing 5-hydroxymethylfurfural (HMF) from lignocellulosic biomass. Catal.

Today 278, 344–349. https://doi.org/10.1016/j.cattod.2016.03.022
Nieves, D.C., Karimi, K., Horváth, I.S., 2011. Improvement of biogas production from oil palm empty fruit bunches (OPEFB). Ind. Crops Prod. 34, 1097–1101. https://doi.org/10.1016/j.indcrop.2011.03.022
Nipattummakul, N., Ahmed, I.I., Kerdsuwan, S., Gupta, A.K., 2012. Steam gasification of oil palm trunk waste for clean syngas production. Appl. Energy 92, 778–782. https://doi.org/10.1016/j.apenergy.2011.08.026
Nitsos, C.K., Matis, K.A., Triantafyllidis, K.S., 2013. Optimization of hydrothermal pretreatment of lignocellulosic biomass in the bioethanol production process. ChemSusChem 6, 110–122. https://doi.org/10.1002/cssc.201200546
Nomanbhay, S.M., Hussain, R., Palanisamy, K., 2013. Microwave-Assisted Alkaline Pretreatment and Microwave Assisted Enzymatic Saccharification of Oil Palm Empty Fruit Bunch Fiber for Enhanced Fermentable Sugar Yield. J. Sustain. Bioenergy Syst. 03, 7–17. https://doi.org/10.4236/jsbs.2013.31002
Noparat, P., Prasertsan, P., O-thong, S., Pan, X., 2015. Dilute Acid Pretreatment of Oil Palm Trunk Biomass at High Temperature for Enzymatic Hydrolysis, Energy Procedia. Elsevier B.V. https://doi.org/10.1016/j.egypro.2015.11.588
Nor, W., Wan, N., Aishah, N., Amin, S., 2016. Multi response optimization of oil palm frond pretreatment by ozonolysis. Ind. Crop. Prod. 85, 389–402. https://doi.org/10.1016/j.indcrop.2016.01.027
Nordin, N.I.A.A., Ariffin, H., Andou, Y., Hassan, M.A., Shirai, Y., Nishida, H., Yunus, W.M.Z.W., Karuppuchamy, S., Ibrahim, N.A., 2013. Modification of oil palm mesocarp fiber characteristics using superheated steam treatment. Molecules 18, 9132–9146. https://doi.org/10.3390/molecules18089132
Ohimain, E.I., Izah, S.C., 2017. A review of biogas production from palm oil mill effluents using different configurations of bioreactors. Renew. Sustain. Energy Rev. 70, 242–253. https://doi.org/10.1016/j.rser.2016.11.221
Palamae, S., Palachum, W., Chisti, Y., Choorit, W., 2014. Retention of hemicellulose during delignification of oil palm empty fruit bunch (EFB) fiber with peracetic acid and alkaline peroxide. Biomass and Bioenergy 66, 240–248. https://doi.org/10.1016/j.biombioe.2014.03.045
Pasquale, G., Vázquez, P., Romanelli, G., Baronetti, G., 2012. Catalytic upgrading of levulinic acid to ethyl levulinate using reusable silica-included Wells-Dawson heteropolyacid as catalyst. CATCOM 18, 115–120. https://doi.org/10.1016/j.catcom.2011.12.004
Peng, L., Lin, L., Zhang, J., Zhuang, J., Zhang, B., Gong, Y., 2010. Catalytic Conversion of Cellulose to Levulinic Acid by Metal Chlorides. Molecules 15, 5258–5272. https://doi.org/10.3390/molecules15085258
Phitsuwan, P., Sakka, K., Ratanakhanokchai, K., 2016. Structural changes and enzymatic response of Napier grass (Pennisetum purpureum) stem induced by alkaline pretreatment. Bioresour. Technol. 218, 247–256. https://doi.org/10.1016/j.biortech.2016.06.089
Piarpuzán, D., Quintero, J.A., Cardona, C.A., 2011. Empty fruit bunches from oil palm as a potential raw material for fuel ethanol production.

Biomass and Bioenergy 35, 1130–1137. https://doi.org/10.1016/j.biombioe.2010.11.038
Pileidis, F.D., Titirici, M.M., 2016. Levulinic Acid Biorefineries : New Challenges for Efficient Utilization of Biomass. ChemSusChem 9, 562–582. https://doi.org/10.1002/cssc.201501405
Pinkert, A., Marsh, K.N., Pang, S., Staiger, M.P., 2009. Ionic liquids and their interaction with cellulose. Chem. Rev. 109, 6712–6728. https://doi.org/10.1021/cr9001947
Pu, Y., Hu, F., Huang, F., Davison, B.H., Ragauskas, A.J., 2013. Assessing the molecular structure basis for biomass recalcitrance during dilute acid and hydrothermal pretreatments. Biotechnol. Biofuels 6, 1–13. https://doi.org/10.1186/1754-6834-6-15
Qing, Q., Yang, B., Wyman, C.E., 2010. Xylooligomers are strong inhibitors of cellulose hydrolysis by enzymes. Bioresour. Technol. 101, 9624–9630. https://doi.org/10.1016/j.biortech.2010.06.137
Qu, Y., Luo, H., Li, H., Xu, J., 2015. Comparison on structural modification of industrial lignin by wet ball milling and ionic liquid pretreatment. Biotechnol. Reports 6, 1–7. https://doi.org/10.1016/j.btre.2014.12.011
Rackemann, D.W., Bartley, J.P., Doherty, W.O.S., 2014. Methanesulfonic acid-catalyzed conversion of glucose and xylose mixtures to levulinic acid and furfural. Ind. Crop. Prod. 52, 46–57. https://doi.org/10.1016/j.indcrop.2013.10.026
Rackemann, D.W., Doherty, W.O.., 2011. The conversion of lignocellulosics to levulinic acid. Biofuels, Bioprod. Biorefining 5, 115–126. https://doi.org/10.1002/bbb
Rahman, S.H.A., Choudhury, J.P., Ahmad, A.L., Kamaruddin, A.H., 2007. Optimization studies on acid hydrolysis of oil palm empty fruit bunch fiber for production of xylose. Bioresour. Technol. 98, 554–559. https://doi.org/10.1016/j.biortech.2006.02.016
Ramli, N.A.S., Amin, N.A.S., 2018. Thermo-kinetic assessment of glucose decomposition to 5-hydroxymethyl furfural and levulinic acid over acidic functionalized ionic liquid. Chem. Eng. J. 335, 221–230. https://doi.org/10.1016/j.cej.2017.10.112
Ramli, N.A.S., Amin, N.A.S., 2017. Optimization of Biomass Conversion to Levulinic Acid in Acidic Ionic Liquid and Upgrading of Levulinic Acid to Ethyl Levulinate. Bioenergy Res. 10, 50–63. https://doi.org/10.1007/s12155-016-9778-3
Ramli, N.A.S., Amin, N.A.S., 2015. Optimization of Oil Palm Fronds Conversion to Levulinic Acid using Fe / HY Zeolite Catalyst. Sains Malaysiana 44, 883–890.
Ramli, N.A.S., Amin, N.A.S., 2014a. Catalytic hydrolysis of cellulose and oil palm biomass in ionic liquid to reducing sugar for levulinic acid production. Fuel Process. Technol. 128, 490–498. https://doi.org/10.1016/j.fuproc.2014.08.011
Ramli, N.A.S., Amin, N.A.S., 2014b. Catalytic hydrolysis of cellulose and oil palm biomass in ionic liquid to reducing sugar for levulinic acid production. Fuel Process. Technol. 128, 490–498. https://doi.org/10.1016/j.fuproc.2014.08.011
Ramli, N.A.S., Ya'aini, N., Amin, N.A.S., 2014. Comparison of response surface methodology and artificial neural network for optimum levulinic acid production from glucose, empty fruit bunch and kenaf.

Int. J. Nano Biomater. 5, 59–74.
Runge, T., Zhang, C., 2012. Two-Stage Acid-Catalyzed Conversion of Carbohydrates into Levulinic Acid. Ind. Eng. Chem. Res. 51, 3265–3270.
Sabiha-Hanim, S., Noor, M.A.M., Rosma, A., 2011. Effect of autohydrolysis and enzymatic treatment on oil palm (Elaeis guineensis Jacq.) frond fibres for xylose and xylooligosaccharides production. Bioresour. Technol. 102, 1234–1239. https://doi.org/10.1016/j.biortech.2010.08.017
Sadhukhan, J., Martinez-Hernandez, E., Murphy, R.J., Ng, D.K.S., Hassim, M.H., Siew Ng, K., Yoke Kin, W., Jaye, I.F.M., Leung Pah Hang, M.Y., Andiappan, V., 2018. Role of bioenergy, biorefinery and bioeconomy in sustainable development: Strategic pathways for Malaysia. Renew. Sustain. Energy Rev. 81, 1966–1987. https://doi.org/10.1016/j.rser.2017.06.007
Saha, B., Abu-omar, M.M., 2014. Advances in 5-hydroxymethylfurfural production from biomass in biphasic solvents. Green Chem. 16, 24–38. https://doi.org/10.1039/c3gc41324a
Saha, B.C., Cotta, M.A., 2006. Ethanol production from alkaline peroxide pretreated enzymatically saccharified wheat straw. Biotechnol. Prog. 22, 449–453. https://doi.org/10.1021/bp050310r
Saha, B.C., Iten, L.B., Cotta, M.A., Wu, Y.V., 2005. Dilute acid pretreatment, enzymatic saccharification and fermentation of wheat straw to ethanol. Process Biochem. 40, 3693–3700. https://doi.org/10.1016/j.procbio.2005.04.006
Salehian, P., Karimi, K., Zilouei, H., Jeihanipour, A., 2013. Improvement of biogas production from pine wood by alkali pretreatment. Fuel 106, 484–489. https://doi.org/10.1016/j.fuel.2012.12.092
Saravanamurugan, S., Riisager, A., 2012. Solid acid catalysed formation of ethyl levulinate and ethyl glucopyranoside from mono- and disaccharides. Catal. Commun. 17, 71–75. https://doi.org/10.1016/j.catcom.2011.10.001
Senthamaraikannan, P., Kathiresan, M., 2018. Characterization of raw and alkali treated new natural cellulosic fi ber from Coccinia grandis . L. Carbohydr. Polym. 186, 332–343. https://doi.org/10.1016/j.carbpol.2018.01.072
Sharip, N.S., Ariffin, H., Hassan, M.A., Nishida, H., Shirai, Y., 2016. Characterization and Application of Bioactive Compounds in Oil Palm Mesocarp Fiber Superheated Steam Condensate as an Antifungal Agent. RSC Adv. 00, 1–9. https://doi.org/10.1039/C6RA13292H
Shen, F., Smith, R.L., Li, L., Yan, L., Qi, X., 2017. Eco-friendly Method for Efficient Conversion of Cellulose into Levulinic Acid in Pure Water with Cellulase-Mimetic Solid Acid Catalyst. ACS Sustain. Chem. Eng. 5, 2421–2427. https://doi.org/10.1021/acssuschemeng.6b02765
Shen, J., Wyman, C.E., 2011. Hydrochloric Acid-Catalyzed Levulinic Acid Formation from Cellulose : Data and Kinetic Model to Maximize Yields. AIChE J. 00, 1–11. https://doi.org/10.1002/aic
Shen, Y., Sun, J., Wang, B., Xu, F., Sun, R., 2014. Catalytic Synthesis of Diphenolic Acid from Levulinic Acid over Bronsted Acidic Ionic Liquids. BioResource 9, 3264–3275.
Shinoj, S., Visvanathan, R., Panigrahi, S., Kochubabu, M., 2011. Oil palm

fiber (OPF) and its composites: A review. Ind. Crops Prod. 33, 7–22. https://doi.org/10.1016/j.indcrop.2010.09.009

Shuai, L., Questell-santiago, Y.M., Luterbacher, J.S., 2016. A mild biomass pretreatment using γ-valerolactone for concentrated sugar production. Green Chem. 937–943. https://doi.org/10.1039/c5gc02489g

Sikarwar, V.S., Zhao, M., Clough, P., Yao, J., Zhong, X., Memon, M.Z., Shah, N., Anthony, E.J., Fennell, P.S., 2016. An overview of advances in biomass gasification. Energy Environ. Sci. 9, 2939–2977. https://doi.org/10.1039/c6ee00935b

Silverstein, R.A., Chen, Y., Sharma-shivappa, R.R., Boyette, M.D., Osborne, J., 2007. A comparison of chemical pretreatment methods for improving saccharification of cotton stalks. Bioresour. Technol. 98, 3000–3011. https://doi.org/10.1016/j.biortech.2006.10.022

Sludge, E.A., Manure, C., 2018. com Effect of Pretreatments on Compost Production from Shredded Oil Palm Empty Fruit Bunch with Palm Oil Mill Effluent Anaerobic Sludge and Chicken Manure 2020, 4998–5012.

Spencer, T.J., Kohl, P.A., 2011. Decomposition of poly (propylene carbonate) with UV sensitive iodonium salts. Polym. Degrad. Stab. 96, 686–702. https://doi.org/10.1016/j.polymdegradstab.2010.12.003

Subhedar, P.B., Gogate, P.R., 2014. Alkaline and ultrasound assisted alkaline pretreatment for intensification of delignification process from sustainable raw-material. Ultrason. Sonochem. 21, 216–225. https://doi.org/10.1016/j.ultsonch.2013.08.001

Sudiyani, Y., Styarini, D., Triwahyuni, E., Sudiyarmanto, Sembiring, K.C., Aristiawan, Y., Abimanyu, H., Han, M.H., 2013. Utilization of biomass waste empty fruit bunch fiber of palm oil for bioethanol production using pilot - Scale unit. Energy Procedia 32, 31–38. https://doi.org/10.1016/j.egypro.2013.05.005

Sukri, S.S.M., Rahman, R.A., Illias, R.M., Yaakob, H., 2014. Optimization of Alkaline Pretreatment Conditions of Oil Palm Fronds in Improving the Lignocelluloses Contents for Reducing Sugar Production. Rom. Biotechnol. Lett. 19, 9006–9018.

Sulaiman, F., Abdullah, N., 2011. Optimum conditions for maximising pyrolysis liquids of oil palm empty fruit bunches. Energy 36, 2352–2359. https://doi.org/10.1016/j.energy.2010.12.067

Sun, B., Peng, G., Duan, L., Xu, A., Li, X., 2015. Pretreatment by NaOH swelling and then HCl regeneration to enhance the acid hydrolysis of cellulose to glucose. Bioresour. Technol. 196, 454–458. https://doi.org/10.1016/j.biortech.2015.08.009

Sun, S., Sun, S., Cao, X., Sun, R., 2016. The role of pretreatment in improving the enzymatic hydrolysis of lignocellulosic materials. Bioresour. Technol. 199, 49–58. https://doi.org/10.1016/j.biortech.2015.08.061

Sweygers, N., Dewil, R., Appels, L., 2017. Production of Levulinic Acid and Furfural by Microwave-Assisted Hydrolysis from Model Compounds : Effect of Temperature , Acid Concentration and Reaction Time. Waste and Biomass Valorization 0, 0. https://doi.org/10.1007/s12649-016-9797-5

Tan-soetedjo, J.N.M., Bovenkamp, H.H. Van De, Abdilla, R.M., Rasrendra, C.B., Ginkel, J. Van, Heeres, H.J., 2017. Experimental and Kinetic Modeling Studies on the Conversion of Sucrose to Levulinic Acid and 5 - Hydroxymethylfurfural Using Sulfuric Acid in Water 13228–13239. https://doi.org/10.1021/acs.iecr.7b01611

Tan, H.T., Dykes, G.A., Wu, T.Y., Siow, L.F., 2013. Enhanced xylose recovery from oil palm empty fruit bunch by efficient acid hydrolysis. Appl. Biochem. Biotechnol. 170, 1602–1613. https://doi.org/10.1007/s12010-013-0298-8

Tan, H.T., Lee, K.T., Mohamed, A.R., 2011. Pretreatment of lignocellulosic palm biomass using a solvent-ionic liquid [BMIM]Cl for glucose recovery: An optimisation study using response surface methodology. Carbohydr. Polym. 83, 1862–1868. https://doi.org/10.1016/j.carbpol.2010.10.052

Teong, S.P., Yi, G., Zhang, Y., 2014. Hydroxymethylfurfural production from bioresources: Past, present and future. Green Chem. 16, 2015–2026. https://doi.org/10.1039/c3gc42018c

Then, Y.Y., Ibrahim, N.A., Zainuddin, N., Ariffin, H., Wan Yunus, W.M.Z., Chieng, B.W., 2014. The influence of green surface modification of oil palm mesocarp fiber by superheated steam on the mechanical properties and dimensional stability of oil palm mesocarp fiber/poly(butylene succinate) biocomposite. Int. J. Mol. Sci. 15, 15344–15357. https://doi.org/10.3390/ijms150915344

Then, Y.Y., Ibrahim, N.A., Zainuddin, N., Chieng, B.W., Ariffin, H., Wan Yunus, W.M.Z., 2015. Influence of alkaline-peroxide treatment of fiber on the mechanical properties of oil palm mesocarp fiber/poly(butylene succinate) biocomposite. BioResources 10, 1730–1746.

Thomas, R.W., Schuette, H.A., 1931. Studies on levulinic acid. I: its preparation from carbohydrates by digestion with hydrochloric acid under pressure. J. Am. Chem. Soc. 53, 2324–2328.

Tiong, Y.W., Yap, C.L., Gan, S., Yap, W.S.P., 2017. One-pot conversion of oil palm empty fruit bunch and mesocarp fiber biomass to levulinic acid and upgrading to ethyl levulinate via indium trichloride-ionic liquids. J. Clean. Prod. 168, 1251–1261. https://doi.org/10.1016/j.jclepro.2017.09.050

Toftgaard, A., Ringborg, R., Grotkjær, T., Pedersen, S., Woodley, J.M., 2015. Synthesis of 5-hydroxymethylfurfural (HMF) by acid catalyzed dehydration of glucose – fructose mixtures. Chem. Eng. J. 273, 455–464. https://doi.org/10.1016/j.cej.2015.03.094

Toquero, C., Bolado, S., 2014. Effect of four pretreatments on enzymatic hydrolysis and ethanol fermentation of wheat straw. Influence of inhibitors and washing. Bioresour. Technol. 157, 68–76. https://doi.org/10.1016/j.biortech.2014.01.090

Tsapekos, P., Kougias, P.G., Treu, L., Campanaro, S., Angelidaki, I., 2017. Process performance and comparative metagenomic analysis during co-digestion of manure and lignocellulosic biomass for biogas production. Appl. Energy 185, 126–135. https://doi.org/10.1016/j.apenergy.2016.10.081

Ul Islam, M.M., Mo, K.H., Alengaram, U.J., Jumaat, M.Z., 2016. Durability properties of sustainable concrete containing high volume palm oil waste materials. J. Clean. Prod. 137, 167–177.

https://doi.org/10.1016/j.jclepro.2016.07.061
Umar, M.S., Jennings, P., Urmee, T., 2014. Sustainable electricity generation from oil palm biomass wastes in Malaysia: An industry survey. Energy 67, 496–505. https://doi.org/10.1016/j.energy.2014.01.067
Upare, P.P., Yoon, J.W., Kim, M.Y., Kang, H.Y., Hwang, D.W., Hwang, Y.K., Kung, H.H., Chang, J.S., 2013. Chemical conversion of biomass-derived hexose sugars to levulinic acid over sulfonic acid-functionalized graphene oxide catalysts. Green Chem. 15, 2935–2943. https://doi.org/10.1039/c3gc40353j
Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for Dietary Fiber, Neutral Detergent Fiber, and Nonstarch Polysaccharides in Relation to Animal Nutrition. J. Dairy Sci. 74, 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2
Verendel, J.J., Church, T.L. and Andersson, P.G., 2011. Catalytic One-Pot Production of Small Organics from Polysaccharides. Synthesis (Stuttg). 11, 1649–1677. https://doi.org/10.1055/s-0030-1260008
Vyver, S. Van De, Geboers, J., Helsen, S., Yu, F., Thomas, J., Smet, M., Dehaen, W., Sels, B.F., 2012. Thiol-promoted catalytic synthesis of diphenolic acid with sulfonated hyperbranched poly (arylene oxindole)s. Chem. Commun. 48, 3497–3499. https://doi.org/10.1039/c2cc30239j
Wada, M., Ike, M., Tokuyasu, K., 2010. Enzymatic hydrolysis of cellulose I is greatly accelerated via its conversion to the cellulose II hydrate form. Polym. Degrad. Stab. 95, 543–548. https://doi.org/10.1016/j.polymdegradstab.2009.12.014
Wang, P., Zhan, S., Yu, H., 2010. Production of Levulinic Acid from Cellulose Catalyzed by Environmental-Friendly Catalyst. Adv. Mater. Res. Vol. 96, 183–187. https://doi.org/10.4028/www.scientific.net/AMR.96.183
Wang, S., Dai, G., Ru, B., Zhao, Y., Wang, X., Zhou, J., Luo, Z., Cen, K., 2016. Effects of torrefaction on hemicellulose structural characteristics and pyrolysis behaviors. Bioresour. Technol. 218, 1106–1114. https://doi.org/10.1016/j.biortech.2016.07.075
Wang, S., Li, F., Zhang, P., Jin, S., Tao, X., Tang, X., Ye, J., Nabi, M., Wang, H., 2017. Ultrasound assisted alkaline pretreatment to enhance enzymatic saccharification of grass clipping. Energy Convers. Manag. 149, 409–415. https://doi.org/10.1016/j.enconman.2017.07.042
Wang, T., Nolte, M.W., Shanks, B.H., 2014. Catalytic dehydration of C 6 carbohydrates for the production of hydroxymethylfurfural (HMF) as a. Green Chem. 16, 548–572. https://doi.org/10.1039/c3gc41365a
Wang, Z., Hou, X., Sun, J., Li, M., Chen, Z., Gao, Z., 2018. Comparison of ultrasound-assisted ionic liquid and alkaline pretreatment of Eucalyptus for enhancing enzymatic saccharification. Bioresour. Technol. 254, 145–150. https://doi.org/10.1016/j.biortech.2018.01.021
Wee, L., Idris, A., 2016. Comparison of steam-alkali-chemical and microwave-alkali pretreatment for enhancing the enzymatic sacchari fi cation of oil palm trunk. Renew. Energy 99, 738–746. https://doi.org/10.1016/j.renene.2016.07.059

Weingarten, R., Conner, W.C., Huber, G.W., 2012. Production of levulinic acid from cellulose by hydrothermal decomposition combined with aqueous phase dehydration with a solid acid catalyst. Energy Environ. Sci. 5, 7559. https://doi.org/10.1039/c2ee21593d

Wettstein, S.G., Alonso, D.M., Gürbüz, E.I., Dumesic, J.A., 2012. A roadmap for conversion of lignocellulosic biomass to chemicals and fuels. Curr. Opin. Chem. Eng. 1, 218–224. https://doi.org/10.1016/j.coche.2012.04.002

Wu, H., Dai, X., Zhou, S., Gan, Y., Xiong, Z., Qin, Y., Ma, J., Yang, L., Wu, Z., Wang, T., Wang, W., Wang, C., 2017. Bioresource Technology Ultrasound-assisted alkaline pretreatment for enhancing the enzymatic hydrolysis of rice straw by using the heat energy dissipated from ultrasonication. Bioresour. Technol. 241, 70–74. https://doi.org/10.1016/j.biortech.2017.05.090

Wu, L., Hu, X., Wang, S., Hasan, M.D.M., Jiang, S., Li, T., 2018. Acid-treatment of bio-oil in methanol : The distinct catalytic behaviours of a mineral acid catalyst and a solid acid catalyst. Fuel 212, 412–421. https://doi.org/10.1016/j.fuel.2017.10.049

Xu, Z., Huang, F., 2014. Pretreatment methods for bioethanol production. Appl. Biochem. Biotechnol. 174, 43–62. https://doi.org/10.1007/s12010-014-1015-y

Ya'aini, N., Amin, N.A.S., Asmadi, M., 2012. Optimization of levulinic acid from lignocellulosic biomass using a new hybrid catalyst. Bioresour. Technol. 116, 58–65. https://doi.org/10.1016/j.biortech.2012.03.097

Yan, K., Jarvis, C., Gu, J., Yan, Y., 2015. Production and catalytic transformation of levulinic acid: A platform for speciality chemicals and fuels. Renew. Sustain. Energy Rev. 51, 986–997. https://doi.org/10.1016/j.rser.2015.07.021

Yan, L., Yang, N., Pang, H., Liao, B., 2008. Production of levulinic acid from bagasse and paddy straw by liquefaction in the presence of hydrochloride acid. Clean - Soil, Air, Water 36, 158–163. https://doi.org/10.1002/clen.200700100

Yang, H., Xie, Y., Zheng, X., Pu, Y., Huang, F., Meng, X., Wu, W., Ragauskas, A., Yao, L., 2016. Comparative study of lignin characteristics from wheat straw obtained by soda-AQ and kraft pretreatment and effect on the following enzymatic hydrolysis process. Bioresour. Technol. 207, 361–369. https://doi.org/10.1016/j.biortech.2016.01.123

Yang, M., Saif, M., Rehman, U., Yan, T., Ullah, A., 2018. Bioresource Technology Treatment of di ff erent parts of corn stover for high yield and lower polydispersity lignin extraction with high-boiling alkaline solvent. Bioresour. Technol. 249, 737–743. https://doi.org/10.1016/j.biortech.2017.10.055

Yasim-Anuar, T.A.T., Ariffin, H., Hassan, M.., 2018. Characterization of cellulose nanofiber from oil palm mesocarp fiber produced by ultrasonication Characterization of cellulose nanofiber from oil palm mesocarp fiber produced by ultrasonication. Mater. Sci. Eng. 368, 012033. https://doi.org/10.1088/1757-899X/368/1/012033

Ye, Z., Berson, R.E., 2014. Factors affecting cellulose hydrolysis based on inactivation of adsorbed enzymes. Bioresour. Technol. 167, 582–586. https://doi.org/10.1016/j.biortech.2014.06.070

Ying, T., Keat, L., Nadiah, W., Abdullah, W., Cheu, L., 2014. The effect of various pretreatment methods on oil palm empty fruit bunch (EFB) and kenaf core fibers for sugar production. Procedia Environ. Sci. 20, 328–335. https://doi.org/10.1016/j.proenv.2014.03.041

Yu, F., Thomas, J., Smet, M., Dehaen, W., Sels, B.F., 2015. Molecular design of sulfonated hyperbranched poly(arylene oxindole)s for efficient cellulose conversion to levulinic acid. Green Chem. https://doi.org/10.1039/c5gc01971k

Yu, X., Bao, X., Zhou, C., Zhang, L., Yagoub, A.E.G.A., Yang, H., Ma, H., 2018. Ultrasound-ionic liquid enhanced enzymatic and acid hydrolysis of biomass cellulose. Ultrason. Sonochem. 41, 410–418. https://doi.org/10.1016/j.ultsonch.2017.09.003

Yuan, Z., Long, J., Xia, Y., Zhang, X., Wang, T., 2016. Production of Levulinic Acid from Pennisetum alopecuroides in the Presence of an Acid Catalyst 11, 3511–3523.

Yuan, Z., Wen, Y., Kapu, N.S., 2018. Ethanol production from bamboo using mild alkaline pre-extraction followed by alkaline hydrogen peroxide pretreatment. Bioresour. Technol. 247, 242–249. https://doi.org/10.1016/j.biortech.2017.09.080

Yunus, R., Salleh, S.F., Abdullah, N., Biak, D.R.A., 2010. Effect of ultrasonic pre-treatment on low temperature acid hydrolysis of oil palm empty fruit bunch. Bioresour. Technol. 101, 9792–9796. https://doi.org/10.1016/j.biortech.2010.07.074

Zahari, M.A.K.M., Zakaria, M.R., Ariffin, H., Mokhtar, M.N., Salihon, J., Shirai, Y., Hassan, M.A., 2012. Renewable sugars from oil palm frond juice as an alternative novel fermentation feedstock for value-added products. Bioresour. Technol. 110, 566–571. https://doi.org/10.1016/j.biortech.2012.01.119

Zainudin, B.H., Abu Bakar, N.K., Muhamad, H., 2009. Determination of cypermethrin in palm oil matrices. Eur. J. Lipid Sci. Technol. 111, 1014–1019. https://doi.org/10.1002/ejlt.200800240

Zakaria, M.R., Hirata, S., Fujimoto, S., Hassan, M.A., 2015a. Combined pretreatment with hot compressed water and wet disk milling opened up oil palm biomass structure resulting in enhanced enzymatic digestibility. Bioresour. Technol. 193, 128–134. https://doi.org/10.1016/j.biortech.2015.06.074

Zakaria, M.R., Hirata, S., Fujimoto, S., Ibrahim, I., Hassan, M.A., 2016. Soluble inhibitors generated during hydrothermal pretreatment of oil palm mesocarp fiber suppressed the catalytic activity of Acremonium cellulase. Bioresour. Technol. 200, 541–547. https://doi.org/10.1016/j.biortech.2015.10.075

Zakaria, M.R., Hirata, S., Hassan, M.A., 2015b. Hydrothermal pretreatment enhanced enzymatic hydrolysis and glucose production from oil palm biomass. Bioresour. Technol. 176, 142–148. https://doi.org/10.1016/j.biortech.2014.11.027

Zakaria, M.R., Hirata, S., Hassan, M.A., 2014. Combined pretreatment using alkaline hydrothermal and ball milling to enhance enzymatic hydrolysis of oil palm mesocarp fiber. Bioresour. Technol. 169, 236–243. https://doi.org/10.1016/j.biortech.2014.06.095

Zakaria, M.R., Norrrahim, M.N.F., Hirata, S., Hassan, M.A., 2015c. Hydrothermal and wet disk milling pretreatment for high conversion of

biosugars from oil palm mesocarp fiber. Bioresour. Technol. 181, 263–269. https://doi.org/10.1016/j.biortech.2015.01.072
Zhang, H., Wu, S., 2014. Dilute ammonia pretreatment of sugarcane bagasse followed by enzymatic hydrolysis to sugars. Cellulose 21, 1341–1349. https://doi.org/10.1007/s10570-014-0233-3
Zhang, J., Wu, S., Li, B., Zhang, H., 2012. Corrigendum: Advances in the Catalytic Production of Valuable Levulinic Acid Derivatives. ChemCatChem 4, 1695. https://doi.org/10.1002/cctc.201200634
Zhang, L., Xi, G., Chen, Z., Qi, Z., Wang, X., 2017. Enhanced formation of 5-HMF from glucose using a highly selective and stable SAPO-34 catalyst. Chem. Eng. J. 307, 877–883. https://doi.org/10.1016/j.cej.2016.09.003
Zhang, Z., Harrison, M.D., Rackemann, D.W., William, O.S., Hara, I.M.O., 2013. Organosolv Pretreatment of Plant Biomass for Enhanced Enzymatic Saccharification. Green Chem. 1–22. https://doi.org/10.1039/x0xx00000x
Zheng, X., Zhi, Z., Gu, X., Li, X., Zhang, R., Lu, X., 2017. Kinetic study of levulinic acid production from corn stalk at mild temperature using FeCl 3 as catalyst. Fuel 187, 261–267. https://doi.org/10.1016/j.fuel.2016.09.019
Zhi, Z., Li, N., Qiao, Y., Zheng, X., Wang, H., Lu, X., 2015. Kinetic study of levulinic acid production from corn stalk at relatively high temperature using FeCl<inf>3</inf> as catalyst: A simplified model evaluated. Ind. Crops Prod. 76, 672–680. https://doi.org/10.1016/j.indcrop.2015.07.058
Zhou, C., Yu, X., Ma, H., He, R., Vittayapadung, S., 2013. Optimization on the conversion of bamboo shoot shell to levulinic acid with environmentally benign acidic ionic liquid and response surface analysis. Chinese J. Chem. Eng. 21, 544–550. https://doi.org/10.1016/S1004-9541(13)60509-1
Zhou, S., Runge, T.M., 2014. Validation of lignocellulosic biomass carbohydrates determination via acid hydrolysis. Carbohydr. Polym. 112, 179–185. https://doi.org/10.1016/j.carbpol.2014.05.088
Zúñiga, C., Lligadas, G., Ronda, J.C., Galià, M., Cádiz, V., 2012. Renewable polybenzoxazines based in diphenolic acid. Polymer (Guildf). 53, 1617–1623. https://doi.org/10.1016/j.polymer.2012.02.026
Zuo, D., Lane, J., Culy, D., Schultz, M., Pullar, A., Waxman, M., 2013. Applied Catalysis B : Environmental Sulfonic acid functionalized mesoporous SBA-15 catalysts for biodiesel production. "Applied Catal. B, Environ. 129, 342–350. https://doi.org/10.1016/j.apcatb.2012.09.029
Zuo, Y., Zhang, Y., Fu, Y., 2014. Catalytic conversion of cellulose into levulinic acid by a sulfonated chloromethyl polystyrene solid acid catalyst. ChemCatChem 6, 753–757. https://doi.org/10.1002/cctc.201300956

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LIST OF PUBLICATIONS

Zulkipli, N.A., Yunus, R., Abidin, Z.Z. and Lim, B.Y., 2019. Broido plot for the effect of acid pretreatments on hydrolysis of oil palm mesocarp fiber. Intern. J. of Current Resear. 1270-1274. https://doi.org/10.24941/ijcr.34032.02.2019.

Zulkipli, N.A., Yunus, R., Abidin, Z.Z. and Lim, B.Y., 2019. Effect of Ultrasonic-Assisted Acid Pretreatment On Production of Levulinic Acid Through Acid Hydrolysis [Paper Submitted]

Zulkipli, N.A., Yunus, R., Abidin, Z.Z. and Lim, B.Y., 2019. Production of Levulinic Acid by Acid Hydrolysis by Reusing Liquor Produced During Acid Pretreatment [Paper Submitted]

Zulkipli, N.A., Yunus, R., Abidin, Z.Z. and Lim, B.Y., 2019. Optimization Studies On Acid Hydrolysis of Oil Palm Mesocarp Fiber for Production of Levulinic Acid [Paper Submitted]

Zulkipli, N.A., Yunus, R., Abidin, Z.Z. and Lim, B.Y., 2019. Enhancing Acid Hydrolysis of Oil Palm Mesocarp Fibre by Ultrasound-Assisted Alkaline Pretreatment [Paper Submitted]

Zulkipli, N.A., Yunus, R., Abidin, Z.Z. and Lim, B.Y., 2019. Pretreatment Methods for Conversion of Oil Palm Biomass into Reducing Sugar [Paper Submitted]

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