UNIVERSITI PUTRA MALAYSIA

BIODEGRADATION OF OIL PALM FIBERS USING LOCALLY ISOLATED FUNGI (Pycnoporus sanguineus) THROUGH PLANT BIOMECHANICS APPROACH

FARAH NADIA BINTI OMAR

FK 2018 20

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By

FARAH NADIA BINTI OMAR

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfilment of the requirement for the Degree of Doctor of Philosophy

November 2017

Dedicated to my family

For your endless love, support and encouragement

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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November 2017

Chairman : Azhari Samsu Baharuddin, PhD
Faculty : Engineering

Utilization of lignocellulosic OPEFB fiber has tremendously seen in Malaysia due to the cellulose and hemicellulose content. Conversion of these biopolymers into valuable products remains a challenging task with the presence of the recalcitrant lignin and scattering silica bodies on the fiber surface. Therefore, this study investigates the mechanical behaviour of the complex lignocellulosic OPEFB fiber containing silica bodies and provide an in-depth understanding of the delignification of OPEFB by fungi for further bioconversion into wide range of biomaterial applications. The microstructure of silica bodies on OPEFB fiber surface was modelled using finite element method, based on the results obtained from scanning electron microscope (SEM) images, tensile tests and X-ray microtomography (micro-CT) images. Silica body geometry, possible anisotropy/ orthotropy, debonding between the interface of the silica body and fiber, fiber thickness and presence of vascular bundle in the OPEFB were investigated through 2D and 3D models and analysed by commercial finite element software, Abaqus.

In 2D model, silica bodies contribute on integrity or strength of the fiber, however, in the 3D model, the effect of silica bodies on the elasticity of the fiber was insignificant when the thickness of the fiber is larger than 0.2 mm. In the developed representative volume element (RVE) and micro-CT models, the simulation results show that the difference of the fiber model with and without silica bodies are larger under shear than compression and tension. However, in comparison to geometrical effect (silica bodies), lignin, cellulose, and hemicellulose components of the fiber are responsible for the complex mechanical and interface behavior of oil palm fibers.

Hence, screening and isolation of lignin degrading fungi for deconstruction of lignin polymer in OPEFB was carried out. About 47 isolated fungi collected from environmental samples with six fungi were able to decolorize selective agar media, indicating possible presence of lignin-degrading enzymes; laccase and peroxidases. The highest producer of ligninolytic enzymes was identified as *Pycnoporus sanguineus* which able to utilize raw OPEFB fiber through solid state fermentation (SSF) with an increment of 1.37 folds of ligninolytic enzymes production as compared to submerged fermentation (SmF). Optimization study of different substrate pre-treatments (sodium hydroxide, Soxhlet extraction), incubation temperatures (20-40°C), ABTS concentrations (0-4%) and substrate amounts (3-15 g) on ligninolytic enzymes production was carried out. Results showed that the optimum conditions for *P. sanguineus* to produce highest laccase (15.49 U/g) with Klason lignin removal at 7.11% were using extractive-free OPEFB fiber, incubation temperature at 30°C, supplemented with 4 mM of ABTS and with 10 g of substrate loading size. Effectiveness of *P. sanguineus* for OPEFB degradation was further evaluated with the different ratio of fiber, fungi and palm oil mill effluent (POME) sludge as inoculum.

The relationship between structural OPEFB fiber degradation and delignification process by *P. sanguineus* was studied through tensile testing data, enzymatic and lignin component data, and micro-CT images. The highest total lignin loss (35.81%) and total phenolic content produced (78.03%) was determined at a condition ratio of fiber to fungi (60:40), yielding of laccase and MnP of 0.18 and 0.02, respectively while production rate of laccase and MnP were 0.98 U/g/d and 0.11 U/g/d, respectively. Micro-CT results revealed that the delignification process damaged the fiber based on the volume reduction data where 14.11% of volume reduction was observed with treated fiber while 11.21% volume reduction was achieved with untreated fiber. It is suggested that *P. sanguineus* could be a potential lignin degrader of OPEFB fiber before being manipulated for other valuable products production.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENGURAIAN FIBER KELAPA SAWIT MENGGUNAKAN KULAT YANG DIPENCILKAN KAWASAN SETEMPAT (*Pycnoporus sanguineus*) MELALUI PENDEKATAN BIOMEKANIK TUMBUHAN

Oleh

FARAH NADIA BINTI OMAR

November 2017

Penyelia : Azhari Samsu Baharuddin, PhD
Fakulti : Kejuruteraan

Penggunaan sisa lignoselulosa gentian tandan kelapa sawit kosong (OPEFB) sangat banyak di Malaysia kerana kandungan selulosa dan hemiselulosa. Penukaran biopolimer ini kepada produk bernilai telah terhalang oleh kehadiran lignin dan partikel silika di permukaan gentian. Oleh itu, kajian penyelidikan tingkah laku mekanikal gentian OPEFB kompleks yang mengandungi partikel silika dijalankan dan memberi kefahaman proses penguraian lignin dalam OPEFB oleh kulat untuk seterusnya melalui proses biopenukaran kepada pelbagai jenis aplikasi biomaterial. Mikrostruktur partikel silika di gentian OPEFB telah disimulasi dengan menggunakan kaedah '*finite element*' berdasarkan keputusan dari gambar imbasan mikroskop elektron (IME), ujian tegangan dan mikro-tomografi (mikro-CT). Geometri partikel silika, kebarangkalian *anisotrophy/ orthotropy*, peleraian ikatan antara permukaan partikel silika dan gentian, ketebalan gentian, dan kehadiran bukaan "*vascular bundle*' telah dikaji menggunakan model 2D dan 3D didalam perisian komersil "*finite element*", Abaqus.

Dalam model 2D, partikel silika menyumbang kepada integriti gentian, manakala dalam model 3D kesan partikel silika kepada kekenyalan gentian tidak signifikan pada ketebalan gentian melebihi 0.2 mm. Dalam model '*representative volume element*' (RVE) dan model mikro-CT, keputusan simulasi menunjukkan perbezaan model gentian dengan dan tanpa partikel silika adalah besar di bawah mod ricih berbanding mampatan dan tegangan. Walau bagaimanapun, jika dibanding dengan kesan geometri (partikel silika), komponen lignin, selulosa dan hemiselulosa bertanggungjawab kepada tingkahlaku mekanikal dan antara permukaan yang kompleks pada gentian kelapa sawit.

Oleh itu, penyaringan dan pemencilan kulat pengurai lignin dijalankan untuk menguraikan polimer lignin dalam OPEFB. Sebanyak 47 kulat dikutip dari kawasan sekitar dan enam kulat mampu menyah-warna agar media saringan menunjukkan kehadiran enzim pengurai lignin; *laccase* dan peroksida. Kulat yang menghasilkan enzim tertinggi dipilih dan dikenali sebagai *Pycnoporus sanguineus* yang mampu menguraikan gentian OPEFB dan menghasilkan enzim yang tinggi melalui fermentasi fasa pepejal iaitu peningkatan sebanyak 1.37 kali ganda berbanding dengan fermentasi fasa terendam. Kajian pengoptimuman menggunakan pelbagai pra-rawatan substrat (natrium hidroksida, pengestrakan Soxhlet), suhu pengeraman (20-40°), kepekatan ABTS (0-4%) dan jumlah substrat (3-15 g) kepada penghasilan enzim ligninolitik dijalankan. Keputusan menunjukkan keadaan optimum penghasilan enzim *laccase* tertinggi (15.49 U/g) dengan penyingkiran Klason lignin sebanyak 7.11% oleh *P. sanguineus* adalah menggunakan gentian OPEFB bebas ekstraktif, suhu pengeraman 30°C, dibekalkan 4 mM ABTS dan dengan menggunakan 10 g substrat.

Kecekapan *P.sanguineus* untuk menguraikan gentian OPEFB dikaji lebih mendalam dengan menggunakan pelbagai nisbah gentian, kulat dan enap cemar dari sisa efluen kilang sawit (POME) sebagai inokulum. Hubungan antara penguraian struktur gentian OPEFB dan proses penguraian lignin oleh *P. sanguineus* dikaji melalui data ujian tegangan, enzim dan data komponen lignin, dan imej mikro-CT. Penyingkiran tertinggi lignin (35.81%) dan jumlah kandungan fenolik yang terhasil (78.03%) dikenalpasti pada keadaan nisbah gentian kepada kulat (60:40) menghasilkan *laccase* dan MnP masing-masing 0.18 dan 0.02, manakala kadar penghasilan *laccase* dan MnP masing-masing adalah 0.98 U/g/d dan 0.11 U/g/d. Keputusan mikro-CT menunjukkan proses penguraian lignin telah merosakkan gentian berdasarkan data pengurangan isipadu di mana 14.11% pengurangan isipadu telah diperolehi dari gentian terawat manakala 11.21% pengurangan isipadu diperolehi dari gentian yang tidak terawat. Ini membuktikan *P. sanguineus* berpotensi untuk menjadi kulat pengurai lignin gentian OPEFB sebelum gentian ini dimanipulasi untuk kegunaan pembuatan produk berharga.

ACKNOWLEDGEMENT

Alhamdulillah, thank you to Merciful God for giving me strength and courage to finish this project. My biggest appreciation goes to my main supervisor and supervisory committee, Dr Azhari Samsu Baharuddin, Dr Mohd Afandi P Mohammed, Dr Umi Kalsom Md Shah and Prof Kenji Sakai for their endless guidance, supports and valuable wisdoms. To all fellow lecturers in Faculty of Engineering that always inspire me and sharing precious know-how both directly and indirectly. I also would like to express my gratitude to Ministry of Science, Technology and Innovation of Malaysia (MoSTI) and Universiti Putra Malaysia for their financial aids throughout my studies.

I humbly thank you to all the technicians and laboratory staffs in Faculty of Engineering for their cooperation and kind help. A special appreciation also goes to my fellow Bioprocess Research Group: Halimatun, Suhaiza, Loo, Ida, Termizi and others for their joyful and memorable friendship moments. The appreciation is beyond words.

Up and foremost, my indebtedness goes to my parents and my husband as well as my family for their faith, understanding, and prayers. They have always been my rock and always will be. Last but not least, I would like to thank to everyone who involved directly and indirectly for completion of my studies. I am truly treasure your help and guidance for all this while. Only God could ever repay each one of you. Thank you.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows;

Azhari Samsu Baharuddin, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Afandi P Mohammed, PhD
Senior Lecturer,
Faculty of Engineering,
Universiti Putra Malaysia
(Member)

Umi Kalsom Md Shah, PhD
Associate Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Member)

Kenji Sakai, Phd
Professor
Faculty of Agriculture
Kyushu University, Japan
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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Name and Matric No: Farah Nadia Binti Omar (GS 35338)

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This is to confirm that:

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Signature: _________________
Chairman of Supervisory Committee: Dr Azhari Samsu Baharuddin

Signature: ________________
Member of Supervisory Committee: Dr Mohd Afandi P Mohammed

Signature: _________________
Member of Supervisory Committee: Dr Umi Kalsom Md Shah

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LIST OF ABBREVIATIONS

ABTS	2,2`-azinobis-(3-ethyl-)benzothiazoline-6-sulphonate
MnP	Manganese peroxidase
LiP	Lignin peroxidase
OPEFB	Oil palm empty fruit bunch
POME	Palm oil mill effluent
SSF	Solid state fermentation
SmF	Submerged fermentation
FEA	Finite element analysis
TPC	Total phenolic compound
KL	Klason lignin
Micro-CT	Micro computed tomography
Si	Silica bodies
SiO_2	Silica oxide
H_2SO_4	Sulphuric acid
NaOH	Sodium hydroxide
RVE	Representative volume element

LIST OF SYMBOLS

˚C	degree celcius
g/L	gram per litre
%	percentage
rev/min	revolutions per minute
β	beta
O_2	oxygen
CO_2	carbon dioxide
H_2O	water
h	hour
min	minutes
µm	micrometer
mm	milimeter
Pa	Pascal
U/g	unit per gram

CHAPTER 1

INTRODUCTION

1.1 Lignin degradation of OPEFB

Malaysia is blessed with valuable oil palm tree plantation where it has been as one of the major exporter of palm oil in the world where total oil palm planted area reported was 5.39 million hectares where it covered more than 73% of agricultural land that makes oil palm as a potential renewable biomass to be exploited for better use (Awaluddin et al., 2015). About 95.38 million tonnes of fresh fruit oil palm bunches were processed and the estimation of oil palm biomass generated from its process was 40.55 milliom tonnes (Loh, 2017). Oil palm empty fruit bunch (OPEFB) alone were contribute about 7.34 million tonnes where current practice of OPEFB manipulation involves incineration of OPEFB to produce bunch ash and further applied as soil conditioner and soil fertilizer and straight dumping on the field as soil mulching agent (Zainudin et al., 2012).

Some researchers have maximized the usage of OPEFB fibers as part of biocomposite materials in construction industries (Hassan et al., 2010) while some researchers use OPEFB as the main feedstock in bioconversion process into value added products such as fermentable sugars (Abu Bakar et al., 2012; Zainudin et al., 2012), biofuel (Sudiyani and Hermiati, 2010; Nieves et al., 2011), organic acids (Akhtar et al., 2014) and others. The cellulose and hemicelluloses is the most intriguing materials in the utilizing of the OPEFB as potential feedstock for the production of biofuel (Jeon et al., 2014; Kim and Kim, 2013), biochemicals (Reeb et al., 2014; Katinonkul et al., 2012). However, the utilization of cellulose and hemicellullose is hindered with the high content of lignin.

Lignin makes up of 15-40% of the dry matter of woody plant gives the rigidity and strength to cell walls and resilient towards degradation (Naseem et al., 2016). It is a highly stable biopolymer made of three cross-linked phenylpropane units and it present interlocking the cellulose and hemicelluloses polymers with strong ether bonds (C-O-C) and normal hydrogen bonds (C-C). Degradation of lignin in lignocellulosic biomass has been reported using various methods; 1) physical pretreatment such as by high pressure steam (Baharuddin et al., 2013); 2) chemical pretreatments by sodium hydroxide (Palamae et al., 2017; Zulkiple et al., 2016; Muryanto et al., 2015); and 3) biological pretreatment by fungal and ligninolytic enzyme. A number of fungi (white and brown rot) and some bacteria are effective as a lignin degrader due to their ability to produce lignolytic enzymes. Ligninolytic enzymes can be categorized as peroxidases (lignin peroxidase, manganese peroxidase, versatile peroxidase) and oxidative enzymes (laccase) could depolymerize the lignin polymers into smaller compounds through oxidative and electron transfer process (Bugg and Rahmanpour et al., 2015). Lignin can be precipitated as droplets on the surface of cellulose and hemicellulose, making them less accessible to enzymes attack. Hence, lignin removal is crucial in further utilization of cellulose and hemicellulose as it tends to adsorb the hydrolytic enzymes more easily and consequently reduce the effectiveness of the hydrolytic enzymes to access the cellulose and hemicellulose sites (Mishra et al., 2017; Li et al., 2009).

In addition, OPEFB fiber has some distinct features on its fiber surface, where random scattering protrusion silica bodies are found. These silica bodies are embedded half-way through the fiber surface, and it is made of silica oxide (SiO_2). It has been reported that silica bodies play a big role in providing mechanical support, strength and rigidity of the plant (Neethirajan et al., 2009; Ma and Yamaji, 2006). The presence of silica bodies in plant has been numerously studied especially on fermentable sugar production (Nurul Hazirah et al., 2016; Shamsudin et al., 2012). However, to this date, there are limited studies investigates the role of silica bodies in providing strength and rigidity towards plant particularly for oil palm tree. This issue, however, will be addressed and explained in this thesis focusing the presence of silica bodies on OPEFB fiber.

1.2 Oil palm fiber biomechanics

Micromechanics is a study of materials by understanding the interaction between constituent materials at microscopic level. Theoretically, it helps to compute and predict the behavior, properties and failure mechanisms of the materials. The main idea of micromechanics is to replace the original material with imaginary microscopic material so that the analysis of the original material could be understand and simplified (Yu, 2016). Micromechanics study have been used widely in building of materials as such each properties and behavior of the building material will be simulated and the overall performance of the material will be evaluated. A simple way to witness the micromechanics study is when natural fiber is used as reinforcement to other composite materials. The behavior of fibers will be simulated at various conditions and barriers and success and failure mechanisms of the overall materials will be evaluated. The micromechanics study of natural fibers like woody and plant cells have been well established (Hayot et al., 2012; Burgert and Dunlop, 2011). However, very limited studies are available in the literature that involves the study of the silica bodies on OPEFB fiber and their contributions to the mechanical behavior of OPEFB fiber. Only recently, there are studies on micromechanics of oil palm fiber performed by a research group in UPM. Hanipah et al. (2016) and Xiang et al. (2015) utilized numerical approach of micromechanics of oil palm fiber and revealed the viscoelastic properties as evident from stress relaxation curves. Likewise, in another study conducted by Wang et al. (2014), finite element analyses study of royal palm at tissue level was performed where cellular structure of the palm was reconstructed with polynomial area weighted tessellation model in order to simulate the vascular tissue behavior and area ratio and parameter ratio of adjacent cells were calculated and compared.

Deeper understanding and investigations of oil palm fiber cellular and tissue structure could be performed with both numerical and analytical micromechanics approaches. The behavior, properties, response and failure mechanisms could be understood and explored. This is essential especially if the utilization of oil palm fiber in composites or any other purposes are required if one aims to utilize it in its most possible way.

1.3 Problem statements

Micromechanics study of silica bodies on OPEFB fiber and its contribution on the fiber integrity has yet been studied, where this information could provide the fundamental background on its behavior, properties as well as other mechanisms. Up to date, there are no detailed models available that discuss the mechanics of the oil palm fiber specifically with silica bodies. Hence, development of model through numerical and analytical methods of micromechanics is essential to predict the behavior of the fiber by providing an in depth understanding of the effects of silica bodies physiologies and structures towards the fiber strength and therefore, may contribute to the decision of the degree of pretreatment for silica bodies removal needed especially in industries with natural fibers utilization like biocomposites and fiber bioconversion process. By knowing this information, it would minimize the energy, time and money spent on the silica bodies removal treatment process. This studies also provides deeper understanding of silica bodies and role of OPEFB fiber as a bioresources material, and the models could also be used for other natural fiber modelling as well.

Unnecessary compound and by-products formation from lignin degradation could be eliminated through biological treatments as it is substrate specific and involve no harsh chemicals. However, involvement of biological treatments usually lead to delayed response and achievements. Therefore, microbes with high production of lignin-degrading enzymes is preferred for lignin degradation to occur effectively. Removal of lignin is important as such it intensely being incorporated into emergent lignocellulose biorefineries.

Additionally, the mechanism of structural degradation between fungi and OPEFB during lignin degradation process is an intriguing subject of research and up to this date, there are no comprehensive studies conducted and discussed in the literatures. The OPEFB biodegradation studies is important not only to solve the solid waste disposal in Malaysia, but also to prepare the fiber for holocellulose utilization which would later on would be greatly useful for numerous valuable products generations such as biosugars, carboxymethyl cellulose etc.

To fill in the gaps mentioned above, a study on micromechanics study on silica bodies on OPEFB fiber was conducted and the degradation of lignin by fungi was evaluated through structural and physico-chemical data analyses. The objectives of this study therefore are:

1. To determine the effect of silica bodies on OPEFB fiber integrity through solid mechanics approach.
2. To optimize the environmental conditions for laccase production from local isolated white rot fungi, *P. sanguineus*.
3. To study the relationship between structural and physico-chemical behavior of OPEFB after degradation process by *P.sanguineus*.

1.4 Scope of research and thesis structure

This study is principally concerned about the micromechanics study of OPEFB and its relationship with biodegradation of OPEFB fiber by local isolated white rot fungi. During this research, and in depth study has been performed in studying the feedstock, OPEFB fiber in terms of the micromechanics behavior and modeling of the silica bodies onto the surfaces of the fiber. A 2D model was adopted to explore the effect of silica bodies' arrangement and spiked geometry of silica bodies. 3D models were later developed in order to further investigate with the contribution of silica bodies towards fiber integrity. On the other hand, white rot fungi was isolated and the ability to perform the degradation on OPEFB was evaluated. The performance of the fungi was evaluated in both submerged and solid state fermentation. Based on the lignocellulosic content and phenol content, the fungi show some potential in depolymerizing the lignocellulosic content in OPEFB. Finally, the relationship between structural and physico-chemical behavior of degraded OPEFB fibers were reported and discussed in detail.

In this thesis, there are 5 chapters will be included in which each chapter will explain independent topics. In the Chapter 1, a brief introduction of the overall research was written together with objectives of the study and the scope of the research. In the Chapter 2, extensive literature review was written covering current available knowledge on the micromechanics of natural fiber OPEFB, fermentation strategies and biodegradation of lignin process through fungal degradation. In Chapter 3, the first objective of the study was elaborated in which to study the micromechanics modeling of the silica bodies on the OPEFB fibers where constitutive material behavior (stress-strain), 2D and 3D modelling were performed in order to investigate the oil palm fiber behavior. In the Chapter 4, the second objective of the research was explained in which to explore the potential of the local isolate white rotting fungi for OPEFB biodegradation in solid state fermentation. In the Chapter 5, the third and final objective was well intricate in which to study the utilization of the micro computed tomography in the microstructure behavior of the degraded OPEFB fibers and the relationship between structural and physico-chemical behavior of degraded OPEFB was discussed. In the final chapter, chapter 6, final conclusions and some of recommendations were mentioned. Appendix and references used in this entire study was listed at the back of the thesis. The overview of the experimental design reported in the thesis is provided in Figure 1.1.

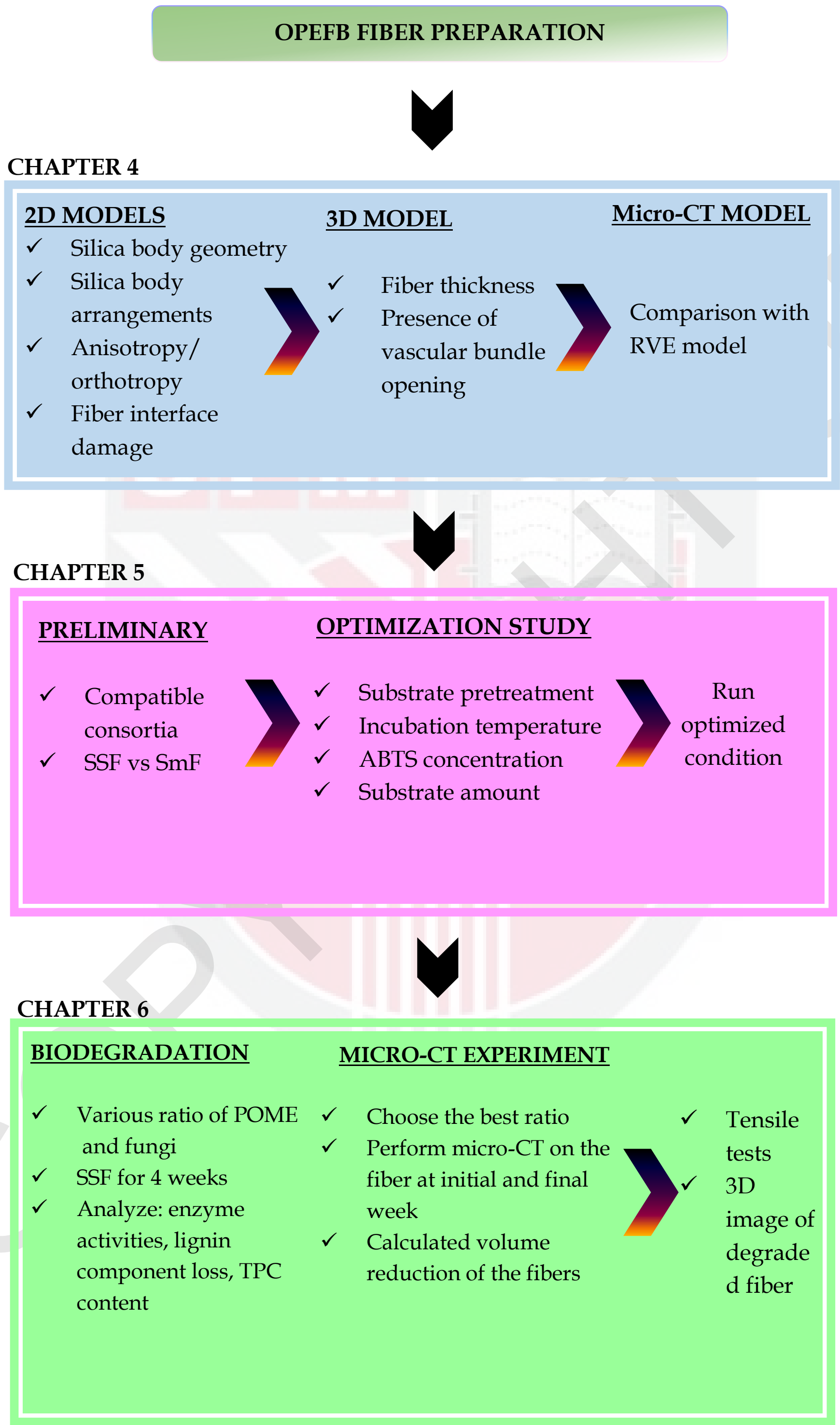

Figure 1.1: Overview of the overall experimental design

REFERENCES

Abaqus (2015) User Manual version 6.9, Hibbitt Karlsson and Sorensen, Providence, RI.

Abdel-Hamid, A. M., Solbiati, J. O., & Cann, I. K. O. (2013). Insights into lignin degradation and its potential industrial applications. *Advances in Applied Microbiology*, *82*, 1–28.

Abd-Elsalam, H. and El-Hanafy, A. (2009). Lignin biodegradation with ligninolytic bacterial strain and comparison of *Bacillus subtilis* and *Bacillus* sp. isolated from Egyptian soil. *American-Eurasian Journal of Agricultural and Environmental Sciences, 5* (1), 39-44.

Abdul Khalil, H. P. S., Siti Alwani, M., Ridzuan, R., Kamarudin, H., and Khairul, A. (2008). Chemical composition, morphological characteristics, and cell wall structure of malaysian oil palm fibers. *Polymer-Plastics Technology and Engineering*, *47* (3), 273–280.

Abdullah, N., and Sulaiman, F. (2013). The oil palm wastes in Malaysia. *Biomass Now – Sustainable Growth and Use*, 75–100.

Abu Bakar, N. K., Zanirun, Z., Abd-Aziz, S., Ghazali, F. M., Hassan, M. A. (2012). Production of fermentable sugars from oil palm empty fruit bunch using crude cellulase cocktails with *Trichoderma asperellum* UPM1 and *Aspergillus fumigatus* UPM2 for bioethanol production. *BioResources*, *7* (3), 3627–3639.

Adejoye, O. D., & Fasidi, I. O. (2009). Biodegradation of agro-wastes by some Nigerian white-rot fungi. *Bioresources*, *4* (2), 816–824.

Adler, D. C., and Buehler, M. J. (2013). Mesoscale mechanics of wood cell walls under axial strain. *Soft Matter*, *9* (29), 7138–7144.

Akhtar, J., Idris, A., Teo, C. L., Lai, L. W., Hassan, N., & Khan, M. I. (2014). Comparison of delignification of oil palm empty fruit bunch (efb) by microwave assisted alkali/acid pretreatment and conventional pretreatment method. *International Journal of Advances in Chemical Engineering and Biological Sciences*, *1* (2), 155–157.

Altschul, S. F., Madden, T. L., Schäffer, A. A., Zhang, J., Zhang, Z., Miller, W., & Lipman, D. J. (1997). Gapped BLAST and PSI-BLAST: A new generation of protein database search programs. *Nucleic Acids Research*, *25* (17), 3389–3402.

AOAC (1997). Official methods of analysis of AOAC International. Method 952.03, 16th ed., ed. Cunniff, P., Maryland: AOAC International.

Arganda-Carreras, I., Kaynig, V., Rueden, C., Schindelin, J., Cardona, A., Seung, H. S. (2016). Trainable_Segmentation: release v3.1.2 [Data set]. Zenodo. doi:10.5281/zenodo.59290

Arun, A., and Eyini, M. (2011). Comparative studies on lignin and polycyclic aromatic hydrocarbons degradation by basidiomycetes fungi. *Bioresource Technology*, *102* (17), 8063–8070.

Asgher, M., Bashir, F., & Iqbal, H. M. N. (2014). A comprehensive ligninolytic pre-treatment approach from lignocellulose green biotechnology to produce bio-ethanol. *Chemical Engineering Research and Design*, *92* (8), 1571–1578.

Asgher, M., Nasir Iqbal, H. M., & Asad, M. J. (2012). Kinetic characterization of purified laccase produced from. *BioResources*, *7* (1), 1171–1188.

Ashik, K. P. and Sharma, R. S. (2015). A review on mechanical properties of natural fiber reinforced hybrid polymer composites. *Journal of Minerals and Materials Characterization and Engineering, 3*, 420-426.

Askarinejad, S., and Rahbar, N., (2015) Toughening mechanisms in bioinspired multilayered materials. *Journal of Royal Society of Interface*, *12* (102), 20140855.

Awalludin, M. F., Sulaiman, O., Hashim, R., & Nadhari, W. N. A. W. (2015). An overview of the oil palm industry in Malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. *Renewable and Sustainable Energy Reviews*, *50*, 1469–1484.

Aziz, M. M. A., Hamad, A. W., Maleka, A. M., & Jakarni, F. M. (2015). Effect of viscoelastic behavior of cellulose oil palm fiber (COPF) modified 60-70 asphalt binder for deterioration for roads and highways. *Jurnal Teknologi*, *75* (11), 17-23.

Baharuddin, A. S., Hock, L. S., Yusof, M. Z. M., Abdul, N. A. R., Shah, U. K. M., Hassan, M. A., Wakisaka, M., Sakai, K., Shirai, Y. (2010). The effect of palm oil mill effluent (POME) anaerobic sludge from 500 m^3 of closed anaerobic methane digested tank on pressed-shredded empty fruit bunch (EFB) composting process. *African Journal of Biotechnology, 9* (16), 2427–2436.

Baharuddin, A. S., Sulaiman, A., Kim, D. H., Mokhtar, M. N., Hassan, M. A., Wakisaka, M., Shirai, Y., Nishida, H. (2013). Selective component degradation of oil palm empty fruit bunches (OPEFB) using high-pressure steam. *Biomass and Bioenergy*, *55*, 268–275.

Baharuddin, A. S., Wakisaka, M., Shirai, Y., & Abd-Aziz, S. (2009). Co-composting of empty fruit bunches and partially treated palm oil mill efluents in pilot scale. *International Journal of Agricultural Research*, *4*, 69–78.

Begley, M. R., Philips, N. R., Compton, B. G., Wilbrink, D. V., Ritchie, R. O., Utz, M., (2012). Micromechanical models to guide the development of synthetic 'brick and mortar' composites. *Journal of Mechanical Physics and Solids*, *60* (8), 1545–1560.

Benvenuto, M. L., Fernández Honaine, M., Osterrieth, M. L., & Morel, E. (2015). Differentiation of globular phytoliths in Arecaceae and other monocotyledons: Morphological description for paleobotanical application. *Turkish Journal of Botany*, *39* (2), 341–353.

Bhargav, S., Panda, B. P., Ali, M., and Javed, S. (2008). Solid-state Fermentation : An Overview. *Chemical Biochemical Engineering*, *22* (1), 49–70.

Bolhassan, M. H. (2012). Diversity of Polyporales and the application of *Ganoderma australe* (fr.) pat. in biopulping of empty fruit bunches of *Elaeis guineensis*. PhD Thesis, Universiti Malaya, Malaysia.

Boonyuen, N., Manoch, L., Luangsa-ard, J. J., Piasai, O., Chamswarng, C., Chuaseeharonnachai, C., Ueapattanakit, J., Arnthong, J., Sri-indrasutdhi, V. (2014). Decomposition of sugarcane bagasse with lignocellulose-derived thermotolerant and thermoresistant Penicillia and Aspergilli. *International Biodeterioration and Biodegradation*, *92*, 86–100.

Bourbonnais, R. and Paice, M. G. (1990). Oxidation of non phenolic substrates: An expanded role of laccase in lignin biodegradation. *FEBS Letters*, *267*(1), 99-102.

Bourbonnais, R., Paice, M. G., Reid, I. D., Lanthier, P., & Yaguchi, M. (1995). Lignin oxidation by laccase isozymes from *Trametes versicolor* and role of the mediator in kraft lignin depolymerization. *Applied and Environmental Microbiology*, *61* (5), 1876–1880.

Brandt, A., Grasvik, J., Hallet, J. P., Welton, T. (2013). Deconstruction of lignocellulosic biomass with ionic liquids. *Green Chemistry,* 15, 550-583.

Brijwani, K., Rigdon, A., and Vadlani, P. V. (2010). Fungal laccases: production, function, and applications in food processing. *Enzyme Research*, 10, 149748, 1–10.

Brodeur, G., Yau, E., Badal, K., Collier, J., Ramachandran, K. B., Ramakrishnan, S. (2011). Chemical and physicochemical pretreatment of lignocellulosic biomass: A review. *Enzyme Research*, e787532.

Brunecky, R., Alahuta, M., Xu, Q., Donohoe, B. S., Crowley, M. F., Kataeva, I. A., Yang, S. J., Resch, M. G., Adams, M. W. W., Lunin, V. V., Himmel, M. E., Bomble, Y. J. (2013). Revealing nature's cellulase diversity: The digestion mechanism of *Caldicellulosiruptor bescii* CelA. *Science 342*, 1513–1516.

Bugg, T. D. H., Ahmad, M., Hardiman, E. M., Rahmanpour, R. (2011). Pathways for degradation of lignin in bacteria and fungi. *Natural Product Reports*, *28* (12), 1883–96.

Bugg, T. D., and Rahmanpour, R. (2015). Enzymatic conversion of lignin into renewable chemicals. *Current Opinion in Chemical Biology*, *29*, 10–17.

Burgert, I. (2006). Exploring the micromechanical design of plant cell walls. *American Journal of Botany*, *93* (10), 1391–1401.

Burgert, I., and Dunlop, J. W. C. (2011). Micromechanics of cell walls. *Mechanical Integrity of Plant Cells and Plants*, *9*,27-52.

Burgert, I., and Fratzl, P., (2009). Actuation systems in plants as prototypes for bioinspired devices. *Philosophical Transactions of Royal Society A, 367*, 1541–1557

Burgert, I., and Keplinger, T. (2013). Plant micro- and nanomechanics: experimental techniques for plant cell-wall analysis. *Journal of Experimental Botany*, *64* (15), 4635-4649.

Campilho, R. D. S. G., Moura, D. C., Gonçalves, D. J. S., Da Silva, J. F. M. G., Banea, M. D., Da Silva, L. F. M. (2013). Fracture toughness determination of adhesive and co-cured joints in natural fibre composites. *Composites Part B: Engineering*, *50*, 120–126.

Castilho, L. R., Polato, C. M. S., Baruque, E. A., Sant'Anna, G. L., & Freire, D. M. G. (2000). Economic analysis of lipase production by *Penicillium restrictum* in solid-state and submerged fermentations. *Biochemical Engineering Journal*, *4* (3), 239–247.

Catherine, H., Penninckx, M., and Frédéric, D. (2016). Product formation from phenolic compounds removal by laccases: A review. *Environmental Technology and Innovation*, *5*, 250–266.

Cave, I. D., and Hutt, L. (1968). The anisotropic elasticity of plant cell wall. *Wood Science Technology*, 2, 268–278.

Chaturvedi, V., & Verma, P. (2013). An overview of key pretreatment processes employed for bioconversion of lignocellulosic biomass into biofuels and value added products. *3 Biotech*, *3* (5), 415–431.

Chen, M., Zeng, G., Tan, Z., Jiang, M., Li, H., Liu, L., Zhu, Y., Yu, Z., Liu, Y., Xie, G. (2011). Understanding lignin-degrading reactions of ligninolytic enzymes: Binding affinity and interactional profile. *PLoS ONE*, *6* (9), e25647.

Chenthamarakshan, A., Parambayil, N., Miziriya, N., Soumya, P. S., Kiran Lakshi, M. S., Ramgopal, A., Dileep, A., Nambisan, P. (2017). Optimization of laccase production from *Marasmiellus palmivorus* LA1 by Taguchi method of design of experiments. *BMC Biotechnology*, *17*(12), 1-10.

Chhaya, U., and Gupte, A. (2013). Effect of different cultivation conditions and inducers on the production of laccase by the litter-dwelling fungal isolate *Fusarium incarnatum* LD-3 under solid substrate fermentation. *Annals of Microbiology*, *63* (1), 215–223.

Chi, Y., Hatakka, A., and Maijala, P. (2007). Can co-culturing of two white-rot fungi increase lignin degradation and the production of lignin-degrading enzymes? *International Biodeterioration and Biodegradation*, *59* (1), 32–39.

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. *Journal of the Taiwan Institute of Chemical Engineers*, *52*, 85–92.

Choi, W. I., Park, J. Y., Lee, J. P., Oh, Y. K., Park, Y. C., Kim, J. S., Park, J. M., Kim, C. H., Lee, J. S. (2013). Optimization of NaOH-catalyzed steam pretreatment of empty fruit bunch. *Biotechnology for Biofuels,* 29, 170-178.

Chow, M. J., H'ng, P. S., Chin, K. L., Chai, E. W., Md Tahir, P., Lee, S. H., Lum, W. C., Chuah, L., Maminski, M. (2015). Empty Fruit Bunches in the Race for Energy, Biochemical and Material Industry in *Agricultural Biomass Based Potential Materials*, ed. Hakeem K. R., Springer International Publishing, Switzerland, pp375–389.

Christopher, L. P., Yao, B., and Ji, Y. (2014) Lignin biodegradation with laccase-mediator systems. *Fronties in Energy Research*, *2*(12), 1-13.

Chundawat, S. P., Beckham, G. T., Himmel, M. E., & Dale, B. E. (2011). Deconstruction of lignocellulosic biomass to fuels and chemicals. *Annual Review Chemical Biomolecular Engineering*, *2*, 121–145.

Coconi-Linares, N., Magana-Ortiz, D., Gusman-Ortiz, D. A., Fernandez, F., Loske, A. M., Gomez-Lim, M. A. (2014). High yield production of manganese peroxidase, lignin peroxidase and versatile peroxidase in *Phanerochaete chrysosporium. Applied Microbiology and Biotechnology, 98*, 9283-9294.

Couto, S. R., Gundín, M., Lorenzo, M., Sanromán, M. Á. (2002). Screening of supports and inducers for laccase production by *Trametes versicolor* in semisolid-state conditions. *Process Biochemistry*, *38* (2), 249–255.

Couto, S. R. and Sanroman, M. A. (2005). Application of solid-state fermentation to ligninolytic enzyme production. *Biochemical Engineering*, *22*, 211-219.

Currie, H. A., and Perry, C. C. (2007). Silica in plants: Biological, biochemical and chemical studies. *Annals of Botany*, *100*, 1383–1389.

d'Almeida, J. R. M., Aquino, R. C. M. P., & Monteiro, S. N. (2006). Tensile mechanical properties, morphological aspects and chemical characterization of piassava (Attalea funifera) fibers. *Composites Part A: Applied Science and Manufacturing*, *37* (9), 1473–1479.

da Costa Sousa, L., Chundawat, S. P., Balan, V., Dale, B. E. (2009). "Cradle-to-grave" assessment of existing lignocellulose pretreatment technologies. *Current Opinion in Biotechnology*, *20* (3), 339–347.

Dashtban, M. (2009). Fungal Bioconversion of Lignocellulosic Residues; Opportunities and Perspectives. *International Journal of Biological Sciences*, *5* (6), 578–595.

Dekker, R. F. H., Barbosa, A. M., Giese, E. C., Godoy, S. D. S., Covizzi, L. G. (2007). Influence of nutrients on enhancing laccase production by *Botryosphaeria rhodina* MAMB-05. *International Microbiology*, *10*, 177-185.

Demir, A., Aytar, P., Gedikli, S., Çabuk, A., Arisoy, M. (2011). Laccase production with submerged and solid state fermentation : Benefit and cost analysis. *Journal of Biology and Chemistry*, *39* (3), 305–313.

Dias, A. A., Freitas, G. S., Marques, G. S. M., Sampaio, A., Fraga, I. S., Rodrigues, M. A. M., Evtuguin, D. V., Bezerra, R. M. F. (2010). Enzymatic saccharification of biologically pre-treated wheat straw with white-rot fungi. *Bioresource Technology*, *101* (15), 6045–6050.

Díaz, R., Alonso, S., Sánchez, C., Tomasini, A., Bibbins-Martínez, M., Díaz-Godínez, G. (2011). Characterization of the growth and laccase activity of strains of *Pleurotus ostreatus* in submerged fermentation. *BioResources*, *6* (1), 282–290.

Dinis, M. J., Bezerra, R. M. F., Nunes, F., Dias, A. A., Guedes, C. V., Ferreira, L. M. M., Cone, J. W., Marques, G. S. M., Barros, A. R. N., Rodrigues, M. A. M. (2009). Modification of wheat straw lignin by solid state fermentation with white-rot fungi. *Bioresource Technology*, *100* (20), 4829–4835.

Dong, X. Q., Yang, J. S., Zhu, N., Wang, E. T., & Yuan, H. L. (2013). Sugarcane bagasse degradation and characterization of three white-rot fungi. *Bioresource Technology*, *131*, 443–451.

Dong, Y. C., Wang, W., Hu, Z., Fu, M. L., Chen, Q. (2012). The synergistic effect on production of lignin-modifying enzymes through submerged co-cultivation of *Phlebia radiata*, *Dichomitus squalens* and *Ceriporiopsis subvermispora* using agricultural residues. *Bioprocess and Biosystems Engineering*, *35* (5), 751–760.

Dwivedi, P., Vivekanand, V., Pareek, N., Sharma, A., Singh, R. P. (2011). Co-cultivation of mutant *Penicillium oxalicum* SAU E-3.510 and *Pleurotus ostreatus* for simultaneous biosynthesis of xylanase and laccase under solid-state fermentation. *New Biotechnology*, *28* (6), 616–626.

Ehrman, T. (1996). Determination of acid soluble lignin in biomass. NREL CAT Task Laboratory Analytical Procedure #004.

Elices, M., Guinea, G. V., Gomez, J., Planas, J. (2002). The cohesive zone model: Advantages, limitations and challenges. *Engineering Fracture Mechanics*, *69* (2), 137–163.

Elisashvili, V., Penninckx, M., Kachlishvili, E., Tsiklauri, N., Metreveli, E., Kharziani, T., & Kvesitadze, G. (2008). *Lentinus edodes* and *Pleurotus species* lignocellulolytic enzymes activity in submerged and solid-state fermentation of lignocellulosic wastes of different composition. *Bioresource Technology*, *99* (3), 457–462.

Ellaiah, P., Adinarayana, K., Bhavani, Y., Padmaja, P., Srinivasulu, B. (2002). Optimization of process parameters for glucoamylase production under solid state fermentation by a newly isolated *Aspergillus* species. *Process Biochemistry*, *38* (4), 615–620.

Eshelby, J. D. (1957). The determination of the elastic field of and ellipsoidal inclusion and related problems. *Proceedings of The Royal Society A*, 241:376–396.

Fang, J. Y., and Ma, X. L. (2006). In vitro simulation studies of silica deposition induced by lignin from rice. *Journal of Zhejiang University. Science. B, 7* (4), 267-271.

Ferhan, M., Leao, A. L., Itamar, S. de M., M, S. (2012). Ligninases production and partial purification of mnp from brazilian fungal isolate in submerged fermentation. *Fermentation Technology*, *1* (5), 1–7.

Fisher, A. B., and Fong, S. S. (2014). Lignin biodegradation and industrial implications. *AIMS Bioengineering*, *1* (2), 92–112.

Flores, E. I. S. and Friswell, M. I. (2012). Multi-scale finite element model for a new material inspired by the mechanics and structure of wood cell-walls.

Journal of Mechanical Physics and Solids, *60* (7), 943-951.

Fonseca, M. I., Shimizu, E., Zapta, P. D., Villalba, L. L. (2010). Copper inducing effect on laccase production of white rot fungi native from Misiones (Argentina). *Enzyme and Microbial Technology, 46*, 534-539.

Fujian, X., Hongzhang, C., & Zuohu, L. (2001). Solid-state production of lignin peroxidase (LiP) and manganese peroxidase (MnP) by *Phanerochaete chrysosporium* using steam-exploded straw as substrate. *Bioresource Technology*, *80* (2), 149–151.

Fu, K., Fu, S., Zhan, H., Zhou, P., Liu, M., Liu, H. (2013). A newly isolated wood rot fungus for laccase production in submerged cultures. *BioResources*, *8* (1), 1385-1397.

Gamauf, C., Metz, B., and Seiboth, B. (2007). Degradation of Plant Cell Wall Polymers by Fungi. *Environmental and Microbial Relationships - The Mycota IV*, 325–340.

Gao, X., Zou, C., Wang, L., & Zhang, F. (2006). Silicon decreases transpiration rate and conductance from stomata of maize plants. *Journal of Plant Nutrition*, *29* (9), 1637–1647.

Garcia-Nunez, J. A., Ramirez-Contreras, N. E., Rodriguez, D. T., Silva-Lora, E., Frear, C. S., Stockle, C., Garcia-Perez, M. (2016). Evolution of palm oil mills into bio-refineries: Literature review on current and potential uses of residual biomass and effluents. *Resources, Conservation and Recycling*, *110*, 99–114.

Gassara, F., Brar, S. K., Tyagi, R. D., Verma, M., Surampalli, R. Y. (2010). Screening of agro-industrial wastes to produce ligninolytic enzymes by *Phanerochaete chrysosporium*. *Biochemical Engineering Journal*, *49* (3), 388–394.

Giardina, P., Faraco, V., Pezzella, C., Piscitelli, A., Vanhulle, S., & Sannia, G. (2010). Laccases: A never-ending story. *Cellular and Molecular Life Sciences*, *67* (3), 369–385.

Gierlinger, N., Sapei, L., and Paris, O. (2008). Insights into the chemical composition of *Equisetun hyemale* by high resolution Raman imaging. *Planta*, 227, 969-980.

Goh, C. S., Tan, K. T., Lee, K. T., & Bhatia, S. (2010). Bio-ethanol from lignocellulose: Status, perspectives and challenges in Malaysia. *Bioresource Technology*, *101* (13), 4834–4841.

Gomaa, O. M., and Momtaz, O. A. (2015) Copper induction and differential expression of laccase in Aspergillus flavus. *Brazilian Journal of Microbiology*.

46 (1), 285-292.

Gomes, E., Aguiar, A. P., Carvalho, C. C., Bonfá, M. R. B., Da Silva, R., & Boscolo, M. (2009). Ligninases production by basidiomycetes strains on lignocellulosic agricultural residues and their application in the decolorization of synthetic dyes. *Brazilian Journal of Microbiology*, *40* (1), 31–39.

Govumoni, S. P., Koti, S., Kothagouni, S. Y., Venkateshwar, S., & Linga, V. R. (2013). Evaluation of pretreatment methods for enzymatic saccharification of wheat straw for bioethanol production. *Carbohydrate Polymers*, *91* (2), 646–650.

Guerriero, G., Hausman, J. F., Strauss, J., Ertan, H., & Siddiqui, K. S. (2016). Lignocellulosic biomass: Biosynthesis, degradation, and industrial utilization. *Engineering in Life Sciences*, *16*(1), 1–16.

Gunawan, F. E., Homma, H., Brodjonegoro, S. S., Hudin, A. B., Zainuddin, A. (2009). Mechanical properties of oil palm empty fruit bunch fiber. *Journal of Solid Mechanical and Material Engineering*, 3(7), 943-951.

Gupte, A., Gupte, S., and Patel, H. (2007). Ligninolytic enzyme production under solid-state fermentation by white rot fungi. *Journal of Scientific and Industrial Research*, *66* (8), 611–614.

Haghighi Mood, S., Hossein Golfeshan, A., Tabatabaei, M., Salehi Jouzani, G., Najafi, G. H., Gholami, M., Ardjmand, M. (2013). Lignocellulosic biomass to bioethanol, a comprehensive review with a focus on pretreatment. *Renewable and Sustainable Energy Reviews*, *27*, 77–93.

Hamisan, A. F., Abd-Aziz, S., Kamaruddin, K., Shah, U. K. M., Shahab, N., Hassan, M. A. (2009). Delignification of oil palm empty fruit bunch using chemical and microbial pretreatment methods. *International Journal of Agriculture Research*, *4*, 250-256.

Hamzah, F., Idris, A., and Shuan, T. K. (2011). Preliminary study on enzymatic hydrolysis of treated oil palm (*Elaeis*) empty fruit bunches fibre (EFB) by using combination of cellulase and β,1-4 glucosidase. *Biomass and Bioenergy*, *35* (3), 1055–1059.

Han, M., Kim, Y., Kim, Y., Chung, B., Choi, G. W. (2011). Bioethanol production from optimized pretreatment of cassava stem. *Korean Journal of Chemical Engineering*, *28* (1), 119–125.

Hanipah, S. H., Mohammed, M. A. P., and Baharuddin, A. S. (2016). Non-linear mechanical behaviour and bio-composite modelling of oil palm mesocarp fibres. *Composite Interfaces*, *23* (1), 37–49.

Hanipah, S. H., Yu Xiang, L., Mohammed, M. A. P., Samsu Baharuddin, A. (2017). Study of non-linear mechanical behavior of oil palm mesocarp fibers. *Journal of Natural Fibers*, *14* (2), 153–165.

Hassan, A., Salema, A. A., Ani, F. N., & Bakar, A. A. (2010). A review on oil palm empty fruit bunch fiber-reinforced polymer composite materials. *Polymer Composites*, *31* (12), 2079–2101.

Hatakka, A., and Hammel, K. (2010). Fungal biodegradation of lignocelluloses. *The Mycota*, 319–340.

Hattaka, A. (1994). Lignin-modifying enzymes from selected white-rot fungi: Production and role from in lignin degradation. *FEMS Microbiology Reviews*, *13* (3), 125–135.

Hayot, C. M., Farousech, E., Goel, A., Avramova, Z., Turner, J. A. (2012). Viscoelastic properties of cell walls of single living plant cells determined by dynamic nanoindentation. *Journal of Experimental Botany*, 53 (7), 2525-2540.

He, C., Wang, L., Liu, J., Liu, X., Li, X., Ma, J., Lin, Y., Xu, F. (2015). Evidence for 'silicone' within the cell walls of suspension-cultured rice cells. *New Phytologist*, 200, 700-709.

Hendriks, A. T. W. M., and Zeeman, G. (2009). Pretreatments to enhance the digestibility of lignocellulosic biomass. *Bioresource Technology*, *100* (1), 10–18.

Hernandez, C., Da Silva, A.M., Ziarelli, F., Perraud-Gaime, I., Gutierrez-Rivera, B., Garcia-Perez, J. A., Alarcon, E. (2016). Laccase induction by synthetic dyes in *Pycnoporus sanguineus* and their possible use for sugar cane bagasse delignification. Applied Microbiology Biotechnology, *101*(3), 1189-1201.

Hill, R. (1952). The elastic behavior of crystalline aggregate: Proceedings of the Physical Society, London, Section A, *65* (5), 349-354.

Hill, R. (1965). A self-consistent mechanics of composite materials. *Journal of Mechanical and Physics of Solids*, *13*, 213-222.

Hildén, K. S., Mäkelä, M. R., Hakala, T. K., Hatakka, A., & Lundell, T. (2006). Expression on wood, molecular cloning and characterization of three lignin peroxidase (LiP) encoding genes of the white rot fungus Phlebia radiata. *Current Genetics*, *49* (2), 97–105.

Ho, H. L. (2014). Biodiversity , Bioprospecting and development effects of medium formulation and culture conditions on microbial xylanase production using agricultural extracts in submerged fermentation (SmF) and solid state fermentation (SSF): A review. *Journal of Biodiversity,* *Bioprospecting and Development*, *1* (3), 1–13.

Honda, Y., Watanabe, T., & Kuwahara, M. (2002). Pre-treatment of oil palm empty fruit bunch by white rot fungi for enzymatic saccharification. *Wood Research*, *89*, 19–20.

Hurtado, J. A., Lapczyk, I., Govindarajan, S. M. (2013). Parallel rheological framework to model non-linear viscoelasticity, permanent set, and Mullins effect in elastomers. *Constitutive Models for Rubber VIII*, Edited by Asier Alonso CRC Press, pp 95–100.

Iberahim, N. Z., Md-Jahim, J., Harun, S., Mohd-Nor, M. T., Hassan, O. (2013). Sodium hydroxide pretreatment and enzymatic hydrolysis of oil palm mesocarp fiber. *International Journal of Chemical Engineering Applications*, *4*(3), 101–105.

Ibrahim, S. M., Badri, K. H., and Hassan, O. (2012). A study on glycerolysis of oil palm empty fruit bunch fiber. *Sains Malaysiana, 41*(12), 1579–1585.

Irshad, M. and Asgher, M. (2011). Purification and characterization of LiP produced by schyzophyllum commune IBL-06 using banana stalk in solid state cultures. *African Journal of Biotechnology*, *10* (79), 18234–18242.

Isroi, Ishola, M. M., Millati, R., Syamsiah, S., Cahyanto, M. N., Niklasson, C., Taherzadeh, M. J. (2012). Structural changes of oil palm empty fruit bunch (OPEFB) after fungal and phosphoric acid pretreatment. *Molecules*, *17* (12), 14995–15012.

Isroi, Millati, R., Syamsiah, S., Niklasson, C., Cahyanto, M. N., Lundquist, K., Taherzadeh, M. J. (2011). Biological pretreatment of lignocelluloses with white-rot fungi and its applications: A review. *BioResources*, *6* (4), 5224–5259.

Jeon, H., Kang, K. E., Jeong, J. S., Gong, G., Choi, J. W., Abimanyu, H., Ahn, B. S., Suh, D. J., Choi, G. W. (2014). Production of anhydrous ethanol using oil palm empty fruit bunch in a pilot plant. *Biomass and Bioenergy*, *67*, 99–107.

Jönsson, L. J. and Martín, C. (2016). Pretreatment of lignocellulose: Formation of inhibitory by-products and strategies for minimizing their effects. *Bioresource Technology*, *199*, 103–112.

Kachlishvili, E., Penninckx, M. J., Tsiklauri, N., Elisashvili, V. (2006). Effect of nitrogen source on lignocellulolytic enzyme production by white-rot basidiomycetes under solid-state cultivation. *World Journal of Microbiology and Biotechnology*, *22* (4), 391–397.

Kadam, A. A., Telke, A. A., Jagtap, S. S., Govindwar, S. P. (2011). Decolorization of adsorbed textile dyes by developed consortium of *Pseudomonas* sp. SUK1 and *Aspergillus ochraceus* NCIM-1146 under solid state fermentation. *Journal of Hazardous Materials*, *189* (1–2), 486–494.

Kalia, S., Kaith, B. S. and Kaur, I. (2007). A short review on rubber / clay nanocomposites with emphasis on mechanical properties. *Polymer Engineering and Sciences*, *49* (7), 12553–1272.

Kamal Bahrin, E. (2012) Optimization and characterization of oil palm empty fruit bunch fermentation for cellulase producyion by *Botrysphaeria rhodina* UPM3, PhD Thesis, Universiti Putra Malaysia, Malaysia.

Kamal Bahrin, E., Baharuddin, A. S., Ibrahim, M. F., Abdul Razak, M. N., Sulaiman, A., Abd-Aziz, S., Hassan, M. A., Shirai, Y., Nishida, H. (2012). Physicochemical property changes and enzymatic hydrolysis enhancement of oil palm empty fruit bunches treated with superheated steam. *BioResources*, *7* (2), 1784–1801.

Kamcharoen, A., Champreda, V., Eurwilaichitr, L., and Boonsawang, P. (2014). Screening and optimization of parameters affecting fungal pretreatment of oil palm empty fruit bunch (EFB) by experimental design. *International Journal of Energy and Environmental Engineering*, *5* (4), 303–312.

Kanmani, P., Karuppasamy, P., Pothiraj, C., Arul, V. (2009). Studies on lignocellulose biodegradation of coir waste in solid state fermentation using *Phanerocheate chrysosporium* and *Rhizopus stolonifer*. *African Journal of Biotechnology*, *8* (24), 6880–6887.

Karp, S. G., Faraco, V., Amore, A., Birolo, L., Giangrande, C., Soccol, V. T., Pandey, A., Soccol, C. R. (2012). Characterization of laccase isoforms produced by *Pleurotus ostreatus* in solid state fermentation of sugarcane bagasse. *Bioresource Technology*, *114*, 735–739.

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* (1), 11–16.

Kausar, H., Sariah, M., Mohd Saud, H., Zahangir Alam, M., Razi Ismail, M. (2010). Development of compatible lignocellulolytic fungal consortium for rapid composting of rice straw. *International Biodeterioration and Biodegradation*, *64* (7), 594–600.

Keiluweit, M., Nico, P., Harmon, M. E., Mao, J., Pett-Ridge, J., Kleber, M. (2015). Long-term litter decomposition controlled by manganese redox cycling. *Proceedings of the National Academy of Sciences*, *112* (38), E5253–E5260.

Kennedy, J. M. and Moeller, H. H. (1990). Thermal and Mechanical Behavior of

Metal Matrix and Ceramic Matrix Composites, *American Society for Testing and Materials,* Philadelphia, USA. pp 136-151.

Koyani, R. D., and Rajput, K. S. (2015). Bioprocessing and biotechniques solid state fermentation : comprehensive tool for utilization of lignocellulosic through biotechnology, *Journal of Bioprocessing and Biotechniques*, *5* (10), 1-15.

Kratky, L. and Jirout, T. (2011). Biomass size reduction machines for enhancing biogas production. *Chemical Engineering and Technology*, *34* (3), 391–399.

Krishna, C. (2005). Solid-state fermentation systems - An overview. *Criticals Reviews in Biotechnology,* 25, 1-30.

Kristiani, A., Effendi, N., Aristiawan, Y., Aulia, F., Sudiyani, Y. (2015). Effect of combining chemical and irradiation pretreatment process to characteristic of oil palm's empty fruit bunches as raw material for second generation bioethanol. *Energy Procedia*, *68*, 195–204.

Kuhar, F., Castiglia, V., and Levin, L. (2015). Enhancement of laccase production and malachite green decolorization by co-culturing *Ganoderma lucidum* and *Trametes versicolor* in solid-state fermentation. *International Biodeterioration and Biodegradation*, *104*, 238-243.

Kumar, P., Barrett, D. M., Delwiche, M. J., Stroeve, P. (2009). Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. *Industrial and Engineering Chemistry Research*, *48*(8), 3713–3729.

Kumar, V. V., Kirupha, S. D., Periyaraman, P. (2011). Screening and induction of laccase activity in fungal species and its application in dye decolorization. *African Journal of Miicrobiology Research*, *5* (11), 1261–1267.

Kuwahara, M., Glenn, J. K., Morgan, M. A., Gold, M. H. (1984). Separation and characterization of two extracellular H_2O_2-dependent oxidases from ligninolytic cultures of *Phanerochaete chrysosporium*, *169* (2), 247–250.

Lai, C., Zeng, G. M., Huang, D. L., Zhao, M. H., Huang, H. L., Huang, C., Wei, Z., Li, N. J., Xu, P., Zhang, C., Xie, G. X. (2013). Effect of ABTS on the adsorption of *Trametes versicolor* laccase on alkali lignin. *International Biodeterioration and Biodegradation*, *82*, 180–186.

Law, K.-N., Wan Daud, W. R., Ghazali, A. (2007). Morphological and chemical nature of fiber strands of oil palm empty-fruit-bunch (OPEFB). *BioResources*, *2* (3), 351–362.

Levin, L., Herrmann, C., Papinutti, V. L. (2008). Optimization of lignocellulolytic enzyme production by the white-rot fungus *Trametes trogii* in solid-state fermentation using response surface methodology. *Biochemical Engineering Journal*, *39* (1), 207–214.

Li, X., Jia, R., Li, P., Ang, S. (2009). Response surface analysis for enzymatic decolorization of Congo red by manganese peroxidase. *Journal of Molecular Catalysis B: Enzymatic*, *56* (1), 1–6.

Limbert, G., Bryan, R., Cotton, R., Young, P., Hall-Stoodley, L., Kathju, S., Stoodley, P. (2013). On the mechanics of bacterial biofilms on non-dissolvable surgical sutures: A laser scanning confocal microscopy-based finite element study. *Acta Biomaterials*, *9* (5), 6641–6652.

Liu, J., Sidhu, S. S., Wang, M. L., Tonnis, B., Habteselassie, M., Mao, J., & Huang, Q. (2015). Fungal pretreatment of switchgrass for improved saccharification and simultaneous enzyme production. *Journal of Cleaner Production*, *104*, 480–488.

Liu, K., and Jiang, L., (2011). Bio-inspired design of multiscale structures for function integration. *Nano Today* 6 (2), 155–175.

Loh, S. K. (2017). The potential of the Malaysian oil palm biomass as a renewable energy source. *Energy Conversion and Management 141*, 285-298.

Lomascolo, A., Uzan-Boukhris, E., Herpoël-Gimbert, I., Sigoillot, J. C., Lesage-Meessen, L. (2011). Peculiarities of *Pycnoporus* species for applications in biotechnology. *Applied Microbiology and Biotechnology*, *92* (6), 1129–1149.

Lonsdale, R., Harvey, J. N., and Mulholland, A. J. (2012). A practical guide to modelling enzyme-catalysed reactions. *Chemical Society Review*, *41* (8), 3025-3038.

Ma, J. F., and Yamaji, N. (2006). Silicon uptake and accumulation in higher plants. *Trends in Plant Science*, *11* (8), 392–397.

Ma, J. F., Yamaji, N., and Mitani-Ueno, N. (2011). Transport of silicon from roots to panicles in plants. *Proceedings of the Japan Academy. Series B: Physical and biological sciences,* 87(7), 377-385.

Ma, K., and Ruan, Z. (2015). Production of a lignocellulolytic enzyme system for simultaneous bio-delignification and saccharification of corn stover employing co-culture of fungi. *Bioresource Technology*, *175*, 586–593.

Maciel, M. J. M., Castro e Silva, A., & Ribeiro, H. C. T. (2010). Industrial and biotechnological applications of ligninolytic enzymes of the basidiomycota: A review. *Electronic Journal of Biotechnology*, *13*(6), 1–13.

Magnusson, M. S., and Östlund, S. (2013). Numerical evaluation of interfibre joint strength measurements in terms of three-dimensional resultant forces and moments. *Cellulose*, *20* (4), 1691–1710.

Mäkelä, M. R., Lundell, T., Hatakka, A., Hildén, K. (2013). Effect of copper, nutrient nitrogen, and wood-supplement on the production of lignin-modifying enzymes by the white-rot fungus *Phlebia radiata*. *Fungal Biology*, *117*(1), 62–70.

Marklund, E., Eitzenberger, J., and Varna, J. (2008). Nonlinear viscoelastic material model including stiffness degradation for hem/lignin composites. *Composites Sciences and Technology*, *68*, 2156-2162.

Martín-Sampedro, R., Rodríguez, A., Ferrer, A., García-Fuentevilla, L. L., Eugenio, M. E. (2012). Biobleaching of pulp from oil palm empty fruit bunches with laccase and xylanase. *Bioresource Technology*, *110*, 371–378.

Martinez, A. T., Speranza, M., Ruiz-dueñas, F. J., Ferreira, P., Camarero, S., Guillén, F., Martinez, M. J., Gutierrez, A., del Río, J. C. (2005). Biodegradation of lignocellulosics: Microbial, chemical, and enzymatic aspects of the fungal attack of lignin. *International Microbiology, 8*, 195–204.

Masran, R., Zanirun, Z., Bahrin, E. K., Ibrahim, M. F., Lai Yee, P., Abd-Aziz, S. (2016). Harnessing the potential of ligninolytic enzymes for lignocellulosic biomass pretreatment. *Applied Microbiology and Biotechnology*, 1–16.

Matsubara, M., Lynch, J. M., and De Leij, F. A. A. M. (2006). A simple screening procedure for selecting fungi with potential for use in the bioremediation of contaminated land, *Enzyme and Microbial Technology*, *39* (7), 1365-1372.

Maza, M., Pajot, H. F., Amoroso, M. J., Yasem, M. G. (2014) Post-harvest sugarcane residue degradation by autochthonous fungi. *International Biodeterioration and Biodegradation*, 87, 18-25.

Mazaheri, H., Lee, K. T., Bhatia, S., & Mohamed, A. R. (2010). Subcritical water liquefaction of oil palm fruit press fiber in the presence of sodium hydroxide: An optimisation study using response surface methodology. *Bioresource Technology*, *101* (23), 9335–9341.

Mazumder, S., Basu, S. K., Mukherjee, M. (2009). Laccase production in solid-state and submerged fermentation by *Pleurotus ostreatus*. *Engineering in Life Sciences*, *9* (1), 45–52.

Md Yunos, N. S. H., Baharuddin, A. S., Md Yunos, K. F., Hafid, H. S., Busu, Z., Mokhtar, M. N., Sulaiman, A., Md Som, A. (2015). The physicochemical characteristics of residual oil and fibers from oil palm empty fruit bunches. *BioResources*, *10* (1), 14-29.

Mihai, L. A., Alayyash, K., and Goriely, A. (2015). Paws, pads and plants: the enhanced elasticity of cell-filled load-bearing structures. *Proceedings of the Royal Society A,* 471, 20150107.

Mishnaevsky, L. (2007). *Computational mesomechanics of composites: Numerical analysis of the effect of microstructures of composites on their strength and damage resistance,* John Wiley and Sons, Chichester.

Mishra, A., Kumar, S., Kumar Pandey, A. (2011). Laccase production and simultaneous decolorization of synthetic dyes in unique inexpensive medium by new isolates of white rot fungus. *International Biodeterioration and Biodegradation*, *65* (3), 487–493.

Mishra V., Jana A.K., Jana M.M., Gupta A. (2017). Enhancement in multiple lignolytic enzymes production for optimized lignin degradation and selectivity in fungal pretreatment of sweet sorghum bagasse. *Bioresource Technology, 236*, 49-59.

Mohammed, I. K., Charalambides, M. N., Williams, J. G., Rasburn, J. (2013). Modelling the deformation of a confectionery wafer as a non-uniform sandwich structure. *Journal of Material Sciences*, *48* (6), 2462–2478.

Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., Islam, M. S. (2015). A review on natural fiber reinforced polymer composite and its applications. *International Journal of Polymer Sciences*, Article ID 243947, 15 pages.

Moilanen, U., Kellock, M., Varnai, A., Andberg, M., Vikari, L. (2014). Mechanisms of laccase-mediator treatments improving the enzymatic hydrolysis of pre-treated spruce. *Biotechnology for Biofuels, 7* (177), 1-13.

Molla, A. H., Fakhru'l-Razi, A., Abd-Aziz, S., Hanafi, M. M., Alam, M. Z. (2001). In-vitro compatibility evaluation of fungal mixed culture for bioconversion of domestic wastewater sludge. *World Journal of Microbiology and Biotechnology*, *17* (9), 849–856.

Mood, S. H., Golfeshan, A. H., Tabatabaei, M., Jouzani, G. S., Najafi, G. H., Gholami, M., Ardjmand, M. (2013). Lignocellulose biomass to bioethanol, a comprehensive review with a focus on pretreatment. *Renewable and Sustainable Energy Reviews*, 27, 77-93.

Mori, T., and K. Tanaka (1973). Average stress in matrix and average elastic energy of materials with misfitting inclusions. *Acta Metallurgica,* 21:571-574.

Morozova, O. V., Shumakovich, G. P., Shleev, S. V., Yaropolov, Y. I. (2007). Laccase-mediator systems and their applications: A review. *Applied Biochemistry and Microbiology*, *43* (5), 523–535.

Moulia, B. (2013). Plant biomechanics and mechanobiology are convergent paths to flourishing interdisciplinary research. *Journal of Experimental Botany, 64* (15), 4617-4633.

Muryanto, T. E., Abimayu, H., Cahyono, A., Cahyono, E. T., Sudiyani, Y. (2015). Alkaline delignification of oil palm empty fruit bunch using black liquor from pretreatment. *Procedia Chemistry*, *16*, 99–105.

Mussatto, S., and Teixeira, J. (2010). Lignocellulose as raw material in fermentation processes. *Applied Microbiology an Microbial Biotechnology*, 2, 897–907.

Mwaikambo, L. Y., and Ansell, M. P. (2006). Mechanical properties of alkali treated plant fibers and their potential as reinformcement materials II. Sisal fibers. *Journal of Material Sciences,* 41, 2497-2508.

Nafu, Y. R., Foba-tendo, J., Njeugna, E., Oliver, G., Cooke, K. O. (2015). Extraction and characterization of fibres from the stalk and spikelets of empty fruit bunch. *Journal of Applied Chemistry*, *2015*, 1–10.

Nascimento, D. C. O., Ferreira, A. S., Monteiro, S. N., Aquino, R. C. M. P., Kestur, S. G. (2012). Studies on the characterization of piassava fibers and their epoxy composites. *Composites Part A: Applied Science and Manufacturing*, *43* (3), 353–362.

Naseem A., Tabasum S., Zia K.M., Zuber M., Ali M., Noreen A. (2016). Lignin-derivatives based polymers, blends and composites: A review. *International Journal of Biological Macromolecules 93*, 296-313.

Neethirajan, S., Gordon, R., Wang, L. (2009). Potential of silica bodies (phytoliths) for nanotechnology. *Trends in Biotechnology*, *27* (8), 461–467.

Nerud, F., and Misurcova, Z. (1996). Distribution of Ligninolytic Enzymes in Selected White-Rot Fungi. *Folia Microbiology*, *41* (3), 1988–1990.

Ngo, T. T., Kohl, J. G., Paradise, T., Khalily, A., Simonson, D. L., (2015) Improving mechanical properties of thermoset biocomposites by fiber coating or organic oil addition. *International Journal of Polymer Sciences*, 840823, 1–7.

Nicholson, D. J., Leavitt, A. T., and Francis, R. C. (2014). A three-stage klason method for more accurate determinations of hardwood lignin content. *Cellulose Chemistry and Technology*, *48*, 53–59.

Nieves, D. C., Karimi, K., and Horváth, I. S. (2011). Improvement of biogas production from oil palm empty fruit bunches (OPEFB). *Industrial Crops and Products*, *34* (1), 1097–1101.

Nishiyama, Y. (2009). Structure and properties of the cellulose microfibril.

Journal of Wood Science, 55 (4), 241–249.

Nitta, Y., Goda, K., Noda, J., & Lee, W. (2011). Effect of Alkali-Treatment on Tensile Properties of Kenaf Long Fibres using Data-based Cross-sectional Area Approximation Method. *18th International Conference on Composite Materials, 21-26th August 2011, Jeju Island, Korea*, (June), 24–28.

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* (8), 9132–9146.

Nurul Hazirah, C. H., Markom, M, Harun, S, Hassan, O. (2016). The effect of various pretreatment methods on empty fruit bunch for glucose production. *Malaysian Journal of Analytical Science*, *20* (6), 1474-1480.

Omar, F. N., Hanipah, S. H., Xiang, L. Y., Mohammed, M. A. P., Baharuddin, A. S., Abdullah, J. (2016) Micromechanical modelling of oil palm empty fruit bunch fibers containing silica bodies. *Journal of Mechanical Behaviour of Biomedical Materials*, 62, 106–118

Omar, F.N., Mohammed, M. A. P., and Baharuddin, A. S. (2014a) Microstructure modelling of silica bodies from oil palm empty fruit bunch (OPEFB) fibres. *BioResources*, 9 (1), 938-951.

Omar, F.N., Mohammed, M. A. P., and Baharuddin, A. S. (2014b) Effect of silica bodies on the mechanical behaviour of oil palm empty fruit bunch fibres. *BioResources*, 9 (4), 7041-7058.

Othman, J., and Jafari, Y. (2014). Selected research issues in the Malaysian agricultural sector. *Jurnal Ekonomi Malaysia*, *48* (2), 127–136.

Palamae, S., Dechatiwongse, P., Choorit, W., Chisti, Y., Prasertsan, P. (2017). Cellulose and hemicellulose recovery from oil palm empty fruit bunch (EFB) fibers and production of sugars from the fibers. *Carbohydrate Polymers*, *155*, 491–497.

Pan, Y., and Pelegri, A. A. (2011). Progressive Damage Analysis of Random Chopped Fiber Composite Using Finite Elements. *Journal of Engineering Materials and Technology*, *133,* 1-7.

Patel, H., Gupte, S., Gahlout, M., Gupte, A. (2014). Purification and characterization of an extracellular laccase from solid-state culture of *Pleurotus ostreatus* HP-1. *3 Biotech,* 4, 77-84.

Pickering, K. L., Efendy, M. G. A., Le, T. M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. *Composite: Part A*, 83, 98-112.

Piñeros-Castro, Y., and Velásquez-Lozano, M. (2014). Biodegradation kinetics of oil palm empty fruit bunches by white rot fungi. *International Biodeterioration and Biodegradation*, *91*, 24–28.

Pinto, P. A., Dias, A. A., Fraga, I., Marques, G., Rodrigues, M. A. M., Colaco, J., Sampaio, A., Bezerra, R. M. F. (2012). Influence of ligninolytic enzymes on straw saccharification during fungal pretreatment. *Bioresource Technology*, *111*, 261-267.

Piscitelli, A., Giardina, P., Lettera, V., Pezzella, C., Sannia, G., Faraco, V. (2011). Induction and transcriptional regulation of laccases in fungi. *Current Genomics*, *12* (2), 104–112.

Placet, V., Cisse, O., and Boubakar, L. (2014). Nonlinear tensile behaviour of elementary hemp fibres. Part 1: Investigation of the possible origins using repeated progressive loading with in situ microscopic observations. *Composite Part A*, *56*, 319–327.

Plácido, J., and Capareda, S. (2015). Ligninolytic enzymes: a biotechnological alternative for bioethanol production. *Bioresources and Bioprocessing*, *2* (1), 23.

Pointing, S. B., Jones, E. B. G., Vrijmoed, L. L. P. (2000). Optimization of laccase production by *Pycnoporus sanguineus* in submerged liquid culture. *Mycologia*, *92* (1), 139–144.

Porter, C. L. (1924). Concerning the characters of certain fungi asexhibited by their growth in the presence of other fungi. *American Journal of Botany*, 11, 168–188.

Preston, R. D. (1952). The molecular architecture of plant cell walls. John Wiley & Sons, New York pp 31-71.

Prychid, C. J., Rudall, P. J., Gregory, M., Url, S., Rudall, P. J., Gregory, M. (2011). Systematics and biology of silica bodies in monocotyledons Published by : Springer on behalf of New York Botanical Garden Press *69* (4), 377–440.

Qi-He, C., Krügener, S., Hirth, T., Rupp, S., Zibek, S. (2011). Co-cultured production of lignin-modifying enzymes with white-rot fungi. *Applied Biochemistry and Biotechnology*, *165* (2), 700–718.

Qing, H., and Mishnaevsky, L. (2009). 3D hierarchical computational model of wood as a cellular material with fibril reinforced, heterogeneous multiple layers. *Mechanics of Materials*, *41* (9), 1034–1049.

Qing, H., and Mishnaevsky, L. (2011). A 3D multilevel model of damage and strength of wood: Analysis of microstructural effects. *Mechanics of Materials*, *43* (9), 487–495.

Rajan, A., Kurup, J. G., and Abraham, T. E. (2010). Solid state production of manganese peroxidases using arecanut husk as substrate. *Brazilian Archives of Biology and Technology*, *53* (3), 555–562.

Ramirez-Cavazos, L. I., Junghanns, C., Ornelas-Soto, N., Cardenas-Chavez, D. L., Hernandez-Luna, C., Demarche, P., Enaud, E., Garcia-Morales, R., Agathos, S. N., Parra, R. (2014). Purification and characterization of two thermostable laccases from *Pycnoporus sanguineus* and potential role in degradation of endocrine disrupting chemicals. *Journal of Molecular Catalysis B: Enzymatic*, 108, 32-42.

Rasband, W. S. (2012). *ImageJ*, U.S. National Institutes of Health, Bethesda, MD.

Ratnasingam, J., Tek, T. C., and Farrokhpayam, S. R. (2008). Tool wear characteristics of oil palm empty fruit bunch particleboard. *Journal of Applied Sciences, 8* (8), 1594–1596.

Reeb, C. W., Hays, T., Venditti, R. A., Gonzalez, R., Kelley, S. (2014). Supply chain analysis, delivered cost, and life cycle assessment of oil palm empty fruit bunch biomass for green chemical production in Malaysia. *Bioresources*, *9* (3), 5385–5416.

Renge, V. C., Khedkar, S. V, and Nandurkar, N. R. (2012). Enzyme Synthesis by Fermentation Method : A Review. *Scientific Reviews and Chemical Communications*, 2 (4), 585–590.

Resch, M. G., Donohoe, B. S., Baker, J. O., Decker, S. R., Bayer, E. A., Beckham, G. T., Himmel, M. E. (2013). Fungal cellulases and complexed cellulosomal enzymes exhibit synergistic mechanisms in cellulose deconstruction. *Energy Environmental Sciences*, *6*, 1858–1867.

Reuss, A. (1929). Berechnung der Fließgrenze von Mischkristallen auf Grund der Plastizitätsbedingung für Einkristalle. *Journal of Applied Mathematics and Mechanics, 9*, 49–58.

Risdianto, H., Sofianti, E., Suhardi, S. H., & Setiadi, T. (2012). Optimisation of laccase production using white rot fungi and agriculture wastes in solid state fermentation. *ITB Journal of Engineering Science*, *44* (1), 93–105.

Rosli, N. S., Harun, S., Md Jahim, J., & Othaman, R. (2017). Chemical and physical characterization of oil palm empty fruit bunch. *Malaysian Journal of Analytical Sciences*, *21*(1), 188–196.

Ruqayyah, T. I. D., Jamal, P., Alam, M. Z., & Mirghani, M. E. S. (2013). Biodegradation potential and ligninolytic enzyme activity of two locally isolated *Panus tigrinus* strains on selected agro-industrial wastes. *Journal of Environmental Management*, *118*, 115–121.

Sabrina, D. T., Gandahi, A. W., Hanafi, M. M., Mahmud, T. M. M., & Nor Azwady, A. A. (2012). Oil palm empty-fruit bunch application effects on the earthworm population and phenol contents under field conditions. *African Journal of Biotechnology*, *11*(19), 4396–4406.

Saha, B. C., Qureshi, N., Kennedy, G. J., Cotta, M. A. (2016). Biological pretreatment of corn stover with white-rot fungus for improved enzymatic hydrolysis. *International Biodeterioration and Biodegradation*, *109*, 29–35.

Sakurai, T., and Kataoka, K. (2007). Structure and function of type I copper in multicopper oxidases. *Cellular and Molecular Life Sciences*, *64* (19), 2642–2656.

Salmén, L. (2004). Micromechanical understanding of the cell-wall structure. *Comptes Rendus - Biologies*, *327* (9), 873–880.

Sánchez, C. (2009). Lignocellulosic residues: Biodegradation and bioconversion by fungi. *Biotechnology Advances*, *27*(2), 185–194.

Santhanam, N., Vivanco, J. M., Decker, S. R., Reardon, K. F. (2011). Expression of industrially relevant laccases: Prokaryotic style. *Trends in Biotechnology*, *29* (10), 480–489.

Saraiva, J. A., Tavares, A. P. M., and Xavier, A. M. R. B. (2012). Effect of the inducers veratryl alcohol, xylidine, and ligninosulphonates on activity and thermal stability and inactivation kinetics of laccase from *Trametes versicolor. Applied Biochemistry and Biotechnology*, *167*, 685-693.

Sarnthima, R., Khammuang, S., and Svasti, J. (2009). Extracellular ligninolytic enzymes by *Lentinus polychrous* Lev. under solid-state fermentation of potential agro-industrial wastes and their effectiveness in decolorization of synthetic dyes. *Biotechnology and Bioprocess Engineering*, *14* (4), 513–522.

Schroyen, M., Vervaeren, H., Van Hulle, S. W. H., Raes, K. (2014). Impact of enzymatic pretreatment on corn stover degradation and biogas production. *Bioresource Technology*, *173*, 59–66.

Senawi, R., Alauddin, S. M., Saleh, R. M., Shueb, M. I. (2013). Polylactic acid/empty fruit bunch fiber biocomposite: influence of alkaline and silane treatment on the mechanical properties. I*nternational Journal of Bioscience, Biochemistry and Bioinformatics*, *3* (1), 59-61.

Shamsudin, S., Md Shah, U. K., Zainudin, H., Abd-Aziz, S., Mustapa Kamal, S. M., Shirai, Y., Hassan, M. A. (2012). Effect of steam pretreatment on oil palm empty fruit bunch for the production of sugars. *Biomass and Bioenergy*, *36*, 280–288.

Sharma, R. K., and Arora, D. S. (2010). Production of lignocellulolytic enzymes and enhancement of in vitro digestibility during solid state fermentation of wheat straw by *Phlebia floridensis*. *Bioresource Technology*, *101* (23), 9248–9253.

Shinoj S., Visvanathan R., Panigrahi S., Kochubabua M. (2011). Oil palm fiber (OPF) and its composites: A review. *Industrial Crops and Products, 33*, 7–22.

Shirkavand, E., Baroutian, S., Gapes, D. J., Young, B. R. (2016). Combination of fungal and physicochemical processes for lignocellulosic biomass pretreatment - A review. *Renewable and Sustainable Energy Reviews*, *54*, 217–234.

Shuit, S. H., Tan, K. T., Lee, K. T., Kamaruddin, A. H. (2009). Oil palm biomass as a sustainable energy source: A Malaysian case study, *Energy*, *34*, 1225-1235.

Simarani, K., Hassan, M. A., Abd-Aziz, S., Wakisaka, M., Shirai, Y. (2009). Effect of palm oil mill sterilization process on the physicochemical characteristics and enzymatic hydrolysis of empty fruit bunch. *Asian Journal of Biotechnology, 1* (2), 57-66.

Singanathan, J. (2010). Production of methane from palm oil mill effluent using membrane anaerobic system, Degree Thesis, Universiti Malaysia Pahang, Malaysia.

Singh, P., Sulaiman, O., Hashim, R., Peng, L. C., Singh, R. P. (2012). Biodegradation study of pycnoporus sanguineus and its effects on structural and chemical features on oil palm biomass chips. *BioResources*, *1* (3), 210–227.

Singhania, R. R., Patel, A. K., Soccol, C. R., Pandey, A. (2009). Recent advances in solid-state fermentation. *Biochemical Engineering Journal*, *44* (1), 13–18.

Singleton, V. L., Orthofer, R., and Lamuela-Ravent, R. M. (1998). Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. *Methods in Enzymology*, *299* , 152–178.

Sluiter, J. B., Ruiz, R. O., Scarlata, C. J., Sluiter, A. D., Templeton, D. W. (2010). Compositional analysis of lignocellulosic feedstocks: 1. Review and description of methods. *Journal of Agricultural and Food Chemistry,* 58, 9043-9053.

Sreekala, M. S., Kumaran, M. G., Joseph, R. and Thomas, S. (2001). Stress-relaxation behaviour in composites based on short oil-palm fibres and phenol formaldehyde resin. *Composite Science and Technology*, *61*, 1175-1188.

Sreekala, M. S., Kumaran, M. G., and Thomas, S. (1997). Oil palm fibers: Morphology, chemical composition, surface modification, and mechanical properties. *Journal of Applied Polymer Science*, *66* (5), 821–835.

Stahl, P. D. and Christensen, M. (1992). In vitro mycelial interactions among members of a soil microfungal community. *Soil Biology and Biochemistry*, 24, 309–316.

Stanbury, PF. Whitaker, A. Hall, S. J. (2013). Principles of fermentation technology. *Journal of Chemical Information and Modeling*, *53* (9), 1689–1699.

Subramaniyam, R., and Vimala, R. (2012). Solid state and submerged fermentation for the production of bioactive substances: A comparative study. *International Journal of Science and Nature*, *3* (2012), 480–486.

Sun, F. H., Li, J., Yuan, Y. X., Yan, Z. Y., & Liu, X. F. (2011). Effect of biological pretreatment with *Trametes hirsuta* yj9 on enzymatic hydrolysis of corn stover. *International Biodeterioration and Biodegradation*, *65* (7), 931–938.

Sun, S., Sun, S., Cao, X., Sun, R. (2016). The role of pretreatment in improving the enzymatic hydrolysis of lignocellulosic materials. *Bioresource Technology*, *199*, 49–58.

Suzuki, S., Ma, J. F., Yamamoto, N., Hattori, T., Sakamoto, M. and Umezawa, T. (2012). Silicon deficiency promotes lignin accumulation in rice. *Plant Biotechnology*, 29, 391–394.

Tan, H., Huang, Y., Liu, C., Geubelle, P. H. (2005). The Mori-Tanaka method for composite materials with nonlinear interface debonding. *International Journal of Plasticity,* 21, 1890-1918.

TAPPI (2002) *Acid insoluble lignin in wood and pulp.* T222om-02 2002 (pp. 3-7).

Thakur, S., Shrivastava, B., Ingale, S., Kuhad, R. C., Gupte, A. (2013). Degradation and selective ligninolysis of wheat straw and banana stem for an efficient bioethanol production using fungal and chemical pretreatment. *3 Biotech, 3* (5), 365-372.

Thomas, L., Larroche, C., & Pandey, A. (2013). Current developments in solid-state fermentation. *Biochemical Engineering Journal*, *81*, 146–161.

Tien, M., and Kirk, T. K. (1988). Lignin peroxidase of *Phanerochaete chrysosporium.*

Methods in Enzymology, *161*, 238–249.

Umikalsom, M. S., Ariff, A. B., Zulkifli, H. S., Tong, C. C., Hassan, M. A., Karim, M. I. A. (1997). The treatment of oil palm empty fruit bunch fibre for subsequent use as substrate for cellulase production by *Chaetomium globosum* kunze. *Bioresource Technology*, *62*, 1–9.

Umikalsom, M. S., and Sariah, M. (2006). Utilization of microbes for sustainable agriculture in Malaysia: current status. Bio prospecting and management of microorganisms. *National Conference on Agro Biodiversity Conservation and Sustainable Utilization*, pp 27–29.

Underwood, E. E. (1970). *Quantitative stereology*, Addidon-Wesley, New York.

United Plantations (2015) Annual Report for 2015, United Plantations Berhad.

Usha, K. Y., Praveen, K., and Reddy, B. R. (2014). Enhanced production of ligninolytic enzymes by a mushroom *Stereum ostrea*. *Biotechnology Research International*, ID 815495.

Uzan, E., Nousiainen, P., Balland, V., Sipila, J., Piumi, F., Navarro, D., Asther, M., Record, E., Lomascolo, A. (2010). High redox potential laccases from the ligninolytic fungi *Pycnoporus coccineus* and *Pycnoporus sanguineus* suitable for white biotechnology: From gene cloning to enzyme characterization and applications. *Journal of Applied Microbiology*, *108* (6), 2199–2213.

Valasek, P., Ruggiero, A., and Muller, M. (2017). Experimental description of strength and tribological characteristic of EFB oil palm fibres/epoxy composites with technologically undemanding preparation. *Composites Part B: Engineering,* 122, 79-88.

Van Bockhaven, J., De Vleesschauwer, D., and Hofte, M. (2013). Towards establishing broad-spectrum disease resistance in plants: Silicon leads the way. *Journal of Exprimental Botany*, *64* (5), 1281-1293.

Van Heerden, A., Le Roux, N. J., Swart, J., Gardner-Lubbe, S., Botha, A. (2008). Assessment of wood degradation by *Pycnoporus sanguineus* when co-cultured with selected fungi. *World Journal of Microbiology and Biotechnology*, *24* (11), 2489–2497.

Vikineswary, S., Abdullah, N., Renuvathani, M., Sekaran, M., Pandey, A., Jones, E. B. G. (2006). Productivity of laccase in solid substrate fermentation of selected agro-residues by *Pycnoporus sanguineus*. *Bioresource Technology*, *97* (1), 171–177.

Voigt, W. (1887). Ueber das Doppler'sche Princip Nachr. *Ges. Wiss. G¨ottingen* 8, 41–51. An English version can be found on Ernst, A. and Hsu, J. P. (2001). First proposal of the universal speed of light by Voigt in 1887, *Chinese Journal of Physics*, 39, 211–230.

Wahab, A. G. (2015) GAIN Report, USDA Foreign Agricultural Service Global Agricultural Information.http://agriexchange.apeda.gov.in/marketreport/Reports/Palm%20Oil%20PSD%20Revisions_Kuala%20Lumpur_Malaysia_12-10-2015.pdf , Retrieved on 11 January 2016.

Wan, C., and Li, Y. (2011). Effectiveness of microbial pretreatment by *Ceriporiopsis subvermispora* on different biomass feedstocks. *Bioresource Technology*, *102* (16), 7507–7512.

Wan Razali, W. A., Baharuddin, A. S., Talib, A. T., Sulaiman, A., Naim, M. N., Hassan, M. A., Shirai, Y. (2012). Degradation of oil palm empty fruit bunches (OPEFB) fibre during composting process using in-vessel composter. *BioResources*, *7*(4), 4786–4805.

Wan Razali, W. A., Samsu Baharuddin, A., Zaini, L. A., Mokhtar, M. N., Taip, F. S., & Zakaria, R. (2014). Effect of seed sludge quality using oil palm empty fruit bunch (OPEFB) bio-char for composting. *BioResources*, *9* (2), 2739–2756.

Webber, J. F., and Hedger, J. N. (1986). Comparison of interactions between C*eratocystis ulmi* and Elm bark saprobes in vitro and in vivo. *Transactions of the British Mycological Society*, 86, 93-101.

Wegst, U. G. K., Bai, H., Saiz, E., Tomsia, A. P., Ritchie, R. O. (2015). Bioinspired structural materials. *Natural Materials*, 14 (1), 23–36.

White, T. J., Bruns, T., Lee, S., & Taylor, J. (1990). Amplification and direct sequencing of fungal ribosomal RNA Genes for Phylogenetics. *PCR Protocols: A Guide to Methods and Applications*, (January), 315–322.

Xiang, L. Y., Hanipah, S. H., Mohammed, M. A. P., Baharuddin, A. S., Lazim, A. M. (2015). Microstructural, mechanical and physicochemical behaviours of alkali pre-treated oil palm stalk fibers. *BioResources*, *10*(2), 2783-2796.

Xiang, L. Y., Mohammed, M. A. P., Baharuddin, A. S. (2016). Characterisation of microcrystalline cellulose from oil palm fibres for food applications. *Carbohydrate Polymers, 148*, 11-20.

Xu, C., Ma, F., & Zhang, X. (2009). Lignocellulose degradation and enzyme production by Irpex lacteus CD2 during solid-state fermentation of corn stover. *Journal of Bioscience and Bioengineering*, *108* (5), 372–375.

Yamamoto, T., Nakamura, A., Iwai, H., Ishii, T., Ma, J.F., Yokoyama, R., Nishitani, K., Satoh, S., Furukawa, J. (2012). Effect of silicon deficiency on secondary cell wall synthesis in rice leaf. *Joural of Plant Research,* 125, 771–779.

Yamanaka, S., Sato, K., Ito, F., Komatsubara, S., Ohata, H., Yoshino, K. (2012). Roles of silica and lignin in horsetail (*Equisetum hyemale*), with special reference to mechanical properties. Journal of Applied Physics, 111, 1-5.

Ying Ying, T., Teong, L. K., Wan Abdullah, W. N., Peng, L. C. (2014). The effect of various pretreatment methods on oil palm empty fruit bunch (EFB) and kenaf core fibers for sugar production. *Procedia Environmental Sciences*, *20*, 328–335.

Yokoyama, S. (2008). The Asian Biomass Handbook. A guide for biomass production and utilization. The Japan Institute of Energy.

Yu, J., Zhang, J., He, J., Liu, Z., & Yu, Z. (2009). Combinations of mild physical or chemical pretreatment with biological pretreatment for enzymatic hydrolysis of rice hull. *Bioresource Technology*, 100(2), 903-908.

Yu, W. (2016) An introduction to micromechanics. Applied Mechanics and Materials, 828,3-24.

Yusoff, M. Z. M., Salit, M. S., and Ismail, N. (2009). Tensile properties of single oil palm empty fruit bunch (OPEFB) fibre. *Sains Malaysiana*, *38* (4), 524–529.

Zadrazil, F., Gonser, A., Lang, E., (1999). Influence of incubation temperature on the secretion of extracellular ligninolytic enzymes of *Pleurotus* sp. and *Dichomitus squalens* into oil. In: *Proceedings of Conference of Enzymes and Environment*, Granada, Spain, pp. 12–16.

Zainudin, M. H. M., Nor' Aini, A. R., Abd-Aziz, S., Funaoka, M., Shinano, T., Shirai, Y., Wakisaka, M., Hassan, M. A. (2012) Utilization of glucose recovered by phase separation system from acid-hydrolysed oil palm empty fruit bunch for bioethanol production. *Pertanika Journal of Tropical Agricultural Sciences, 35* (1), 117-126.

Zanirun, Z. (2016). Lignin pretreatment of oil palm empty fruit bunch using ligninolytic enzyme mediator and cellulose hydrolysis dor fermentable sugar production. *PhD Thesis*, Universiti Putra Malaysia.

Zanirun, Z., Bahrin, E. K., Lai-Yee, P., Hassan, M. A., Abd-Aziz, S. (2015). Enhancement of fermentable sugars production from oil palm empty fruit bunch by ligninolytic enzymes mediator system. *International Biodeterioration and Biodegradation*, *105*, 13–20.

Zhang, J., Ren, X., Chen, W., Bao, J. (2012). Biological pretreatment of corn stover by solid state fermentation of *Phanerochaete chrysosporium*. *Frontiers of Chemical Science and Engineering*, *6* (2), 146–151.

Zheng, Y., Zhao, J., Xu, F., Li, Y. (2014). Pretreatment of lignocellulosic biomass for enhanced biogas production. *Progress in Energy and Combustion Science*, *42* (1), 35–53.

Zhu, C., Bao, G., and Huang, S (2016). Optimization of laccase production in the white rot fungus *Pleurotus ostreatus* (ACCC 52857) induced through yeast extract and copper. *Biotechnology & Biotechnology Equipment, 30* (2), 270-276.

Zhuang, J., and Marchant, M. (2007). Economic analysis of cellulase production methods for bio-ethanol. *Applied Engineering in Agriculture, 23* (5), 679–687.

Zhuo, R., Ma, L., Fn, F., Gong, Y., Wan, X., Jiang, M., Zhang, X., Yang, Y. (2011). Decolorization of different dyes by a newly isolated white-rot fungi strain *Ganoderma* sp.En3 and cloning and functional analysis of its laccase gene. *Journal of Hazardous Materials*, *192*, 855-873.

Zimbardi, A. L. R. L., Camargo, P. F., Carli, S., Neto, S. A., Meleiro, L. P., Rosa, J. C., De Andrade, A. R., Jorge, J. A., Furriel, R. P. M. (2016) A high redox potential laccase from *Pycnoporus sanguineus* RP15: Potential application for dye decolorization. *International Journal of Molecular Science*, *17* (672), 1-24.

Zulkiple, N., Maskat, M. Y. and Hassan, O. (2016). Pretreatment of oil palm empty fruit bunch (OPEFB) with aqueous ammonia for high production of sudar. *Proceedia Chemistry* 18, 155-161.