CHARACTERIZATION OF HEMICELLULOSE-CARBOXYMETHYL CELLULOSE BLEND BIOFILM FABRICATED FROM OIL PALM TRUNK

FARAH FAZLINA BINTI MOHD RIDZUAN

UNIVERSITI SAINS MALAYSIA

2024

CHARACTERIZATION OF HEMICELLULOSE-CARBOXYMETHYL CELLULOSE BLEND BIOFILM FABRICATED FROM OIL PALM TRUNK

by

FARAH FAZLINA BINTI MOHD RIDZUAN

Thesis submitted in fulfilment of the requirements
for the degree of
Master of Science

June 2024

ACKNOWLEDGEMENT

Alhamdulillah, I would like to express our gratitude to Allah SWT for giving an opportunity and help endlessly in finishing the Master Thesis. I would like to express my sincere gratitude to Allah (SWT), the most Gracious and the most Merciful for giving me the chance to go through all things that happen in my life and in my study. Peace be upon Prophet Muhammad S.A.W, his family, and his companions. I would like to express my gratitude to my supervisor, Associate. Professor. Dr Mohamad Haafiz Bin Mohamad Kassim for his valuable guidance, advice, suggestions, encouragement, and moral support and to my co-supervisor's, Ts. Dr. Nurul Fazita Mohammad Rawi, Associate Professor Dr Leh Cheu Peng and the others lecturer Dr Nur Izzaati Saharudin and Dr Nur Adilah Abu Hassan for their assist, support, and inspiration to make sure I'm able to complete my research study. Their immense knowledge and guidance helped me a lot during completing my study and writing of this thesis.

A special thank I would like to express for my beloved parents, Mr Muhammad Zaidi Bin Yun and Mrs Nor Ruzilah Binti Hussain and not forgotten my siblings, Muhamad Faizul Bin Mohd Ridzuan and Muhammad Iqbal Aminuddin Bin Muhammad Zaidi, for their generous support throughout my studies and in my entire life. They have helped me achieve an excellent education by supporting, inspiring, and encouraging me.

I am also grateful to our lab assistant, Mr Azhar Mohd Noor who has helped me a lot with the setup for the project. In advance, I also would like to thank another laboratory assistant, Mr Mazlan Mohamed Jakeri, Mrs Noraida Bukhari, Mr Abdul Rahim Md sari and Mrs Nor Faizah Hamid for their help in their guidance and preparing machines to undergoes testing during my journey to complete this research.

Finally, a very special gratitude goes out to all my best friend for supporting me, Nuraina Hanim Binti Mohd Nizam, Noorfarisya Izma Binti Jeffri, Hanis Farihah Binti Ismail, Muhammad Lutfan Aiman Bin Zamri and Natra Joseph for always being there for me and giving a positive support all the time. Additionally, I'd like to express my gratitude to individuals who are left off the list but who nonetheless contributed to my accomplishments. Mostly in long term, I really hope that this effort will prove to be beneficial. Again, I would like to thank all my lecturers, family, fellow friends, laboratory assistant and administration of the School of Industrial Technology, Universiti Sains Malaysia.

May God less all these people with long, happy, and peaceful life. Thank you so much.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF SYMBOLS

μm	Micrometer
cm	Centimeter
mm	Millimeter
kg	Kilogram
g	Gram
ml	Milliliter
min	Minutes
MPa	Megapascal
Ɵ	Diffraction angle
˚ C	Centigrade degree
%	Percentage
T_g	Glass transition temperature
T_m	Melting temperature
T_{max}	Maximum temperature

LIST OF ABBREVIATIONS

$AgNO_3$	Silver Nitrate
CA	Citric acid
CMC	Carboxymethyl cellulose
DP	Degree of polymerization
Ds	Degree of substitution
DSC	Differential scanning calorimetry
EFB	Empty fruit bunch
FTIR	Fourier transform infrared spectroscopy
Hc	Hemicellulose
K_2CrO_4	Potassium chromate
MCA	Monochloroacetic acid
MMT	Montmorillonite
$NaClO_2$	Sodium chlorite
NaOH	Sodium hydroxide
OH	Hydroxyl
OPF	Oil palm fronds
OPT	Oil palm trunk
POME	Palm oil mill effluent
SEM	Scanning electron microscopy
TGA	Thermogravimetric analysis
XRD	X-ray diffraction

LIST OF APPENDICES

PENCIRIAN BIOFILEM CAMPURAN HEMISELULOSA-KARBOSIMETIL SELULOSA FABRIKASI DARIPADA BATANG KELAPA SAWIT

ABSTRAK

Penggunaan polimer sintetik tidak sesuai pada masa kini kerana isu alam sekitar. Oleh itu, bahan hijau telah diekstrak daripada sisa biojisim untuk menghasilkan biopolimer bagi menggantikan polimer sintetik. Batang kelapa sawit (OPT) merupakan sisa pepejal yang banyak didapati sepanjang tahun. Disebabkan kebimbangan ini, filem hemiselulosa (Hc) dan karboksimetil selulosa (CMC) berjaya disediakan daripada batang kelapa sawit (OPT) dalam kajian penyelidikan ini. Hc dan CMC telah diadun melalui kaedah tuangan larutan untuk menghasilkan biofilm adunan pada 0%, 20%, 40%, 60%, dan 80% Hc dan pemuatan CMC. CMC yang digunakan dibandingkan antara CMC komersial (CMC-C) dan OPT CMC (CMC-T) yang diekstrak. Bahan mentah dan sampel biofilm dicirikan oleh komposisi kimia, spektroskopi infra-merah transformasi Fourier (FTIR), spektroskopi sinar-X penyebaran tenaga (SEM-EDX), pembelauan sinar-X (XRD), ketebalan, ketelusan visual, sudut sentuhan, keterlarutan, kandungan lembapan kekuatan tegangan, mikroskopi elektron pengimbasan (SEM), kalorimetri pengimbasan pembezaan (DSC), analisis termogravimetrik (TGA) dan analisis biodegradasi. Mengikut keputusan, komposisi kimia menunjukkan bahawa berkas vaskular mempunyai lebih banyak selulosa manakala parenkim mempunyai lebih hemiselulosa. Selain itu, FTIR parenkim dan berkas vaskular berjaya dikenalpasti. Kemudian, SEM-EDX dan XRD mendedahkan unsur dalam CMC, dan kehabluran selulosa berkurangan apabila struktur kimia terganggu oleh penambahan kumpulan karboksimetil. Hasil biofilm campuran Hc-CMC mendedahkan bahawa ketebalan meningkat manakala sudut sentuhan ketelusan visual dan sudut sentuhan berkurangan. Sudut sentuhan pada 20Hc-80CMC biofilem pada 94° disebabkan oleh permukaan hidrofobik tinggi dan keterlarutan rendah dalam air pada 37.5 %. Sementara itu, spektroskopi FTIR menunjukkan bahawa penggabungan Hc kepada CMC tidak mempunyai perubahan dalam struktur kimianya. XRD mendedahkan kehabluran filem campuran pada kandungan CMC tinggi manakala amorfus pada pemuatan Hc tinggi. Selain itu, kekuatan tegangan menurun sehingga 80- 90 %. Ini disebabkan interaksi antara molekul yang terhad di kalangan Hc dan CMC memberi kesan dengan pembentukan aglomerasi dan lompang dalam struktur filem yang dibuktikan dalam analisis SEM. Selain itu, analisis DSC menunjukkan bahawa suhu peralihan kaca (Tg) beralih kepada suhu yang lebih tinggi daripada 160 °C hingga 167 °C manakala suhu lebur (Tm) filem Hc-CMC beralih kepada suhu yang lebih rendah yang berkaitan dengan kehabluran filem campuran diikuti dengan analisis TGA. Berdasarkan keputusan keseluruhan, biofilm 20Hc-80CMC-T dengan pemuatan 20% Hc muncul sebagai komposisi campuran pilihan kerana mempunyai struktur morfologi homogen, sifat fizikal dan mekanikal yang baik, dan sinergi kestabilan haba. Penemuan ini mencadangkan bahawa biofilm campuran boleh digunakan dalam aplikasi pertanian atau salutan seperti baja berkapsul yang menunjukkan sifat biofilm hidrofobik.

CHARACTERIZATION OF HEMICELLULOSE-CARBOXYMETHYL CELLULOSE BLEND BIOFILM FABRICATED FROM OIL PALM TRUNK

ABSTRACT

The use of synthetic polymers is not essential due to environmental issues. Hence, the green materials have been extracted from biomass waste to produce a biopolymer in order to replace the synthetic polymer. Oil palm trunk (OPT) is a solid waste that is abundantly available throughout the year. Due to this concern, hemicellulose film (Hc) and carboxymethyl cellulose (CMC) were successfully prepared from oil palm trunk (OPT) in this research study. Hc and CMC were blended by the solution casting method to produce blend biofilm at 0%, 20%, 40%, 60%, and 80 % Hc and CMC loading. The CMC used was compared between commercial CMC (CMC-C) and the extracted OPT CMC (CMC-T). The raw material and biofilm sample were characterized by chemical composition, Fourier transmission infrared spectroscopy (FTIR), energy-dispersive X-ray spectroscopy (SEM-EDX), x-ray diffraction (XRD), thickness, visual transparency, contact angle, solubility, moisture content, tensile strength, scanning electron microscopy (SEM), differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) and biodegradability analysis. According to the results, chemical composition showed that the vascular bundle had more cellulose while the parenchyma had more Hc. Moreover, the FTIR of parenchyma and vascular bundle were successfully identified. Then, the SEM-EDX and XRD revealed the element in CMC, and the crystallinity of cellulose reduced when the chemical structure was interrupted by the addition of carboxymethyl group. Then, the result of Hc-CMC blend biofilm revealed that the thickness increased while the visual transparency contact angle decreased. The contact angle of 20H-80CMC

biofilm at 94° due to high hydrophobic and low solubility in water at 37.5 %. Meanwhile, FTIR showed that adding Hc to CMC did not modify its chemical structure. The XRD exposed the crystallinity of blend biofilm at high CMC content while amorphous at high Hc loadings. Moreover, the tensile strength decreased up to 80 - 90 %. This is due to the limited intermolecular interaction among Hc and CMC affect with the formation of agglomeration and void in the film structure proven in SEM analysis. Moreover, the DSC analysis displayed that the glass transition temperature (Tg) shifted to higher temperature from 160 °C up to 167 °C while melting temperature (Tm) of Hc-CMC films shifted to a lower temperature that related to the crystallinity of the blend film followed by TGA analysis. Based on the overall results, the 20Hc-80CMC-T biofilm with 20% Hc loadings appeared as the preferred blending composition for having homogenous morphological structures, good physical and mechanical properties with synergism of thermal stability. These findings suggest that blend biofilm can be used in agricultural or coating applications such as encapsulated fertilizers that show hydrophobic biofilm properties.

CHAPTER 1

INTRODUCTION

1.1 Research of Background Study

Plastic is widely used and has become essential in human daily life and is mostly used in various applications. However, the usage of plastic nowadays has extremely tremendously until it is thrown away everywhere as a waste. Since 2017, Malaysia has been the world's top importer of plastic waste and consumption of single-use plastic (H. L. Chen et al., 2021). The disposal of discarded packaging materials in landfills is one of the most destructive ways that cause environmental consequences (Ncube et al., 2020). Moreover, the increased usage of synthetic plastics derived from petrochemicals and synthetic polymer has led to environmental contamination due to their non-biodegradable qualities (Thew et al., 2023). As a result, petroleum-based plastics are no longer appropriate for use in the production of distinctive plastic (Zhao et al. 2020) because led to ecologically damaging, ending up in streams, oceans, and open spaces, killing millions of species, and these materials do not biodegrade quickly (Mangal, Rao, & Banerjee, 2023). Therefore, despite the pollution and disposal issues caused by plastic waste derived from synthetic polymer and petroleum-based plastic, biodegradable plastic made from biopolymer materials is a growing trend.

Nowadays, green material extracted from renewable sources act as biopolymer is used to produce a biodegradable film to fulfil the demand in various industries. Due to the concerns to environmental and sustainability issues, the development of blend film from biopolymer has included remarkable due to these films are composed of a combination two or more different materials, often incorporating biodegradable and renewable elements, designed to replace the traditional single-use plastic. Besides, there has been a lot of interest in blend biofilm in recent years because of the potential for it to partially replace non-biodegradable synthetic materials and petroleum-based plastic that offer a promising solution in the realm of sustainable materials (Kumar et al., 2022). Nowadays, blend biofilms can be tailored to serve specific purposes, ranging from packaging applications to agricultural use or even in biomedical contexts. For instance, some blends incorporate starch-based polymers, cellulose, or other natural materials which aid in biodegradability and reduce reliance on non-renewable resources. These materials can be extracted from different plant fibers such as oil palm fiber, flax, cotton, recycled wood or paper-based fibers, and even waste products from food crops (Ilyas et al., 2020).

In recent years, oil palm industries have generated huge biomass residues produced such as oil palm frond (OPF), oil palm trunk (OPT), empty fruit bunch(EFB), palm kernel shell (PKS), mesocarp fiber and palm oil mill effluent (POME) (Jafri, Jimat, Azmin, Sulaiman, & Nor, 2021). OPT is usually left to decay or burnt without utilization, hence some attention is needed to focus on the usage of OPT because it consists of the lignocellulose materials acting as a biopolymer for starting raw materials to produce a biodegradable film. Moreover, OPT is easy to find and less expensive as compared to wood, the second largest biomass generated, and consists of high lignocellulose material which is cellulose, hemicellulose, and lignin. The composition of cellulose and hemicellulose in OPT were around 40-60% and 20-40%, respectively (Lamaming et al., 2014). Aforementioned, lignocellulose derived from renewable resources has received recognition in the field of film production owing to its potential to replace synthetic polymer.

Furthermore, hemicelluloses are a popular biopolymer because they are flexible, biodegradable, gas permeable, and have a large number of branches (Berglund et al., 2020). Previously, a few studies reported that hemicellulose was extracted from different raw materials which are wheat straw (L.-Z. et al., 2021), maize bran (Yue et al., 2022), rice husk (RH), rice straw (RS), and barley straw (BS) barley (Kim, Kwak, Kim, & Oh, 2020). In other hand, hemicellulose in OPT is high and has unique properties due to its functional hydroxyl groups and various structures, which are easy to modify to meet different requirements. According to (Zhao et al., 2021), hemicellulose films and coatings are good oxygen barriers. Even though, hemicellulose has good properties, but it is hydrophilic and the films it produces are hygroscopic, resulting in poor properties in high humidity, high brittleness, and poor mechanical properties, according to Weerasooriya et al. (2020). From the previous research, hemicellulose films have been extracted from other natural sources such as EFB (Haafiz et al. 2019 and Weerasooriya et al. 2020), sugarcane bagasse (da Silva Braga & Poletto, 2020), *Caesalpina pulcherrima* (Senarathna et al., 2022) and bamboo (Jing Li et al., 2021). However, because of some limitation mentioned cause from hemicellulose itself, it was inappropriate for hemicellulose certain applications.

As for now, a number of researchers proposed that combining or/and blending hemicellulose with other biopolymers is a good way to solve the challenges faced by these materials (Haafiz et al. 2019 and Weerasooriya et al. 2020). Blending hemicellulose with carboxymethyl cellulose (CMC) is one of the best combinations to produce a biodegradable film due to both components are extracted from natural resources. CMC is a cellulose derivative, also acts as a significant industrial biopolymer with no adverse effects on human health, and is a highly effective polymer for enhancing the quality of the product (Weerasooriya et al., 2020). Among its numerous useful properties are film formation, plasticizer, emulsification, suspension stabilization, water retention, binding, and thickening agent (Haafiz et al., 2019). Moreover, CMC has a favorable impact on mechanical characteristics, transparency, flexibility, and moisture absorption that helps to improve film production (Weerasooriya et al., 2020) and it has been widely commercialized (Dikriansyah, 2018). However, the use of commercial CMC is highly costly hence to reduce the usage of commercial CMC, a new approach to extracting CMC from OPT is recommended besides no report has been studied yet for this material. Therefore, the uses of hemicellulose (Hc) are expected to improve the film properties with the aid of the presence of CMC and to characterize the properties of Hc and CMC obtained from OPT. Enhancing the mechanical properties of the blend Hc-CMC film is still ongoing. The blend CMC film properties improved with addition of citric acid as crosslinking according to (Wilpiszewska, Antosik, & Zdanowicz, 2019).

To the best of our knowledge, limited information on the integration of Hc with CMC. The previous study found that adding Hc to CMC improves mechanical properties and performance. The film with 60 wt.% hemicellulose and montmorillonite (MMT) performed best properties whereas MMT acts as a filler in the film production (Weerasooriya et al., 2020). Therefore, it would be interesting to understand whether Hc embedded with CMC extracted from OPT helps to improve the properties in terms of tensile, thermal and biodegradability properties and examine the best Hc loadings when blending with CMC. Hence, the results of this study contribute to a deeper comprehension of the physical, physicochemical, mechanical, structural, and thermal features of Hc film derived from OPT blend with CMC.

1.2 Problem statement

The usage of polymeric materials are used widely in the global industry over the past two decades, due to its adaptability and durability. However, many synthetic polymers that have been developed are mainly derived from petroleum and coal as raw material, which make them incompatible with the environment, since they cannot be included in the natural recycling system (Rendón-Villalobos et al., 2016). Nowadays, the petroleum based plastic was derived from this synthetic polymer becomes a tremendous waste daily until affects the environment. Hence, the usage of these polymeric materials was changed by using biopolymers that derived from natural resources.

In Malaysia, the majority of the oil palm tree (90%) is perceived as biomass, in which palm oil constitutes only 10% of the total bio mass (Cherie et al., 2021). Oil palm biomass refers to agricultural by-products produced by the oil palm industry during replanting, pruning, and milling operations. Oil palm trunks (OPT) and oil palm fronds (OPF) are formed at plantations during replanting and pruning. In contrast, oil palm shell (OPS), palm kernel shell (PKS), empty fruit bunch (EFB), and palm oil mill effluent (POME) are generated during the milling process at the oil palm processing mills (Jafri et al., 2021). More than 20 and 18.5 million m^3 of biomass from OPT are available annually in Malaysia and Indonesia, respectively (Jafri et al., 2021). Normally, these OPT are left in the field with no further use or are burnt and cause environmental problems. Due to OPT as the second largest biomass in the oil palm industry and high lignocellulose components, it can be further utilized to produce other useful products and applications such as biopolymer in the production of green film (Sabiha-Hanim et al., 2012) to replace synthetic polymer and petroleum-based plastic.

To date, no single study or information on the usage of lignocellulose from OPT biomass waste for biofilm production. However, by using hemicellulose in the creation of films exhibits poor performance as it is hygroscopic in nature, excessive brittleness, low mechanical characteristics, humidity sensitivity, and high hydroxyl groups limit its use as a starting raw material (Weerasooriya et al. 2020; Haafiz et al. 2019 and Zhao et al. 2020).

Hence, to avoid this limitation, carboxymethyl cellulose (CMC) is an excellent example of a biopolymer that has piqued the interest of researchers in incorporating hemicellulose in making films. However, commercial CMC is costly and there is no significant report on the raw materials production of CMC. This research studies the incorporation of hemicellulose and CMC to enhance the properties of blend biofilms produced and reduce the usage of commercial CMC.

1.3 Research Objectives

An approach to overcome the environmental issues caused by the synthetic polymer by replaced with biopolymer that derived from natural resources. These biopolymer was used to produces a biodegradable plastic or blend biofilm through simple blending process such as solution casting method. Due to this, the objective of this current study is as followed:

1. To isolate the biopolymer from oil palm trunk such as hemicellulose (Hc) and carboxymethyl cellulose (CMC) derived from parenchyma and vascular bundle.

2. To characterize the physicochemical properties and morphological structure of hemicellulos (Hc) and carboxymethyl cellulose(CMC) extracted from OPT biomass.

3. To facbricate and analyse the obtained biofilm from OPT on the physicochemical, thermal, mechanical, morphological and biodegradable properties.

1.4 Research Novelty/Scope of Study

The research focused on utilizing the biomass waste generated from oil palm industries, such as oil palm trunks (OPT). These OPTs can become natural resources to provide lignocellulose materials that have advantages for the environment. These biomaterials can be used to produce biofilm to replace synthetic polymers in film production. The biofilm was prepared by using the extracted hemicellulose from the parenchyma of OPT and blending it with other biopolymers like carboxymethyl cellulose (CMC). The CMC was extracted from the vascular bundle of the OPT, which utilizes both components of the OPT. The limitations of other materials, such as hemicellulose, can be overcome by blending it with other biopolymers through a simple technique such as the solution casting method in order to enhance the biofilm properties. The blend biofilm was characterized and suggested for some suitable applications based on the properties obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 Oil palm tree

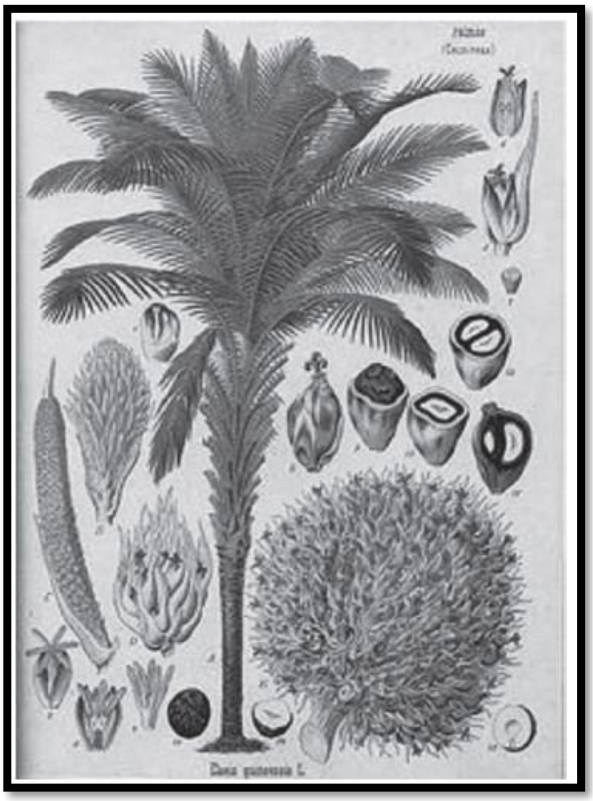
2.1.1 Oil palm history

The oil palm tree, or Elaeis guineensis, is native to West African tropical forests as shown in Figure 2.1. In 1848, the oil palm tree was brought to Indonesia's Bogor Botanical Garden. The British introduced palm oil to the Malaysian peninsular as an attractive plant in the 1870s. Its economic potential was first appreciated in the 1960s, when the Malaysian government embarked on a poverty eradication program through agricultural diversification by planting palm oil to complement its rubber production (Abubakar et al., 2021). In 1871, it was first planted as an ornamental plant in Malaysia The number of oil palm trees planted in Malaysia has grown quickly every year, especially between 1975 and 2010 (Sulaiman et al. 2012). Around 5,000,000 hectares (19,000 square miles) of Malaysian land produced 18.79 million metric tonnes of crude palm oil in 2012 and growth rapidly in recent years due to high demand in oil palm industries. Indonesia produces more palm oil, but Malaysia exported 18 million tonnes in 2011, making it the world's largest exporter. China, Pakistan, the EU, India, and the US are Malaysia's top palm oil export markets. China imported the most Malaysian palm-based oleochemical products, up 0.2% to 0.53 million tonnes. The palm oil usually used in wood industries such as manufacturing of plywood (Loh et al., 2022), medium-density panel, fiberboard and chip board (M. Ahmad et al., 2022). It is now an alternative raw material for paper and pulp (Al et al., 2020), industrial, fertilizers, animal feeds (Ramon et al., 2022), chemical derivatives and others (Dungani et al., 2018).

Figure 2.1 Oil Palm Tree (*Elaeis guineensis*)

2.1.2 Taxonomy and Classification of Oil Palm

Palm tree species are classified as genus Elaeis, one of several genera in the subfamily *Arecoideae* of the family *Arecaceae* (formerly known as *Palmaceae*). The scientific classification of oil palm trees can be seen in Figure 2.2 (Fatimah Mhd. Ramle, 2022). The common name of oil palm is African oil palm that is the world's most important commercial oil palm (*E. guineensis Jacq*.). Oil and other resources have been extracted from the African oil palm (*Elaeis guineensis Jacq*.) for thousands of years. Oil palm also has a significant impact on the manufacturing of many products with added value.



Kingdom: *Plantae*
Family: *Arecaceae*
Subfamily: *Arecoideae*
Tribe: *Cocoseae*
Subtribe: *Elaeidinae*
Genus: *Elaeis*

Figure 2.2 Scientific classification of oil palm tree

2.1.3 Structure and Morphology of Oil Palm Tree

Oil palm fibers have a bilayer cell wall structure such as a primary layer (P) and a secondary layer known as S1, S2 and S3 layers (M. M. Abe et al., 2021). There is considerable variety in the size, shape, and structure of the cell walls of oil palm fibers. Virtually every fiber structure is round. The layers of S1, S2, and S3 are strongly connected and form structures like sandwiches where the corners of micro fibrils S1 and S3 are parallel to S2 layers . This sandwich structure gives the fiber more strength to help it resist water strain, bend resistance to help it stand up to compression force and bending stiffness to help it stand up to bending force. The main walls of all oil palm fibers look like a thin layer. Some primary walls are very different from each other in the middle lamella (Dungani et al., 2018). The S2 layer makes up most of the cell wall. The strength of a single fiber is affected by this layer. At 3.43 µm, the S2 layers on OPT fibers are the thickest. Based on the thickness of the S2 layer, the OPT is thought to be the strongest. This is because the strength of the fiber depends on the way the cellulose micro fibrils line up with the fiber axis of the S2 layer (Dungani et al., 2018). The simple Figure of plant cell wall made up of bilayer shown in Figure 2.3 (Rytioja et al., 2014) below.

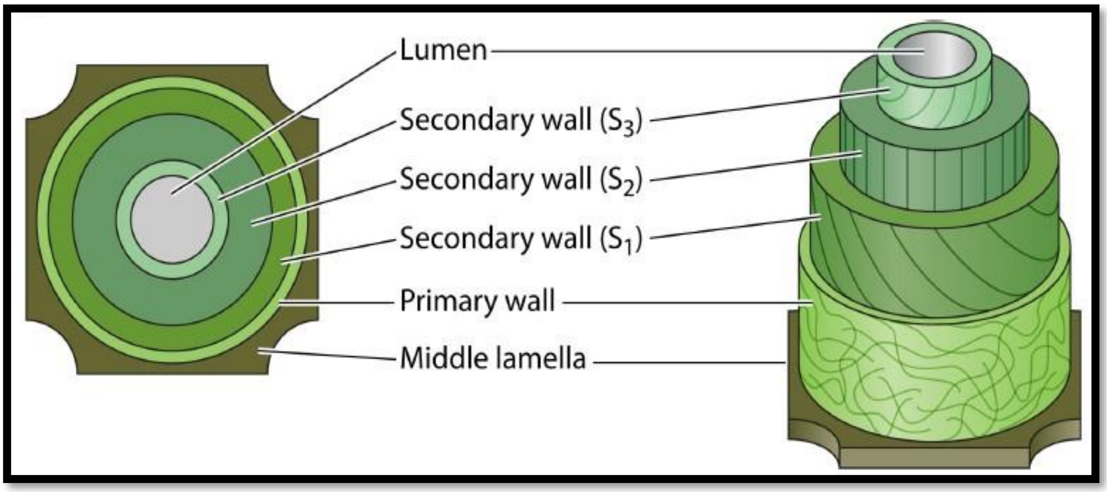


Figure 2.3 The theoretically bilayers cell wall of the oil palm tree (Rytioja et al., 2014)

2.1.4 Oil Palm Industry

Malaysia is a tropical country with hot and humid weather throughout the year. This climate promotes oil palm growth and, subsequently, increased the oil palm cultivation in Malaysia (Jafri et al., 2021). Malaysia's oil palm industry is critical to the country's agricultural and economic development (Kushairi et al., 2018) so the palm oil economy has expanded quickly over the past 20 years. Over 5 million hectares of land in Malaysia are used to grow oil palm trees in 2013 and growth further in previous year (Aljuboori 2013). In 2022, the oil palm tree plantation almost 5.67 million hectares even though there are a slightly decline in the oil palm plantation area in 2021 about 1.1% from 5.74 million hectares. This is because the planted area in Peninsular Malaysia and Sabah has decreased by 2.4% (2.54 million hectares) and 1.0% (1.50 million hectares), respectively as shown in Table 2.1(Parveez et al., 2023).

Table 2.1 Malaysian Palm Oil Industry area in December 2021 and 2022 (Parveez et al., 2023)

	Planted Area (million hectares)		Mature Area (million hectares)	
	2021	2022	2021	2022
Peninsular Malaysia	2.61	2.54	2.36	2.31
Sabah	1.52	1.51	1.33	1.33
Sarawak	1.61	1.62	1.45	1.49
Malaysia	5.74	5.67	5.14	5.13

This huge area of plantations makes a huge amount of oil palm biomass waste generated. The main places where biomass residue is made are plantations and mills (Aljuboori 2013). Malaysia grows oil palm trees as an agricultural crop, which generates a lot of biomass residue from plantations and mills. This biomass residue includes plantation-produced oil palm fronds (OPF) and trunks (OPT) while mill site generated empty fruit bunches (EFB), palm kernel shells, mesocarp fiber, and palm oil mill effluent (POME) as shown in Figure 2.4 (Aljuboori, 2013). Due to the overflow of biomass residue generated each year, Malaysia could use biomass waste efficiently and effectively to produce other valuable goods. Palm oil is dominant in the global economy, where palm oil is one of the seventeen main oils and fats on the international market. The palm oil market is also crucial to Malaysia's economy.

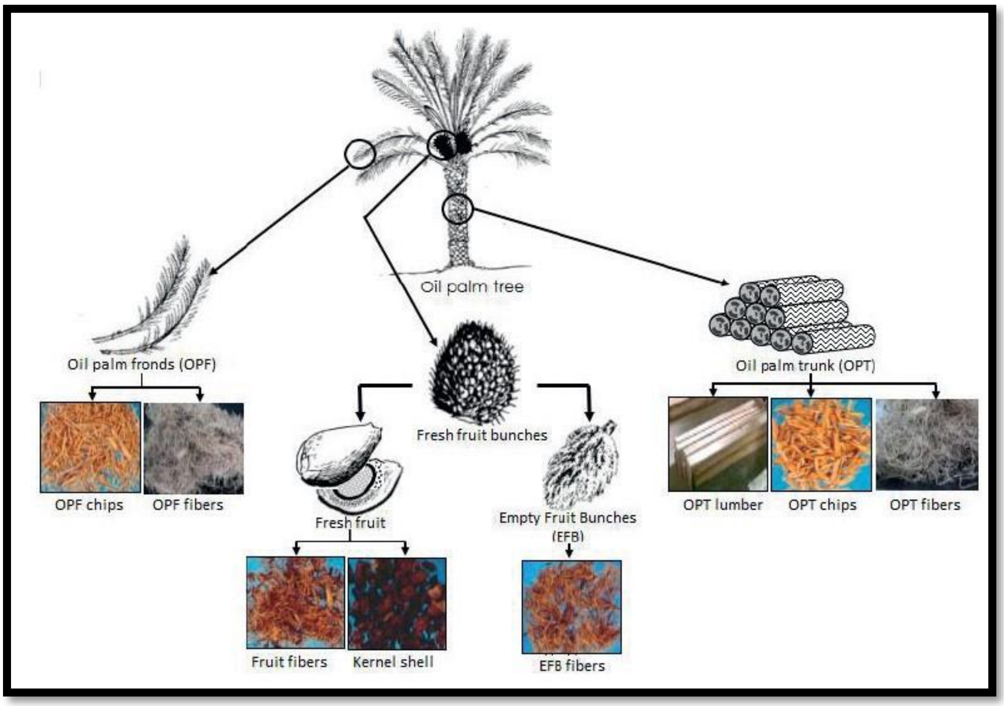


Figure 2.4 Biomass generated from oil palm tree

The overall exports of palm oil and other palm based products (POPP) in 2022 amounted to 24.72 million tonnes, an increase of 1.8% compared to 2021 (24.28 million Tonnes) as tabulated in Table 2.2. The increase in palm oil exports was attributable to the increased demand from the United Arab Emirates, Saudi Arabia, Japan, Bangladesh, and Egypt, which outweighed the decrease in demand from India, the European Union, and China (Parveez et al., 2023).

Table 2.2 Malaysian Export of Palm Oil and Oil Palm Products (Parveez et al., 2023)

	Volume (million tonnes)		Value in RM million	
	2021	2022	2021	2022
Palm oil	15.56	15.72	64.61	82.49
Palm Kernel oil	1.08	1.04	6.67	7.62
Palm Based Oleochemicals	3.25	3.04	26.80	33.61
Other oil palm based products	2.09	2.78	9.04	12.46
Palm kernel cake	2.30	2.14	1.39	1.71
Total	24.28	24.72	108.52	137.89

Based on the export report, it was an effective measurement for improvement toward palm oil economy yearly. The progress of the palm oil industry in Malaysia is the product of ideal weather, advanced technologies, and facilities for milling and processing, practical and good management skills, and research and development. The government of Malaysia is wholly committed to the industry's growth and supports the global expansion of palm oil production. As a result, palm oil is now readily embraced internationally, and palm oil has been exported to more than 140 countries in the world by Malaysia.

2.1.5 Oil Palm Biomass and Its Utilization

The Malaysian palm oil industry has grown rapidly in the last decades. This growth has resulted in a rapid expansion of oil palm cultivation areas, as well as a rise in the number of operating palm oil mills. The oil palm industry produces a significant quantity of biomass waste in both the cultivation areas and the mills where oil palm is processed. Waste materials, specifically oil palm trunks (OPT) and oil palm fronds (OPF), are generated because of replanting and pruning activities conducted in oil palm plantations once have reached the end of their useful life. In palm oil mills, converting fresh fruit bunch (FFB) into crude palm oil (CPO) has led to the production of high volumes of solid and liquid waste. The solid wastes from mills include empty fruit bunches (EFB), oil palm shells (OPS), and palm kernel shells (PKS). Meanwhile, the liquid waste is palm oil mill effluent (POME). Oil palm trunk (OPT) is a solid waste that is abundantly available throughout the year. A lot of OPT biomass waste is collected during replanting, when trees that are no longer useful are cut down. When compared to wood, it is thought to be the least expensive lignocellulose raw material. Leaving the trunk and fronds in the field without further processing will physically hinder the process of planting new crops as the stern can take about five years to decompose completely. Alternatively, by converting the oil palm biomass into others valuable products because agro-wastes from the oil palm industry such as oil palm trunks (OPT), oil palm fronds (OPF), and empty fruits bunches (OPEFB) have attracted attention as potential sources for new value-added materials for various industry to reduce the environmental pollutant.

As known that oil palm is a versatile crop that can be used for various purposes, such as food, fuel, and bio-based materials. Oil palm biomass can be converted to biofuels, such as ethanol, butanol, syngas, and bio-oil, through different pretreatment and conversion methods, such as hydrolysis, fermentation, gasification, and pyrolysis to generate electricity as reported by Wardani et al. (2021) that studies on the production of ethanol of oil palm trunk biomass. Besides, oil palm waste can be turned into bio-based chemicals such as lactic acid, vanillic acid, bio vanillin, protocatechuic acid, and vanillin, through biological or chemical processes, such as enzymatic hydrolysis, microbial fermentation, and oxidation. It can also help to reduce greenhouse gas emissions and promote soil fertility (Hakeem, Jawaid, & Rashid, 2015). One of the potential applications of oil palm biomass is to produce biodegradable plastics, such as polyhydroxyalkanoate (PHA), which are biopolymers that can be used for food packaging, medical devices, and agricultural films. PHA can be produced from palm oil mill effluent (POME), by using bacterial fermentation chemical solvent extraction (Shakirah et al., 2020).

Moreover, the generated waste can be utilized by preparing it as a valuable resource in the application of producing bio composite and wood products. Oil palm biomass can be processed to wood products, such as plywood, fiber mats, and bio composite, by using different techniques, such as hot pressing, steam explosion, and extrusion. These products can be used for furniture, packaging, and construction applications. Particleboard or fiberboard with cement or thermosetting adhesives has been studied extensively such as urea formaldehyde made from EFB waste, as well as liquid waste from oil palm factories, as filler in the production of bio composites (Dungani et al., 2018). Therefore, according to previous studies on the making of medium density fiberboard (MDF) using oil palm fibre by (Awang et al., 2023).

In other hand, oil palm biomass also can be converted into activated carbon which is a porous material with high surface area and adsorption capacity, by using physical or chemical activation methods, such as carbonization, impregnation, and pyrolysis. Activated carbon can be used for water purification, gas separation, and energy (Zakaria et al., 2023). Additionally, as the products are made of sustainable green materials, it will benefit the environment. Also, by preventing it from being burned or buried in the field, this will help reduce the cost to the economy caused by oil palm waste (Lamaming et al., 2015).

Each component of the oil palm tree produces a significant amount of biomass, which requires additional research to explore its potential for creating value-added products suitable for various applications across several industries. Efforts are ongoing to address these challenges and promote sustainable practices in the oil palm industry, recognizing the importance of balancing economic development with environmental issues. Nevertheless, it is imperative to address the issues of OPT as it remains the second greatest biomass waste that requires treatment, as it can either be burned or left to decompose.

2.2 Oil Palm Trunk (OPT)

Waste products, such as oil palm fronds (OPF) and oil palm trunks (OPT), have been generated in high volumes due to the expansion of oil palm plantations during replanting. During the annual harvest of fresh fruit bunches (FFB), each oil palm tree typically yields 24% OPF. At the same time, 70% of the replanting efforts were completed by OPT. As the plantation expands and is periodically replanted, the possibility of OPT availability rises steadily throughout the year (Dungani et al., 2018).

The trunks are usually left in the field and are not used after that. They are usually cut into pieces and burned down to keep insects from eating them (Ramle et al., 2019). Hence, due to abundant amount of OPT, the researcher gives attention to these issues. A very high level of carbohydrates can be found in the OPT in the form of sugar that contains starch and also lignocellulosic materials made up of cellulose, hemicellulose and lignin. According to Lamaming et al. (2017), since OPT contain a lot of sugar (10% free sugar) and starch (25%), it can be used in industries like making paper and making binder less panels (Lamaming et al. 2017). OPT, which are monocotyledons, are made up of vascular bundles and parenchyma, respectively. OPT has a high moisture content, less cellulose and lignin but more water-soluble and NaOH-soluble compared with rubber wood and bagasse (Lee et al., 2022). Besides, studies reported the amount of cellulose, hemicellulose, and lignin percentages in the OPT are 34.4%, 23.90%, and 35.9%, respectively (Yap, 2021).

2.2.1 Parenchyma and Vascular Bundle of OPT

The trunk is composed tissue made up of parenchyma and vascular bundle (Ramle et al., 2019). Vascular bundles and parenchyma accounted for 71-76 % and 24-29%, respectively. This tissue can be separated and discriminated from each other by using mechanical crush as shown in Figure 2.5 (Fatimah Mhd. Ramle, 2022).

In parenchyma, it consist a lot of starch contents. Due to this, fungus grows rapidly on the surface of OPT cross sections. Besides, it has extremely tough outer bark and high content of decayable parenchyma cells (Fatimah Mhd. Ramle, 2022). However, fibers that suitable for materials uses are found in the vascular bundle, whilst living cells holding sugars and carbohydrates useful for energy and livestock feed are found primarily in the parenchyma (Mokhena et al., 2016). The oldest and first to develop cells were parenchyma, making them one of most primitives of all eukaryotic cell types. This cell structure consists only a primary wall with no secondary wall. However, information about the individual cell of parenchyma and vascular bundle still requires additional research.

Moreover, vascular bundle cells in OPT are a type of transport tissue, which is a group that includes vascular tissue. Vascular tissue functions as a transport system which contains many plant cells. This tissue moves water, organic, and inorganic molecules generated or ingested by the plant for use or storage. The way the vascular tissue in the stems of dicotyledonous and monocotyledonous plants set up is different (Fatimah Mhd. Ramle, 2022). The information can be seen clearly from schematic diagram and actual end cross section cut of OPT in Figure 2.6 (Dungani et al., 2013).

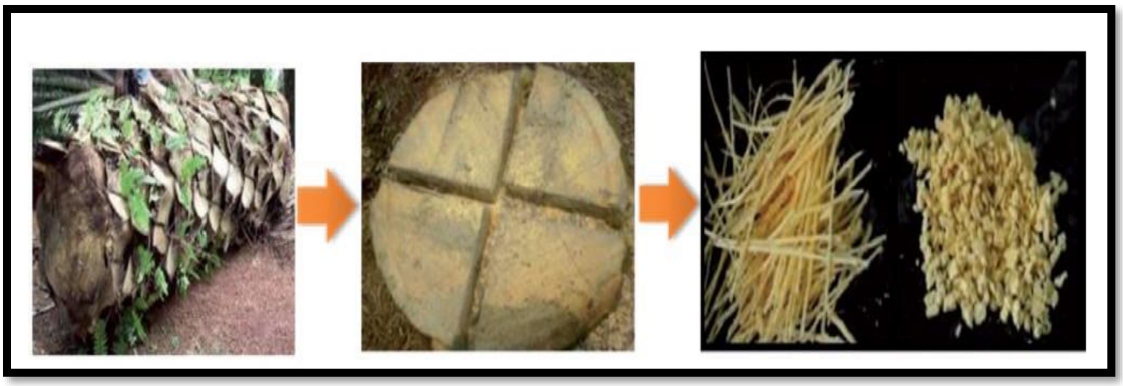


Figure 2.5 Process of extraction parenchyma and vascular bundle from OPT(Fatimah Mhd. Ramle, 2022)

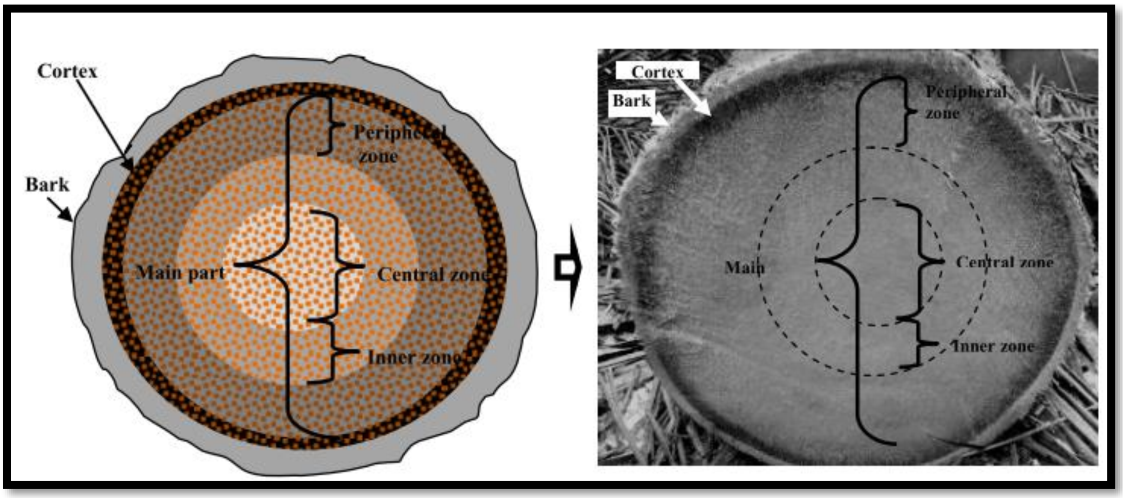


Figure 2.6 Schematic diagram and actual end cross section cut of OPT (Dungani et al., 2013)

2.2.2 Utilization of Oil Palm Trunks in Industry and Daily Life

Nowadays, OPT is being used to make more valuable products by enhancing the chemical, physical, and biological properties. Saw wood, plywood, lumber, and binder less particleboard are all examples of wood products made from the OPT as it contains a lignocellulose material. Large amounts of sap can be found in the felled OPT, making it an ideal feedstock for the manufacture of bioethanol (Wardani et al., 2021). In addition, research has shown that OPT may be converted into compost and roughage that is comparable to rice straw for use in feeding ruminants (Kaniapan et al., 2021).

Despite producing a large quantity of biomass classified as agricultural wastes, only 10% of this material can be used as an alternative raw material in fertilizers, animal feeds, chemical derivatives, and other similar fields. Thus, this huge amount of leftover waste is bad for the environment when it is left alone in farms and processing plants. According to Dungani et al., (2018), it is possible to produce variety of new product from biomass and other types of farm waste, such as medium-density panel, chip board, thermoset composite and thermoplastic, nanobiocomposite, and pulp and paper (Dungani et al., 2018). Moreover, OPT can be used as a precursor for activated carbon production, which is a porous material that can be used as an adsorbent, catalyst, or catalyst support for various industrial and environmental applications. Activated carbon from OPT can be produced by thermal carbonization or chemical activation (Safana, Abdullah, & Sulaiman, 2018). Ongoing research and innovation in materials science may explore new ways to use OPT fibers in the development of advanced and environmentally friendly packaging materials as biodegradable packaging. Biodegradable packaging is gaining importance as an eco-friendly alternative to replace synthetic polymer or traditional packaging materials, especially in response to concerns about plastic pollution. Previous research study on the preparation and characterization of bio-film composite based on high density polyethylene and oil palm trunk fiber (Laftah, Majid, & Ibrahim, 2022).

2.3 Lignocellulose Components

The main organic compounds in plant cell walls such oil palm are cellulose, hemicellulose, and lignin as tabulated in Table 2.2 (Dikriansyah 2018). These main organic compounds are categorized as lignocellulose components. Besides, extractive components of lignocellulose materials include lignin, lipid, fats, and waxes. Non-extractive components include silica, carbonates, and others (Obele et al. 2017). In addition, lignocellulose materials contain small amounts of extraneous organic compounds. Moreover, lignocellulosic biomass can be derived from agricultural crops, forests, and industrial waste materials. These sources are appealing primarily because of the low cost of the raw materials (Zadeh et al., 2020).

Table 2.3 Chemical composition of plant cell wall (Dikriansyah 2018)

Type	Cellulose	Hemicellulose	Lignin
Subunits	D-Pyran glucose units	D-Xylose, mannose, Larabinose, galasctose,glucornic acid	Guaiacylpropane (G), syringylpropane (S)
Bonds between the subunits	ß-1,4 Glysocidic	ß-1,4 Glysocidic bonds in main chains: ß-1-2, ß-13, ß-1-6-glucosidic bonds in side chains	Various ether bonds and carbon-carbon bond, mainly –O-4 ether bond
Polymerization	Several hundred to tens of thousands	Less than 200	4000

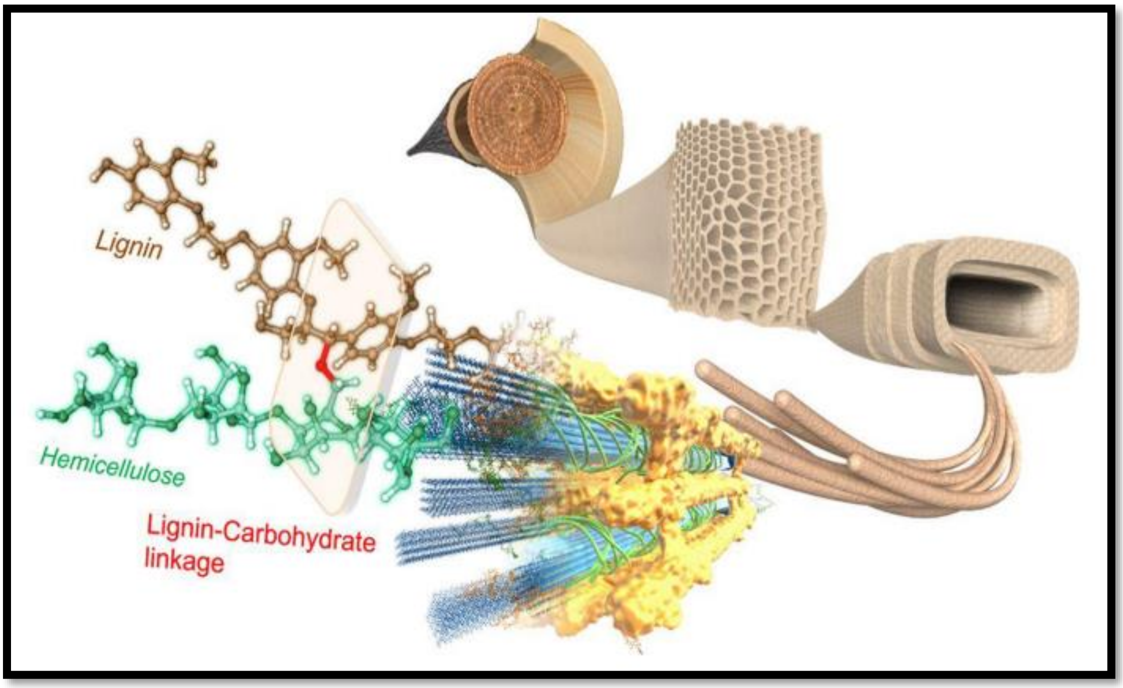


Figure 2.7 Graphical illustration of lignin, cellulose, and hemicellulose in the plant cell (Zadeh et al., 2020)

2.3.1 Holocellulose

Holocellulose refers to the carbohydrate component of lignocellulosic biomass, encompassing the entirety of the polysaccharide fraction derived from natural sources after the removal of extractives and lignin (Segato et al. 2014). In the Merriam–Webster online dictionary, holocellulose is defined as "the total polysaccharide fraction of wood or straw and the like that is made up of cellulose and all of the hemicelluloses and that is obtained by removing the extractives and the lignin from the original natural material" as shown in Figure 2.7 (Segato et al., 2014). Most discussions on holocellulose have focused on wood's chemical composition, and fibres have received little attention when it comes to potential new materials (Yang & Berglund, 2021). Holocellulose has been the subject of several studies that provide information regarding its characteristics, extraction techniques, and potential