

**THE EFFECT OF ADDITIVES ON THE PROPERTIES OF OIL
PALM TRUNK BINDERLESS PARTICLEBOARD**

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by

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TABLE OF CONTENTS

Contents	Page
Acknowledgement	ii
Table of Contents	iii
List of Tables	vii
List of Figures	viii
List of Symbol and Abbreviations	ix
Abstrak	x
Abstract	xii
1. Chapter 1: INTRODUCTION	
1.1 General	1
1.2 Justification	3
1.3 Objective	4
2. CHAPTER 2: LITERATURE REVIEW	
2.1 The Oil Palm	5
2.1.1 Oil Palm Review and Its Future In Malaysia	5
2.1.2 Oil Palm Biomass and Its Utilization	7
2.1.3 Oil Palm Trunk	9
2.1.3.1 Anatomy and properties of oil palm trunk	9
2.1.3.2 Physical properties of oil palm trunk	10
2.1.3.3 Fiber morphology of oil palm trunk	10
2.1.3.4 Chemical composition of oil palm trunk	11
2.1.3.5 Sugar content of oil palm trunk	13
2.1.3.6 Oil palm trunk utilization	15

2.1.4 Lignocellulosic Materials	18
2.1.4.1 Cellulose	18
2.1.4.2 Hemicellulose	19
2.1.4.3 Lignin	22
2.1.4.4 Extractives	23
2.1.4.5 Starch	24
2.2 Development of Binderless Board	26
2.2.1 Postulation on bonding mechanism	29
2.2.2 Potential Use of Binderless Board	34
2.3 Additives	34
2.3.1 Glucose	35
2.3.2 Xylose	35
2.3.3 Sucrose	36
2.3.4 Potato starch	37

3. CHAPTER 3: MATERIALS AND METHODS

3.0 General Flow Chart Of Methodology	38
3.1 Sample preparation	38
3.2 Hot Water Extraction	38
3.3 Binderless Board Manufacture	40
3.4 Determination of Mechanical and Physical properties of boards	41
3.4.1 Bending test	41
3.4.2 Internal Bond Strength	41
3.4.3 Density	42
3.4.4 Water Absorption	42

3.4.5 Thickness Swelling	43
3.5 Determination of Sugar Content	44
3.5.1 Sample Preparation for HPLC Analysis	44
3.5.2 HPLC Preparation for Sugar Analysis	44
3.6 Determination of Total Sugar	45
3.6.1 Standard sugar preparation by Colorimetric Method	45
3.6.2 Sample Preparation for Total Sugar Analysis	46
3.7 Spectroscopic Study by Fourier Transform Infra Red (FTIR)	47
3.8 Scanning Electron Microscopy	48
3.9 Chemical Analysis	
3.9.1 Determination of Extractives	48
3.9.1.1 Preparation of Samples	48
3.9.1.2 Preparation of Extractives Free Wood	48
3.9.1.3 Moisture Content	49
3.9.2 Determination of Holocellulose	49
3.9.3 Determination of Alpha cellulose	50
3.9.4 Determination of Lignin Content	51
3.9.5 Determination of Ash Content	52
3.10 Determination of Starch Content	53

4. CHAPTER 4: RESULTS AND DISCUSSION

4.1 Particle size distribution ratio	54
4.2 Chemical composition of oil palm trunk before and after extraction	56
4.3 Properties of binderless board with addition of additives	57
4.3.1 Modulus of rupture (MOR)	57

4.3.2 Internal bond (IB) strength	60
4.3.3 Thickness Swelling and Water Absorption	62
4.4 Chemical changes during heat treatment by hot pressing	64
4.4.1 Chemical composition of oil palm trunk binderless particleboard with addition of additives	64
4.5 Starch content	69
4.6 Sugar content analysis	70
4.6.1 Sugar analysis by High Performance Liquid Chromatography (HPLC)	70
4.6.2 Total sugar content by colorimetric method	73
4.7 Spectroscopic Characterization by FTIR	74
4.8 Microstructure Study by Scanning Electron Microscopy	75
5. CHAPTER 5: CONCLUSION AND RECOMMENDATION	
5.1 Conclusion	83
5.2 Recommendation	85
REFERENCES	86
APPENDICES	
APPENDIX A	
List of publications	105
APPENDIX B	
Calculation for yield of extractive	106
APPENDIX C	
Comparison between mechanical properties of all binderless board made with old and young oil palm trunk	107
APPENDIX D	
Chromatogram for standard sugar in HPLC	108

LIST OF TABLES

Table	Title	Page
Table 2.1:	Oil Palm Planted Area and Output	5
Table 2.2:	The wet weight of potential oil palm biomass available in Malaysia 2009	8
Table 2.3:	Chemical composition of oil palm trunk	12
Table 2.4:	Utilisation and value added product of trunk	17
Table 2.5:	The binderless board from different kind of materials	28
Table 3.1:	Types of boards manufactured	39
Table 4.1:	Chemical composition of oil palm trunk particleboard before and after extraction	57
Table 4.2:	Chemical composition for all types of board	65
Table 4.3:	Sugar composition for all types of board using HPLC and colorimetric method	71
Table 4.4:	FTIR spectra for all types of boards	77

LIST OF FIGURES

Figure	Title	Page
Figure 2.1:	A schematic illustration of cellulose	18
Figure 2.2:	A schematic illustration of sugar units of hemicelluloses	21
Figure 2.3:	A schematic illustration of buildings unit of lignin	23
Figure 2.4:	A schematic illustration of starch	25
Figure 2.5:	Binderless board made from oil palm trunk	27
Figure 3.1:	General flowchart of methodology	39
Figure 3.2:	Standard curves absorbance against concentration of standard sugar (%) determined by colorimetric method using UV-vis spectrophotometer	46
Figure 4.1:	Particle size distribution of oil palm particles for board manufacture	54
Figure 4.2:	Average modulus of rupture (MOR) value for all boards	58
Figure 4.3:	Average internal bond (IB) strength value for all boards	61
Figure 4.4:	Average thickness swelling and water absorption value for all boards	63
Figure 4.5:	FTIR spectra of all boards with the addition of sugars and starch	75
Figure 4.6:	Micrographs of unextracted board and extracted board after board making	79
Figure 4.7:	Micrographs of unextracted board with the addition of sugars and starch after board making	80
Figure 4.8:	Micrographs of extracted board with the addition of sugars and starch after board making	81

LIST OF SYMBOL AND ABBREVIATIONS

%	percentage
MPa	mega pascal
cm	centimeter
g/cm ³	gram per centimeter cube
g	gram
SEM	Scanning Electron Microscopy
FTIR	Fourier Transform Infra Red
OPT	oil palm trunk
°C	degree Celsius
IB	internal bond
MOR	modulus of rupture
KBr	potassium bromide
MPOC	Malaysian Palm Oil Council
HPLC	High Performance Liquid Chromatography
MDF	Medium Density Fibreboard
mm/year	millimeter per year
pH	potential hydrogen
GHG	Green House Gases
DDI	Distilled De-Ionized
ASTM	American Society for Testing and Materials
UV-VIS	Ultraviolet/Visible Spectrometry
rpm	revolution per minute

**KESAN ADITIF TERHADAP SIFAT-SIFAT BOD PARTIKEL TANPA
PENGIKAT DARIPADA BATANG KELAPA SAWIT**

ABSTRAK

Dalam kajian ini, kesan bahan-bahan aditif kepada sifat-sifat bod partikel tanpa pengikat daripada batang kelapa sawit dinilai berdasarkan satu siri analisis yang merangkumi analisis mekanikal, fizikal dan kimia. Sepuluh jenis bod partikel tanpa pengikat telah dihasilkan termasuk bod partikel daripada batang kelapa sawit sebagai bod kawalan, bod partikel dengan tambahan aditif iaitu xilosa, sukrosa, glukosa dan juga kanji ubi kentang, bod partikel yang telah mengalami proses pengekstrakan menggunakan air panas, dan juga bod partikel yang dihasilkan menggunakan partikel yang telah melalui proses pengekstrakan menggunakan air panas ditambah dengan bahan aditif seperti yang telah disebutkan di atas. Bod partikel yang dihasilkan berketumpatan 0.8 g/cm^3 dan dikenakan tekanan panas pada suhu 180°C selama 20 minit. Perubahan kimia yang mungkin berlaku dalam bod-bod partikel tanpa pengikat ini telah dinilai melalui ujian analisis kimia yang dijalankan termasuk penentuan kandungan ekstraktif, holoselulosa, alfa-selulosa, kandungan lignin, kandungan kanji, kandungan gula individu dan jumlah gula yang terdapat dalam bahan-bahan tersebut. Pencirian spektroskopi dilakukan menggunakan Fourier Transform Inframerah (FT-IR) spektroskopi untuk mengesan kehadiran kumpulan berfungsi yang wujud dalam gentian kelapa sawit selepas bod dihasilkan. Perubahan kepada struktur-struktur gentian kelapa sawit sebelum dan selepas penambahan bahan-bahan aditif diperhatikan menggunakan Mikroskop Pengimbas Elektron (SEM). Keputusan menunjukkan penambahan bahan aditif terutamanya gula kepada bod partikel yang dihasilkan menggunakan partikel yang tidak dan menjalani proses pengekstrakan menunjukkan nilai kekuatan modulus kepecahan dan kekuatan ikatan

dalaman yang meningkat manakala nilai pengembangan ketebalan dan penyerapan air yang semakin baik. Pada umumnya, kebanyakan daripada panel-panel yang dihasilkan memenuhi kriteria yang ditetapkan oleh piawaiian “Japanese Industrial Standard (JIS A 5908)” untuk Jenis 8 dan sesetengah bod partikel juga memenuhi kriteria untuk Jenis 13 dan Jenis 18. Berdasarkan keputusan yang didapati, hasil dan penemuan-penemuan, ia boleh dicadangkan yang gula memainkan peranan utama di ikatan bod partikel tanpa pengikat. Penambahan bahan aditif terutamanya gula ke dalam bod-bod partikel meningkatkan prestasi fizikal dan mekanikal bod-bod tersebut. Ini membuktikan bahawa, gula yang terdapat dalam bod membantu dalam proses pengikatan yang terjadi antara partikel dengan partikel yang lain.

THE EFFECT OF ADDITIVES ON THE PROPERTIES OF OIL PALM TRUNK BINDERLESS PARTICLEBOARD

ABSTRACT

In this study, the effects of additives on the properties of oil palm trunk binderless board were evaluated through a series of mechanical, physical and chemical analyses. Ten types of binderless boards from oil palm trunk particles were made that include control boards, boards with addition of additives namely xylose, sucrose, glucose and potato starch, boards made from oil palm trunk particles that were extracted with hot water, and boards made from oil palm trunk particles that were extracted with hot water with addition of additives. All binderless boards were made to a target density of 0.8 g/cm^3 and pressed at 180°C for 20 minutes. Chemical changes that may occur in the binderless board were evaluated by chemical analyses including extractives, holocellulose, alpha-cellulose, lignin content, starch content, individual sugar and total sugar content. Spectroscopic characterization was done using Fourier Transform Infrared (FT-IR) spectroscopy to detect the presence of the functional group that exists in oil palm binderless boards. The structural changes of the manufactured panels before and after the addition of additives were viewed using Scanning Electron Microscopy (SEM). The results showed that addition of additives particularly sugar onto the board made from oil palm trunk particles with and without extraction increased the modulus of rupture (MOR) and internal bond (IB) strength and also improved the thickness swelling (TS) and water absorption (WA) values. Generally, most of the panels met the Japanese Industrial Standard (JIS A-5908) for the Type 8 and some satisfied the requirements for Type 13 and Type 18. Based on the findings of this study, it can be suggested that sugar play a major role in the bonding of the binderless board. Addition of additives especially sugar onto

the particleboard enhanced and improved the physical and mechanical performances of the boards. Thus, it can be proved that the sugar in the boards contributed in the self-bonding between particles and the other particles to occur.

CHAPTER 1 INTRODUCTION

1.1 General

The oil palm industry especially in Malaysia is evolving and venturing into downstream activities with greater vigour. The oil palm trunk, considered as a renewable natural resource biomass has also been utilized as a cellulosic raw material in the production of panel products for instance particleboard, medium density fibreboard (MDF), mineral-bonded particleboard, blockboard, plywood, furniture and recently useful in the development of binderless board. In short, the use of biomass in these sectors of the oil palm industry will not only provide additional revenue to the industry but will also help achieve the long-term zero waste strategy adopted by the industry (Basiron and Simeh, 2005). World-wide demand for wood-based panels is to continue skyrocketed. Since all commercial panel products in the market use an adhesive to bind the constituent wood elements together, an alternative is still under progress to reduce the use of adhesive and produce environmentally friendly wood-based panels.

Binderless board formed into board using hot pressing without addition of any resin or adhesives, by means of activating chemical components of the board constituents (Okuda and Sato, 2004). Binderless board will become an important new value-added product for effective utilization of biomass waste, especially in developing countries where there is limited and shortage of wood resources (Mobarak et al, 1982).

In the manufacturing, of binderless board, resin or adhesives are not used so that self bonding strength is significantly affected by changes in chemical composition of the boards caused by the heat / steam treatments (Widyorini et al,

2005). Clarification and evaluation of the self-bonding mechanism will be an important issue for further improvement of the development and study of binderless board performance, and for the possibility of expanding its application to other lignocellulosic materials (Okuda et al, 2006).

In this regard, many researchers have done various studies on the production of binderless boards from various regions for instance using kenaf and bagasse as a raw material. Okuda et al (2006) give some basic information on the self bonding from their studies through a series of chemical analyses and chemical changes conducted on the kenaf core binderless board during the hot press process. So far, only a little information emerged on the detail of the self-bonding mechanism and study on the binderless board is very limited.

Many studies done in this area are mainly using steam explosion to pre-treat the samples first. However, there is no study until now discovered on the binderless board using the oil palm trunk without using the steam explosion but only the hot press process. In this study, we select the oil palm trunk as a raw material to made the binderless board.

Therefore, this research was design to investigate the self-bonding of the binderless board. In order to achieve this aims, raw materials using was added with and without additives to see the effect of the additives (sugars and starch) added on the properties of boards as well as chemical changes during hot pressing. Extraction process was also conducted to the raw materials to extract the water soluble materials from the raw materials. The extraction particles were then made into boards by adding with additives (sugars and starch). The board properties were

compared to the unextracted boards and chemical changes with the addition of the additives were investigated.

1.2 Justification

In a country like Malaysia and Indonesia with the oil palm as the main agricultural, the main problem these countries facing are the waste generates from the palm itself. The urge to convert this waste materials onto value-added products become the thoughts among the researchers. There was abundant oil palm biomass waiting to be utilized. Oil palm trunk, empty fruit brunch, oil palm frond and others biomass waste are the waste generates from the oil palm plantation. One of the bright futures promising for this waste is turning the oil palm trunk into particleboard. In the production of particleboard, the problem faced by the manufacturers is the cost of manufacturing is high due to the use of adhesives.

Therefore, omitting the use of adhesives in particleboard production will bring new hope to produce an environmentally products yet more cheap in production cost. This board called as binderless board only depends on the activating the chemical changes that happen in the board during steam/heat treatment. However, information on the self-bonding of the binderless board is very limited especially when using different raw materials. Thus, this study attempts to investigate the self-bonding mechanism of binderless board particularly in the role of sugar and starch when using oil palm trunk as raw materials.

1.3 Objectives of Research

The aims of this study are:

- a) To study on the effects of additives on the mechanical and physical properties of oil palm trunk in order to assess the self-bonding mechanism.
- b) To determine the chemical composition, starch and sugar content of the board made and its effect on the board properties

CHAPTER 2 LITERATURE REVIEW

2.1 The Oil Palm

2.1.1 Oil Palm Review and its future in Malaysia

Originated in West Africa, oil palm (*Elaeis guineensis jacq.*) becomes the commercial planting material for the rapid expansion developing plantation in Malaysia (Hartley, 1988). By the early 1960s, plantations of oil palm had increased dramatically in Malaysia and Indonesia and by 2000, these two countries accounted for just over half of the world's total plantation area (Basiron and Simeh, 2005). Today, the cultivation of oil palm in Malaysia covers an area of 4.85 million hectares in 2010 (Malaysian Palm Oil Council, 2010), increasing from 3.47% from 4.69 million hectares from the year before as shown in Table 2.1.

Table 2.1: Oil Palm Planted Area and Output in Malaysia

	Jan –Dec 2009	Jan –Dec 2010	Change	Change (%)
Planted area (ha)	4,691,160	4,853,766	162,606	3.47
Production (tonnes)				
Crude palm oil	17,564,937	16,993,715	-571,222	-3.25
Crude palm kernel oil	2,097,059	2,014,943	-82,116	-3.92
Closing Stocks (tonnes)				
Palm oil	2,239,257	1,614,671	-624,586	-27.89
Palm kernel oil	305,912	243,235	-62,677	-20.49

Source: Malaysian Palm Oil Council (2010)

The palm productivity decreased after 20–25 years. Of this, the plant spends its first 11–15 months in the nursery, then first harvesting in 32–38 months, and peak yield is 5–10 years from planting. Normally, oil palm grows in the lowlands of the humid tropics with evenly distributed rainfall of 1800–5000 mm/year. According to Hartley (1988), palm has a wide adaptability range of soils and low pH, but sensitive to high pH (> 7.5), and to stagnant water. Oil palms are cultivated on large plots of land with planting density of 128–148 plants per hectare. They are largely dependent on the planting materials, soil, temperature and climate.

Early interest in oil palm as an industrial crop arose from the need to replace animal fat in the production of candle wax, soap and margarine. Hence, oil palm used as cooking oil, the base for most liquid detergents and shampoos, serves as the base for lipstick, waxes, and polishes. It also used to reduce friction during the manufacture of steel. At a still rapidly increasing population especially in the developing countries, cooking oil consumption expected to rise both due to increased population and rising affluence. Palm oil being the cheapest oil that can be sustainably produced is likely to meet this need. Oil palm plantations expected to increase as an existing old palm tree will be replace with new plant trees (Basiron and Simeh, 2005).

Also, responding to consumer health and environmental concerns, secondary and by-products from the palm oil industry have spawned new industries, such as in vitamins A and E and other antioxidant health supplements from the oil, animal feed and organic fertilizers from the kernel, and sludge cakes and wastes from oil extraction mills have served as value additions. Therefore, this valuable agriculture has a better future as increasing in demand for the oil based products.

2.1.2 Oil Palm Biomass and Its Utilization

Oil palm industry produce a large quantity of biomass in the form of empty fruit bunches, palm kernel shells, fronds, trunks of the plant, fibre, leaves and effluent. When palm oil is extracted and processed, it's not only produces effluents with high organic matter but also suspended matter, oil and grease. These wastes cause ecosystem degradation and affect the health of the communities. Oil palm plantations widely known for their negative environmental impacts that included land and water pollution, local inhabitant losing their land resources unbalance in biodiversity brought by cultivation and management. Therefore, the urged to utilize these wastes into value added products becomes the topics among the researchers.

Table 2.2 present the weight of potential oil palm biomass availability in year 2009. Some of the byproducts derive from these wastes are energy, mulch, compost or organic fertilizer from empty fruit bunches shells and sludge from effluent treatment. Empty fruit bunches and palm kernel shells were converted into peat by mixing it with goat manure or poultry manure and were helpful in developing oil palm nurseries and other food crops. Bio gas and electricity can be generated from effluent management. Through biotechnology, biochemicals product like ethanol, fatty acids, waxes and others could be produced. Palm oil wastes contribute to Green House Gases (GHG) and conversion to energy is a good way of obtaining carbon credit facility for sustainable management. Left materials are also used in cultivating mushrooms. These technologies find wider application in developing African and Asian countries where oil palm plantations are major economic resource (Basiron and Simeh, 2005).

Table 2.2: The Wet Weight of Potential Oil Palm Biomass Available in Malaysia in 2009

Sources of oil palm biomass	Unit	
	Million cubic meter per year	Million tonnes per year
Oil Palm Trunk (OPT)	15.2	23.6
Oil Palm Frond (OPF)	83.0	-
Empty Fruit Bunches (EFB)	17.5	-
Total	115.7	23.6

Source: Malaysian Palm Oil Council (2010)

2.1.3 Oil Palm trunk

2.1.3.1 Anatomy of oil palm trunk

At replanting age, the trunk height ranges between 7 m to 13 m and 45 cm to 65 cm in diameter, measured 1.5 meter above the ground level (Koh et al., 1999; Husin et al., 2000). As a monocotyledonous species, oil palm does not have cambium, secondary growth, growth rings, ray cells, sapwood and heartwood or branches or knots. Thus, the growth and increase in diameter of the trunks is due to the overall cell division and cell enlargement in the parenchymatous ground tissues, together with the enlargement of the fibres of the vascular bundles.

The trunks are divided into three main zones which is cortex, periphery and central. The outer part of the trunk covered by narrow cortex with approximately 1.5-3.5 cm in wide. This part largely composed of ground parenchyma with numerous strands of small and irregular shaped fibrous strands and vascular bundles. In the periphery region, it consist of narrow layers of parenchyma and congested vascular bundles that generate rise to a sclerotic zone which provides the main mechanical support for the palm. The central region that covered with 80 % of the total area of the trunk is composed of vascular bundles. Slightly larger and widely scattered vascular bundles are embedded in the thin-walled parenchymatous ground tissues. The size of the vascular bundles tends to increase and more widely scattered towards the core of the trunk.

2.1.3.2 Physical properties of oil palm trunk

According to Killman & Lim (1985), the initial moisture content of the oil palm trunk (based on oven dried weight) varies between 100 to 500 percent. An increasing in moisture content is indicated along the trunk height and towards the central zone, with the lower zones having far lower values than the other two zones (Lim and Khoo, 1986; Lim and Gan, 2005). This increment trend in the moisture content is due to the distribution of the parenchymatous cell which hold more moisture than vascular bundles. Mainly these tissues are more abundant towards the apex of the palm trunk as well as radially from the periphery towards the centre pithy region.

There is a wide variation of density values at different parts of the oil palm trunk due to its monocotyledonous nature. The variation in density along the cross-section of the trunk indicates that the highest mean density is at peripheral zones and decrease gradually towards the central core. This is due to the high concentration of vascular bundles that can be found in the peripheral zones which decrease gradually towards the central zone. Mohd. Noor et al., (1984) reported that, in the longitudinal direction, the trunk does not give any clear pattern in density variation, but roughly the density tends to decrease with the height increasing.

2.1.3.3 Fiber morphology of oil palm trunk

Previous studies on the length, width and cell wall thickness also recorded by Mohd. Noor et al., (1984). According to the studies, the fiber length measured ranges from 1.02 mm to 1.97 mm. Generally, the fiber length tends to decrease from the peripheral zone towards the central zone and from the bottom towards the top. The width of the fiber measured ranges from 28.9 to 45.1 micron whilst the cell wall

thickness ranges from 2.1 to 6.3 micron. However, only a little changes in cell wall thickness with the increase in height.

2.1.3.4 Chemical composition of oil palm trunk

The chemical composition of oil palm trunk from the research finding is exhibited in Table 2.3. The majority of most plants consist of cellulose, hemicellulose and lignin which make up the biomass of trees and agricultural by products. Cellulose and hemicellulose are made up of chains of sugars. Cellulose made of linked glucose molecules that strengthen the cell walls of most plants. Hemicelluloses or polyose is a mixture of various monosaccharides namely glucose, xylose, mannose, galactose, arabinose, fructose and 4-O-methyl glucuronic acid. Cellulose gives mechanical strength to plant tissue while lignin provides rigidity and stiffness (Widyorini et al., 2005). The cellulose content of the oil palm trunk was fall within the range of 29% -50 % and lignin was 20% -25%. The value can be varies depending on the part of the trunk. The low lignin content (15.70% – 24. 51 %) is a positive attribute for pulp and paper-making industry.

Previous studies conducted by Sudin et al., (1987) reported that, the chemical composition varies with height and zone. Murai et al., (2009) also added that ages of the tree also influence the composition of carbohydrates in trees. Polysaccharides in oil palm trunk including the glucose was released from cellulose and hemicelluloses derived from various monosaccharides such as mannose, galactose, xylose and arabinose. It recorded by various researchers (Husin, 2000; Balat et al., 2008; Murai et al., 2009) that 3 main free sugar namely glucose, sucrose and fructose accumulated and distributed along the trunks particularly on the center part contributing in the higher proportion of free sugar.

Table 2.3: Chemical Composition of oil palm trunk

Chemical compositions (%)	Hashim et al., 2010		Mohd Noor et al., 1984	Abdul Khalil et al., 2008	Chin et al., 2011
	Mid part of trunk	Core part of trunk			
Extractives	14.50	9.10	Na	5.35	Na
Holocellulose	72.60	50.73	45.7	73.06	78.5
Alpha-cellulose	50.21	43.06	29.2	41.02	47.5
Lignin	20.15	22.75	18.8	24.51	18.4
Ash	Na	Na	2.3	2.2	1.69

* Na - Not available

Chemical composition varies in the plant and within plants from different parts of the same plant. It also varies within plants from different geographic locations, ages, climate, and soil conditions (Rowell,2000).

2.1.3.5 Sugar content of oil palm trunk

Previous studies engaged on sugar composition of the oil palm trunk are in the form of sap. According to Ogan (1998) and Henson et al., (1999), they indicate that oil palm trunks contain high proportional of sap which includes abundant amount of free sugars, saccharides and polysaccharides. The sap was obtained either by using tapping method, squeezing or compressing method. The sap is sweet due to the presence of sucrose and clear to yellowish in colour. Other than sugars, alcohols, amino acids, organic acids, mineral, vitamin and proteins are also can be found in the sap (Bassir, 1962; Van Pee and Swings, 1971; Faparusi and Bassir, 1972).

Oil palm reported containing high sugar content which is, around 10 and 12 % on sugar composition. (Bassir, 1962; Okafor, 1975; Eze and Ogan, 1988). Total sugar content of sap samples indicates that sucrose, glucose and fructose form as a main free sugar with the glucose contributing to the highest constituent of sugar (Yamada et al., 2010; Kosugi et al., 2010). Other short chain of polysaccharides namely maltose, xylose, galactose, arabinose and inositol also present in a small quantity from a total amount of sugar inside the oil palm trunks.

The trend also same in particles form after the drying process. Total sugar content of particles form shows that xylose, arabinose, and fructose form as main sugar with glucose contributes to the highest constituent of sugar (Hashim et al., 2010). In the particles form, the sucrose was not listed as one of the main sugar. This is presumably due to the structure of sucrose which could easily breakdown into

glucose and fructose by action of microorganism during the drying, storage and heating process.

The total sugar content in the oil palm trunk may difference by time to time. The differences may influenced by age and species of the tree, soil, time of tapping and also the storage time for the oil palm trunk to keep (Tomimura,1992, Yamada et al., 2010; Kosugi et al., 2010).

2.1.3.6 Oil Palm Trunk Utilization

The availability of the oil palm trunks is only when the economic life-span of the palm reached its maturity limits. After the oil palm becoming old, the palm tree will be cutted down so that the replanting plan can be started. Throwing away the trunks give a slow breakdown of the material. The freshly felled trunks cannot be easily burnt due to the presence of the high amount of moisture in the trunks and leaving the trunks in the field without further processing will hinder the replanting process. Oil palm trunk normally takes about five to six years to rot and mineralize. At this time, the left trunks will become the habitat and breeding ground for oil palm pest. Physical removal of these unwanted trunks to the dump sites is costly due to the weight of freshly felled trunk which is about 3 to 4 times its dry weight (Husin et al., 1986).

Another popular way to handle the trunks is by poisoning it before they are felled to increase the decomposition rate and to avoid insect and disease infection. In some plantation, the poisoning trunks will be cut into pieces with a chopper mounted on the tractor, pulverized using a specialized chipping machine then distributed to the field as mulch and source of nutrients. However, this method is costly. At this point, the problems arisen from the disposal of the trunks and the cost incurred during replanting process make them relevant to be reviewed. The potential uses of the trunks gathered attention among the researchers to convert this waste into value-added products (Husin et al., 1986).

By the 1980's, the judicious utilization of the various co-products through nutrient recycling in the fields had reduced the environment impact paving the way towards a zero-waste policy. From 1990's until the present day, there is an ongoing

research conducted to improve and to fully utilize the use of these co-products through the development of the value-added products. The research that deals with the utilization of the trunks is tabulated in Table 2.4.

Table 2.4: Utilisation and value-added product of trunks

Use	References
Recycled as nutrient in plantation	Arokiasamy, 1968, Chan et al., 1981
Use as erosion control measure by placing at the lip of planting terraces	Pestana et al., 1979
As a mulch for young palms when chipped	Lim et al., 1994
Wood products as: Urea particle board Cement bonded particle board Gypsum bonded particle board Medium density fibre board Panel products Binderless particle board Laminated veneer lumber	Chew, 1987; Chew & Nurulhuda, 1991; Rahim Sudin et al., 1991; Khozirah Shaari et al., 1991; Asahari Abd. Jalil et al., 1991; Chew et al., 1991; Woon, 1991; Hashim et al., 2010a, 2010b, 2011 Sulaiman et al., 2009
Furniture i) tiger wood ii) desk tops and chairs	Mohamad Husin et al., 1989b; Kamarudin et al., 1993
Pulp for paper	Mohamad Husin et al., 1989a
As animal feed	Abu Hasan Omar et al., 1989; Ismail & Hoi, 1991; Woon, 1991
Palm heart	Yap et al., 1991
Glucose	Lim, 1992
Cellulose	Putri Faridatul Akmar et al., 1991
Fuel	Wood & Corley, 1991
Palm Wine	Nagnan et al., 1992
Bioethanol	Yamada et al., 2009; Murai et al., 2009; Murai & Kondo, 2011; Kosugi et al., 2010

Source: Modified based on Weng (1999)

2.1.4 Lignocellulosic Materials

2.1.4.1 Cellulose

Cellulose is major structural polysaccharides in plants particularly in farm wastes and the most abundant organic compound in nature. As a polymer of glucose, cellulose has the formula $(C_6H_{10}O_5)_n$ where n ranges from 500 to 5,000 units long, depending on the source of the polymer (Anonymous, 2011). It is composed of glucose units joined together in the form of the repeating units of the disaccharide cellobiose with numerous cross linkages. The glucose units in cellulose linked in a linear fashion, as shown in Figure 2.1.

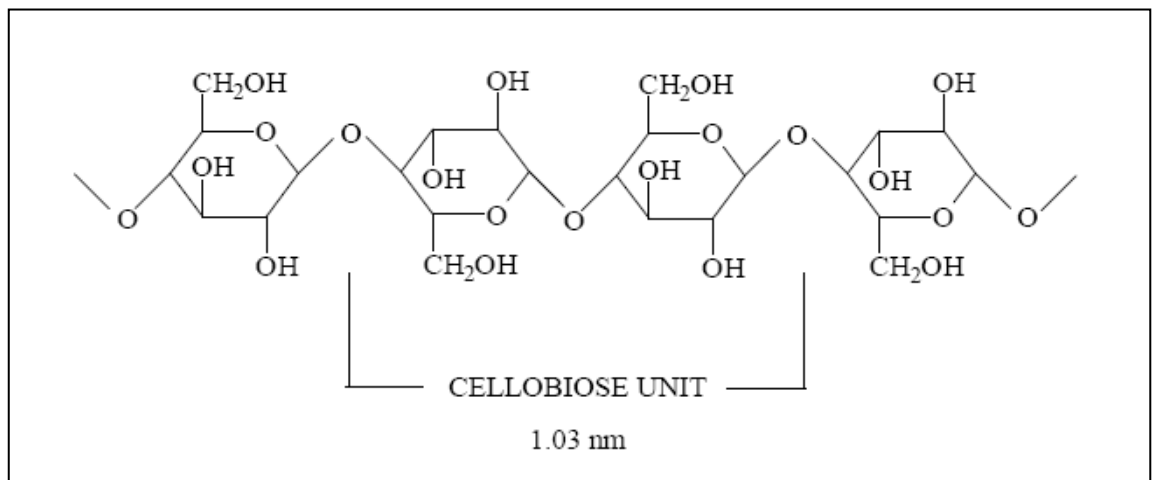


Figure 2.1: A schematic illustration of cellulose (Fengel and Wegener, 1989)

The links in the cellulose long chain are β -D-glucose. The beta-glycoside bonds permit these chains to stretch out, and this conformation is stabilized by intramolecular hydrogen bonds (Anonymous, 2011). A parallel orientation of adjacent chains also favored by intermolecular hydrogen bonds. The cellulose microfibrils bound to each other and hemicellulose polymers by hydrogen bonding (Valnet and Albersheim, 1974) but, there is no evidence of covalent linkage between cellulose and other cell wall constituents (Morrison, 1979). Although an individual hydrogen bond is relatively weak, many such bonds acting together can impart excellent stability to certain conformations of large molecules. According to Sjostrom (1993), cellulose has a high tensile strength as a consequence of its fibrous structure and strong hydrogen bonds. Cellulose commonly accompanied by a lower molecular weight, branched and amorphous polymer called hemicellulose.

2.1.4.2 Hemicellulose

Hemicellulose is non-cellulosic, non-pectic cell wall polysaccharides. The hemicelluloses consisted of various elementary sugar units, primarily the six-carbon sugars, D-glucoses, D-galactose and D-mannose, and the five carbon sugars, L-arabinose and D-xylose as shown in Figure 2.2. Hemicelluloses are chemically complex and composed of homopolymer or heteropolymers linear backbone called xylans, mannans, glucomannans, galactan and arabinogalactans (Sun and Sun, 2002).

This linear chain backbone particularly glucomannans and xylan chains are highly branched and have a lower degree of polymerization than cellulose. The sugars in the hemicelluloses structure exhibit hydrogen bonding both within the hemicelluloses chain as well as between other hemicelluloses and amorphous

cellulose regions. Most hemicelluloses are found interspersed within or on the boundaries of the amorphous cellulose chains and in close association with the lignin. It also may be the connecting material between cellulose and lignin (Winandy and Rowell, 2005).

In contrast to cellulose, hemicellulose is structurally weak and easily hydrolyzed by dilute acids and alkalis (Sun and Sun, 2002). The random and amorphous structure of hemicellulose makes it easy to be hydrolyzed (Hu et al. 2008). Because of the amorphous, hemicelluloses are partially soluble or swell able in water. Compared to other carbohydrates, hemicellulose is the most hydrophilic polymer. In the cell wall, hemicelluloses are responsible for the sticking and stabilizing different components of the wall. Hemicellulose is natural plant rubbers thus, they have good flexibility and mechanical properties (Gaspar et al., 2005).

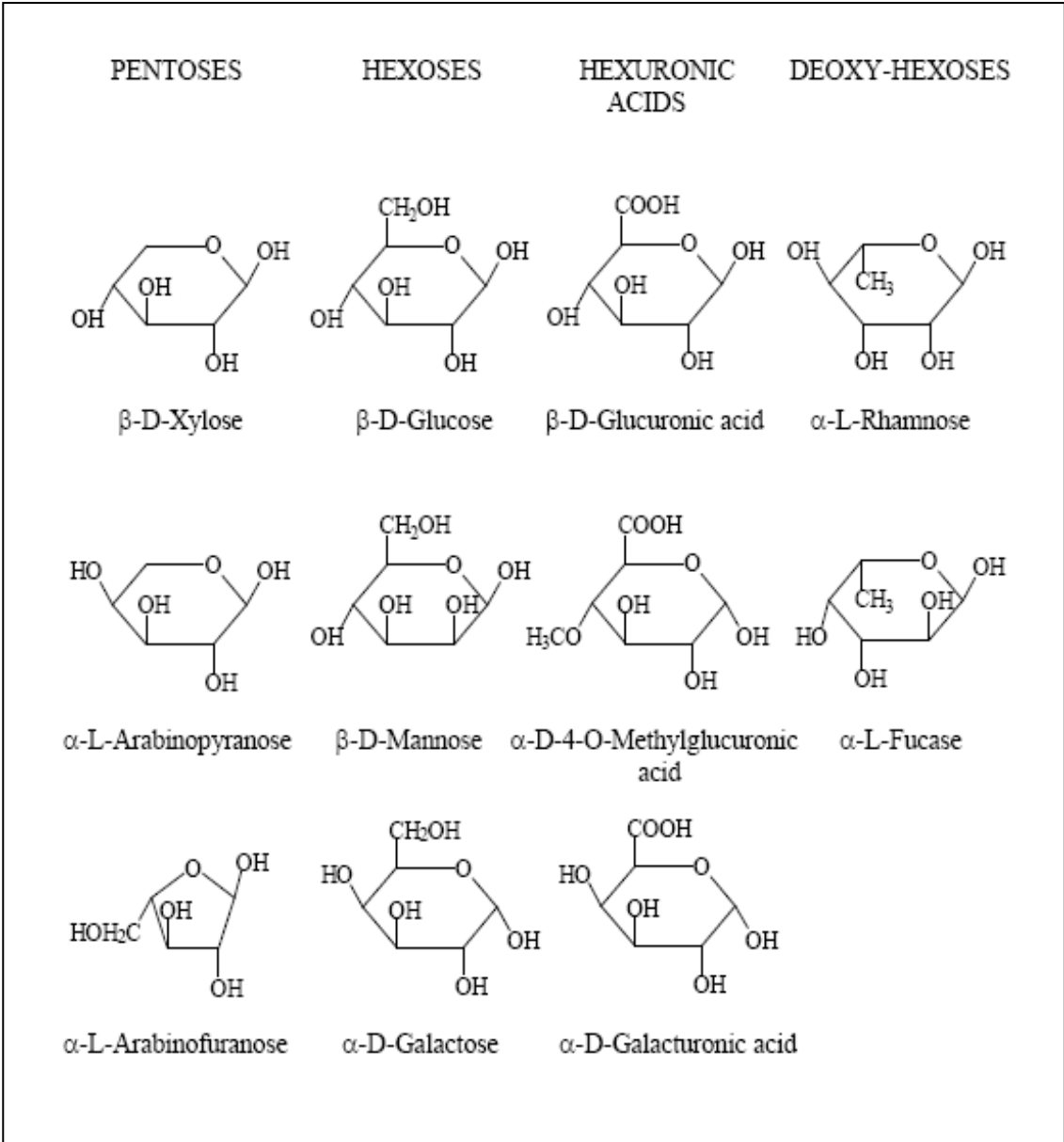


Figure 2.2: Schematic illustration of sugar units of hemicelluloses (Fengel and Wegener, 1989)

2.1.4.3 Lignin

Lignin is a complex, crosslinked polymer that forms a large molecular structure. It is the most abundant natural non-carbohydrate organic compound in fibrous materials. Armstrong (2006) reported that lignin gives the wood its characteristic brown color, density and mass. Lignin is an amorphous macromolecule functioning as a cementing material in the wood cells (Miller, 1999) and imparting mechanical strength to the tree (Sjostrom, 1993). It gives mechanical strength to wood by gluing the fibers together and acting as a reinforcing agent between the cell walls (Mazlan, 1998). Other than that, it also serves as a disposal mechanism for metabolic waste (Wardrop, 1971).

The monomeric building units of lignin exhibited in Figure 2.3. Rowel et al., (2005) mentioned that the guaiacyl unit is dominant in the softwood whilst syringyl units are dominant in hardwood. Besides the 20 different types of bonds present within the lignin itself, lignin seems to be particularly associated with the hemicellulosic polysaccharide (Xiao et al., 2001). Lignin can be isolated using several methods that include Klason lignin. This method removed the polysaccharides from the extracted wood by hydrolysis with 72% sulphuric acid (Sjostrom, 1993).

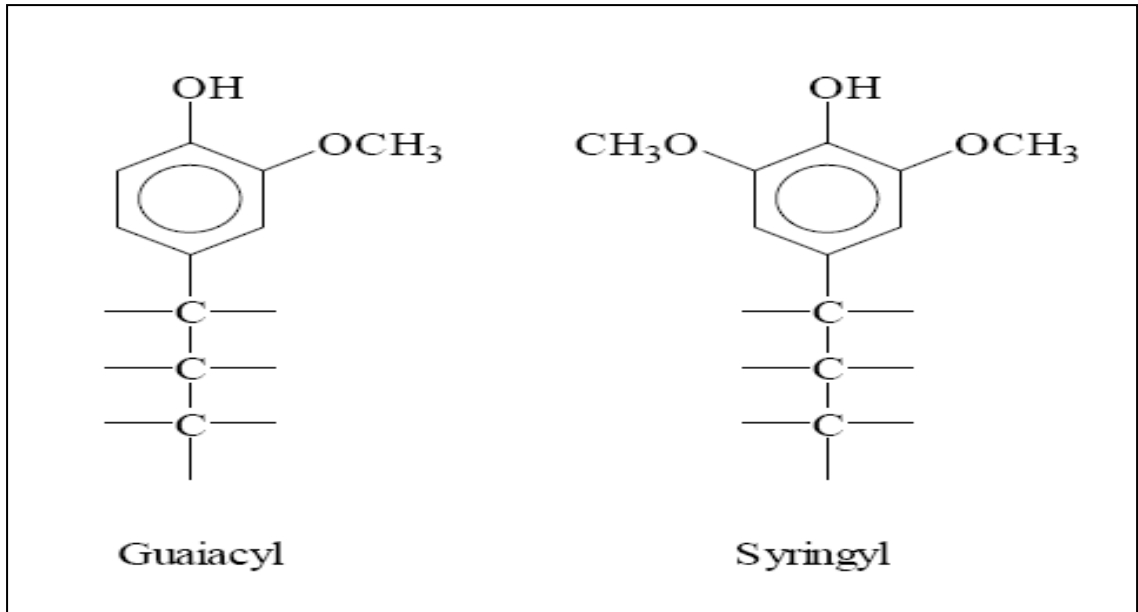


Figure 2.3: Schematic illustration of building units of lignin (Fengel and Wegener, 1989)

2.1.4.4 Extractives

Extractives are organic substances in the wood that can be extracted using polar or non-polar solvents. It is a group of cell wall chemicals mainly consist of fats, fatty acids, fatty alcohols, phenol, terpenes, steroids, resin acids (Mazlan, 1998). In addition to lignin and carbohydrates, minor amounts of lipophilic and hydrophilic extractives are present in wood (Sjostrom, 1993). Typical lipophilic extractives are free and esterified fatty acids, terpenoids and resin acids. The hydrophilic extractives are mostly phenolic substances including lignans (phenylpropane dimers), tannins and flavonoids. The extractives can be found mostly in resin canal and ray parenchyma cells and small amount in middle lamella and cell walls of tracheids (Mazlan, 1998). It usually acts as a source of energy for wood cells or protects the wood against microbiological attack. Their amount seldom exceeds 10% of the dry wood weight.

The amount of extractive in plant is different range between 1-10%. But in some tropical species the extractive composition can reach up to 20%. Their composition in wood can varies between 3-6% of the weight of the wood depending on the species. Concentration of extractives can be higher in certain parts of the tree such as branches, roots and damaged area (Tsoumis, 1991).

2.1.4.5 Starch

Starch is an essential polysaccharide and a polymer of glucose. It is the storage form of carbohydrate in plants abundantly found in roots, rhizomes, seeds, stems, tubers and corms of plants, as microscopic granules having characteristic shapes and sizes (Hoover, 2001). The structure of starch is more complex than that of cellulose. The intact granules are insoluble in cold water, but grinding or swelling them in warm water causes them to burst. The released starch consists of two fractions namely amylose and amylopectin as shown in Figure 2.4.

Amylose is a linear or non-branched polymer of glucose and about 20% is a water soluble material. Molecules of amylose are linear chains of several thousand glucose units joined by alpha C-1 to C-4 glycoside bonds. Amylose solutions are dispersions of hydrated helical micelles. The majority of the starch is much higher in molecular weight substance, consisting of nearly million glucose units called amylopectin. Molecules of amylopectin are branched networks built from C-1 to C-4 and C-1 to C-6 glycoside links, and are essentially water insoluble. Hydrolysis of starch, usually by enzymatic reactions, produces a syrupy liquid consisting largely of glucose.

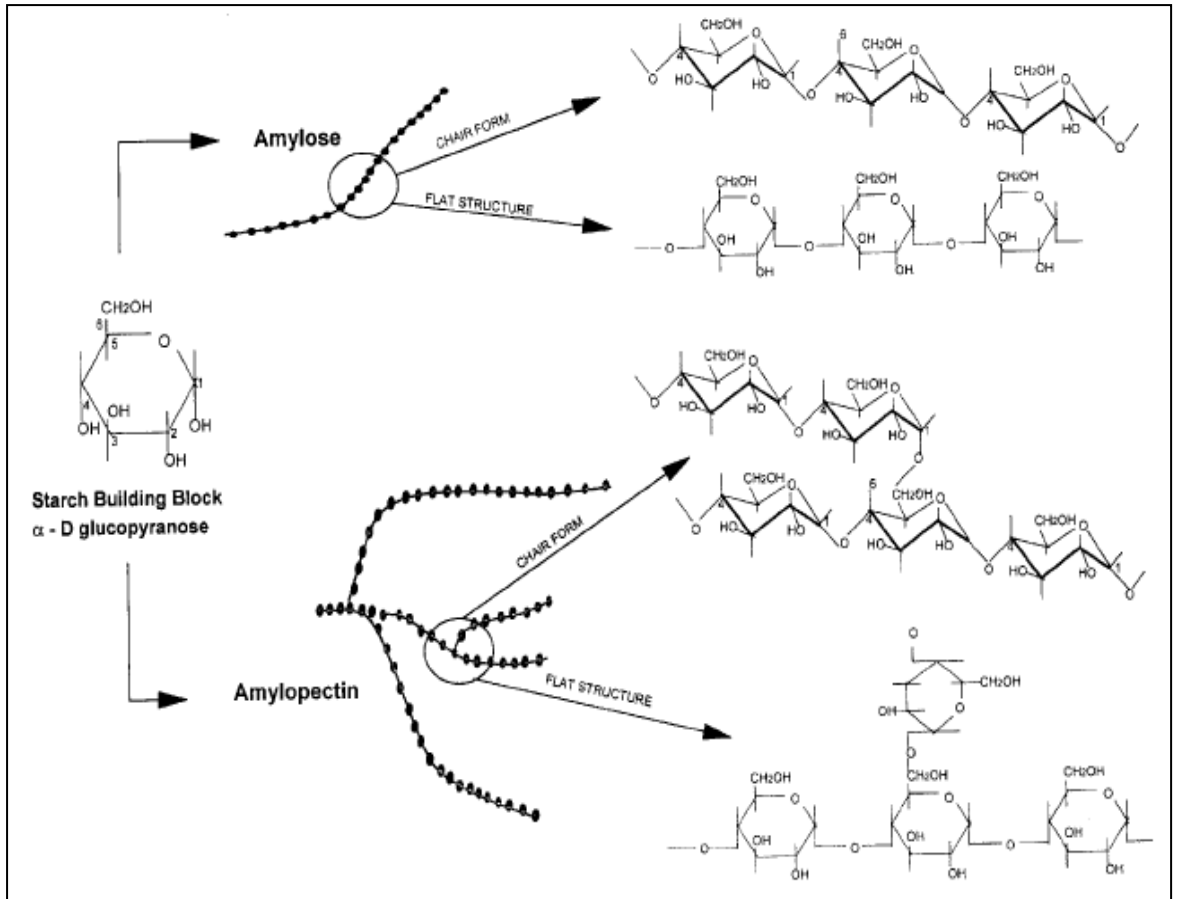


Figure 2.4: A schematic illustration of starch (Murphy, 2000)