ACCUMULATION OF CARBOHYDRATE RESERVE AND ITS COMPOSITION IN OIL PALM TRUNK

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by

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LIST OF SYMBOLS AND ABBREVIATIONS

FV	Final volume
ΔA	Absorbance
A_{max}	leaf photosynthesis rates
α	Alpha linkage
ε	Absorptivity of p-nitrophenol in 1 % trisodium phosphate solution
β	Beta linkage
I	Incubation time (min)
t ha^{-1}	Tonne per hectare
μmol	Micromole
V_e	Extraction volume
V_r	Total volume in the cell tube (mL)
V_S	Volume of sample analyzed
U	Conversion factor from μg to mg (1/1000)
W	Weight in milligrams (mg)
V_r	Total volume in the cell tube (mL)
AD	Air dry weight
ADP	Adenosine diphosphate
AMG	Amyloglucosidase
ANOVA	Analysis of variance
AOAC	Association of official agricultural chemists
ATP	Adenosine triphosphate
CPKO	Crude palm kernel oil
CPO	Crude palm oil
DNA	Deoxyribonucleic acid

EDX	Electron Dispersive X-ray Spectroscopy
EFB	Empty fruit bunch
FELCRA	Federal Land Consolidation and Rehabilitation Authority
FESEM	Field Emission Scanning Electron Microscope
FELDA	Federal Land Development Authority
GC	Gas Chromatography
F	Fiber
HPLC	High Performance Liquid Chromatography
LC	Liquid chromatography
MC	Moisture content
MDF	Medium density fiberboard
MPOB	Malaysian Palm Oil Board
Mx	Metaxylem
NSC	Non-structure carbohydrate
NIFOR	Nigerian Institute of Oil Palm Research
OD	Oven dry weight.
OPA	Oil palm ash
OPT	Oil palm trunk
P	Phloem
PT	Parenchyma tissues
PTFE	Polytetrafluoroethylene
POME	Palm oil mill effluent
PORIM	Palm Oil Research Institute of Malaysia
RISDA	Rubber Industry Smallholders Development Authority
SEM	Scanning Electron Microscope

UV-VIS	Ultraviolet–visible
V	Vessel
VB	Vascular bundle

PENGUMPULAN SIMPANAN KARBOHIDRAT DAN KOMPOSISINYA DI DALAM BATANG KELAPA SAWIT

ABSTRAK

Objektif utama kajian ini ialah untuk mengkaji pengumpulan kandungan simpanan karbohidrat yang juga di kenali sebagai karbohidrat bukan struktur yang terkandung di dalam batang pokok kelapa sawit. Pokok yang di gunakan dalam eksperimen ini telah di bahagi kepada dua kumpulan iaitu pokok yang tidak di buang buah dan pokok di buang buah. Kesan pembuangan buah pada kandungan karbohidrat bukan struktur di dalam pokok kelapa sawit telah dinilai. Dengan mengaitkan kandungan karbohidrat ini dengan kepelbagaian cuaca, ia dapat membantu memahami kesan perubahan cuaca ke atas kandungan karbohidrat bukan struktur. Pokok kelapa sawit menunjukkan kebolehupayaan untuk menyesuaikan kandungan karbohidrat tidak berstrukturnya dengan permintaan semasa dan ketika proses penghasilan buah. Kanji dan gula merupakan komponen utama di dalam karbohidrat bukan struktur. Kajian ke atas taburan topografi dalam batang kelapa sawit menunjukkan kanji merupakan komponen utama yang terkandung di dalam bahagian atas pokok. Kandungan kanji di dalam pokok kelapa sawit muda dan tua telah ditentukan. Hasilnya, pokok kelapa tua mengandungi kanji yang tinggi kerana ia kurang digunakan berbanding dengan pokok muda dengan kandungan purata di antara 2.02% dan 3.93%. Untuk rawatan pembuangan buah, kandungan kanji di dalam batang pokok kelapa sawit adalah lebih tinggi berbanding pokok yang tidak menjalani proses pembuangan buah dan gula menunjukkan kecerunan yang bertentangan. Sukrosa adalah gula utama yang terkandung pada batang kelapa sawit

untuk kedua-dua pokok samada pokok yang tidak di buang buah atau pokok yang di buang buah, diikuti dengan glukosa, fruktosa dan gula yang lain. Di bawah rawatan pembuangan buah juga, kami menjangkakan karbohidrat bukan struktur dalam pokok kelapa sawit akan meningkat dari semasa ke semasa daripada bulan pertama sehingga akhir kajian. Namun, ia tidak menunjukkan sebarang perubahan dalam pengumpulan dari masa ke semasa bermula dari awal hingga akhir masa eksperimen di jalankan. Ketidakstabilan ini disebabkan oleh ketidakseimbangan sumber-simpanan seperti sewaktu pembuahan dan tekanan persekitaran. Kepelbagaian iklim menunjukkan tindakbalas kepada turun naik kandungan karbohidrat bukan struktur dalam batang kelapa sawit. Kandungan karbohidrat bukan struktur di dalam batang kelapa sawit yang di tebang yang telah melalui rawatan pembuangan buah di bawah masa penyimpanan telah di kaji dan pengumpulan jumlah keseluruhan gula telah di dapati meningkat dan pengurangan pada kandungan kanji. Kajian ke atas aktiviti α-amilase activiti dan fungsinya di dalam batang kelapa sawit yang di tebang telah di nilai. Keputusan menunjukkan aktiviti α- amilase wujud dan ia berfungsi untuk memecahkan struktur kanji menjadi gula. Kandungan protein di dalam batang pokok kelapa sawit yang ditebang selepas melalui proses penyimpanan pada hari yang tertentu menunjukkan bacaan rendah pada permulaan eksperimen sebelum ia meningkat naik selepas 15 hari dan menjadi malar selepas itu.

ACCUMULATION OF CARBOHYDRATE RESERVE AND ITS COMPOSITION IN OIL PALM TRUNK

ABSTRACT

This objective of this study was to investigate the accumulation and composition of carbohydrate reserves which is also known as non-structural carbohydrate in the oil palm trees. The experimental trees were divided equally into 2 groups namely non-fruit removal and fruit removal trees. The effect of fruit removal on the non-structural carbohydrate in oil palm trees was assessed. By associating the mechanisms of this reserve to the climate changes, it could help to understand the effects of climate change to the carbohydrate content. Oil palm trees showed an ability to adjust it temporary non-structural carbohydrate to a current demand and during the fruit production. Starch and sugar are the main component of non-structural carbohydrate contained in the oil palm tree. Study on the topological distribution in oil palm trunks showed that the starch was the major component at the top part of the trees. The starch content in the young and old oil palm trees has been determined. As a result, old oil palm tree contains high starch content due to it less utilized compared to young tree with the mean concentration between 2.02% and 3.93%. Under the fruit removal treatment, starch content in the oil palm trees was found higher compared to the non-fruit removal trees while the sugar content showed opposite gradient. Sucrose is a predominant sugar present in the oil palm trunks for both non-fruit removal and fruit removal trees, followed by glucose, fructose and other sugars. Under this fruit removal treatment also, we postulated that the non-structural carbohydrate in oil palm trees will increase from the beginning until the end of the study. As a result, it did not show any changes in accumulation and

remains constant during the experimental periods. This fluctuation may due to the source-sink imbalances periods such as fruit filling and environmental stress. Climate change showed a respond to a fluctuation of non-structural carbohydrate in the oil palm trunks. The non-structural carbohydrate in felled trees from the fruit removal treatment under the storage time has been examined and the accumulation of total sugar was found increase and reduction of starch content. The study of α- amylase activity and it function in the felled trunks has been evaluated. The result showed that the α- amylase activity exist and functional to degrade the starch into sugar. Protein content in the felled trunks after storage days showed to be low at initial days before it increased after 15 days and became constant thereafter.

CHAPTER 1

INTRODUCTION

1.1 General Introduction

In Malaysia, oil palm tree was initially planted as an ornamental plant especially in the early 1920's before it was turned into commercial crops. Within 56 years, the production of palm oil product increased almost 315 times from 94 000 tonne in 1960 to 29.67 million tonnes in 2015. Arising interest on palm oil products in various usages has prompted the expansion of oil palm plantations area from 0.54 million hectares in 1960 to 5.64 million hectares in 2015. As the total acreages under cultivation grew, the massive amount of oil palm biomass also generated every year (Basiron, 2007; Sumathi et al., 2008; Malaysian Palm Oil Board, 2015). In 2014, almost 96 million tonne of oil palm solid biomass had been produced from oil palm plantation and expecting more in the future. The largest part was coming from fronds about 50.7 million tonnes, 38.48 million tonnes from oil palm trunk and the rest is from empty fruit bunch (Astimar, 2015).

Oil palm tree is flowering plants from a species of monocotyledons. This tropical plant came from the Palmae family where it grows to be solitary cylindrical trunk (Corley and Tinker, 2003). The oil palm species is considered to be a non-wood tree. The stem tree essentially consists of the vascular bundle, fibrous phloem sheaths and an abundant amount of ground parenchyma tissue (Husin, 2000). This ground parenchyma function as assimilating tissues to reserve the photosynthesis product and present in the mass amount to make it bulk and fulfil the structure of oil palm trunk (Pruyn and Spicer, 2001). Observation by Tomlinson (2011) shows the ground parenchyma cells consist of a mainly thin layer of spherical cell walled. The walls of these parenchyma cells are gently dark and thicker from inner to the outer region. In this part, non-structural carbohydrate reserves could be revealed in abundantly.

Non-structural carbohydrate is an organic substance formulated from carbon, hydrogen and oxygen giving a structure of $(CH_2OH)_n$ where it produced from the photosynthesis process. Non-structural carbohydrate also can be referred as an accumulation of compound excess energy from metabolism and growth process before it is converted into storage carbohydrate (Scott, 2008). Non-structural carbohydrate in the tree can be fractionated into several functions. The largest portion was consumed for oxidation in the respiration process. In this process, energy was release for reconstruction of a new cell of protoplasm and cell wall in the plant tissues which is known as assimilation. Another usage of non-structural carbohydrate is to supply the energy for the metabolic process at night when photosynthesis did not occur and dependent on storage reserves produced during the day (Kozlowski et al., 2012). Non-structural carbohydrate reserves also play a several implications to a physiological and biochemical processes in the trees especially during the fluctuation time due to productivity and reproduction of fruit and environmental stress (Newell et al., 2002; Legros et al., 2009*a*). At this period, the internal demand is very high, and carbohydrate reserves function in supplying energy in the form of carbon sources to fulfil the imbalance need (Kozlowski, 1992; Silpi et al., 2007).

Accumulation non-structural carbohydrate reserve in plant tree is defined as a difference between the amount of product produced by photosynthesis and amount of this product used for a survival of the tree (Kozlowski et al., 2012). Accumulation of non-structural carbohydrate is not consistence, and it depends on the external and internal factors (Nguyen et al., 1990; Ackermann et al., 1992; Chomba et al., 1993;

Clair-Maczulajtys et al., 1994). Accumulation of non-structural carbohydrate occurs in various organs and tissues of the plant cells. Leaves, trunk and roots contain a relatively high concentration of non-structural carbohydrate depending on the living cells exist. However this accumulation of non-structural carbohydrate is not affected by the length of photosynthesis periods (Pallardy, 2010). It has been proved by a study on the soybean plant (Glycine max) that the accumulation of non-structural carbohydrate is related to the energy demand. Heavy consumption of non-structural carbohydrate for assimilation, flowering, development and production of fruit cause the declining of this reserves level and rising back after removal of this sink (Hopkins and Hüner, 1995; Henson et al., 1999).

1.2 Research background

Non-structural carbohydrate accumulates abundantly in the starch form along the tree before it is being converted into soluble sugar of sucrose and transported to non-photosynthetic tissue (Hopkins and Hüner, 1995). An earlier study by Henson et al. (1999) was recorded about 24 % of starch presence in oil palm trunks. Starch existed in granule form and located fairly high in parenchyma tissues of the trunks. Prawitwong et al. (2012) made a comprehensive study of the separated oil palm starch in the parenchyma and vascular bundle. The starch content in parenchyma tissue is much higher than in the vascular bundle which is about 46.7 % and 0.08 %. Starch content obtained from this study also has successfully been utilized in bioethanol production using the fermentation technique.

Apart from starch, sucrose is also a non-structural carbohydrate that exists in the liquid form. In the oil palm trunks, sucrose can easily obtain by extracting this liquid sap from the trunk. This sap is beneficially use in many proposes where it has been proven by many scientists. Owolarafe et al. (2007) reported that oil palm sap containing about 10 - 12 % sugar and through a fermentation process. The sap is used extensively in the medicine field, bio-fuel industry and daily consumed for cooking and beverages. Fresh sap has a sweet taste caused by the sucrose content where it tends to hydrolyze into glucose. In the meantime, sap can be easily converted into alcohol after long exposure at ambient temperature due to the natural fermentation process and it very useful in the production of bioethanol as a renewable green energy. Kosugi et al. (2010) finding has confirmed that the extracted sap in the central region of oil palm trunks contain high concentration amount of sugar content which is about 8.69 % and have a potential to be used as a raw material in for the production of fuel ethanol and lactic acid. An extensive study by Lokesh et al. (2012) has reported that exploitation on extracted sap from oil palm trunk is efficient to be utilized as an inexpensive promising source in polyhydroxyalkanoate production.

Thus, further research on oil palm biomass as a feedstock for the second generation in bioethanol production should be emphasized. High sugar and starch content in oil palm trunks that can be converted into glucose is a major factor that drives this purpose. Sugars are the main source used in the bioethanol production. There are two steps involved during the bioethanol process; i) sugar fermentation (transforming sugar into ethanol) and ii) saccharification of starch which is can be described as a starch converted into sugar followed by hydrolysis process to obtain sugar (Chew and Bhatia, 2008). Sugar cane juice and beet molasses are the major feedstock used in the bioethanol production. However, these two sources are also a major source in the food industry. Therefore, new initiatives should be taken to find other alternatives way for bioethanol production from non-food plant source (Balat et al., 2008).

Production of biodiesel derived from crude palm oil (CPO) and crude palm kernel oil (CPKO) have been widely commercialized in Malaysia since 1996. By converting these oil palm trunk biomasses into methyl ester gives almost similar properties as petroleum diesel (Sumathi et al., 2008). In 2008, Malaysia was produced about 500, 000 tonnes of biofuel generated from oil palm residue. These numbers were expected to increase consistently due to rising in a cost of fossil fuel as supply lessens (Mekhilef et al., 2011).

1.3 Problem statement

A tremendous expansion of oil palm industry has produced a huge amount of oil palm biomass during the replanting and processing activity in the form of solid and liquid waste. This routine was also led to the major disposal problem. Oil palm tree already reached the high proportion of standing biomass at the age of 10 years old which is estimated about 50 % from the upper ground. It was estimated about 75 % of solid biomass as fronds and trunks are available on the plantations after replanting and harvesting. Another 25 % solid waste is generated in the palm mills during the processing and extraction, remaining empty fruit bunch (EFB), mesocarp fiber, shell and palm oil mill effluent (POME) in the form of liquid waste (Lee and Ofori-Boateng, 2013). The advantages of oil palm biomass are its versatility which consists of fiber and cellulose rich that makes every part of the oil palm can be utilized into new products (Khalil et al., 2010). Through the National Biomass Strategy 2020, government in collaboration with industry has developed a reliable method to treat the solid and effluent waste from plantation and mill to mitigate pollution (Malaysia, 2011). Numerous studies on the utilization of oil palm biomass have been conducted to reduce the effect of pollution on the environment (Chin et al., 2010; Tanweer et al., 2011; Prawitwong et al., 2012). Potential of oil palm trunks as a renewable source for the production of bio-based product has been envisaged by many scientists (Yamada et al., 2010; Prawitwong et al., 2012; Zahari 2012). However, the challenges encountered are the product yield, and efficiency production of bio-based product depends on the optimal carbohydrate content in the oil palm tree.

Apart from its heavy weight and large size, oil palm trunks contain high moisture content compared to wood (Yamada et al., 2010). High moisture content in oil palm trunks is major problems happen during the production in the industry especially when it involved to the high transportation costs due to its size and weight. High energy required for drying process which is resulted in a limitation of usages oil palm trunk in the lumber industry. Besides, the high moisture content also causes a slow drying process, and it leads to incidence pests or fungus on the trunks before the trunk even dry. One of the methods that have been adopted to solve this problem is the exploitation of the moisture content in oil palm trunk for other use. Moisture content also known as sap can be up to 70 - 80 % based on total mass of the tree (Murata et al., 2013). Yamada et al. (2010) studied the accumulation of sugar and starch in the felled trunks oil palm trunk indicates that high accumulation of sugar can be obtained with appropriate storage time. This hypothesis has been successfully proven with the increasing about 8.3 % of total sugar in fresh trunks to 15.3 % while starch content decreased from 3.5 % to 0.5 % of 30 days storage. This technique successfully increases the sugar content of sap while the starch content in the trunk continues to decrease. However, it is only applicable to destructive samples by means of felled trunks and not on the living tree.

Non-structural carbohydrate content in plant tree fluctuates, and it depends on many factors such as seasonal variation, environmental stress, growth and physiological process (Gupta and Kaur, 2000). Extensive studies have been conducted by Mialet-Serra et al. (2010) channelling on the accumulation of sugars and starch in a coconut tree. The coconut tree and oil palm tree came from the same family which is both have the same taxonomy. They found that the starch pool is located at the top part of the oil palm tree. During the climate changes, the non-structural carbohydrates were also changes to accommodate the whole plant system. At this condition, starch at the trunk top was degraded into simple sugar and used up for the physiological process of the tree (Tester et al., 2004). The non-structural carbohydrate content in the oil palm trunk is very sensitive to the climate changes. Little is known about the physiological function and mobilisation of non-structural carbohydrate reserves in the oil palm tree during the climate changes. Adjustment the source – sink imbalance during this condition is still not completely understood. Thus, in this study, we were interested to know the topological distribution of non-structural carbohydrate especially starch in oil palm tree and interaction of climate changes on this reserve. Secondly, to understand the mechanism of accumulation and the adjustment of source-sink in the oil palm and respond the artificial treatment (fruit removal) on the oil palm tree.

1.4 Objectives of the studies

The objectives of this study are to develop a simple and comprehensive method in order to maximize the accumulation of non-structural carbohydrate reserve in the oil palm trunk naturally. We also consider various factors that are affecting the source-sink relationship. Thus, we investigated the following parameters that are included in this research work:

1. To study the accumulation of non-structural carbohydrate within the experimental tree by fruit removal treatment on the standing oil palm tree.
2. To investigate the trend of non-structural carbohydrate, enzyme activities and protein content in felled oil palm trunk after certain periodical storage.
3. To evaluate the effect of climate changes on the non-structural carbohydrate content in oil palm trunk.
4. To investigate the distribution of non-structural carbohydrate within the oil palm trunk based on topological distribution and age.

1.5 Research hypothesis

Non-structural carbohydrate in the form of sugar and starch are the main product from photosynthesis process. It acts as a transitory carbon reserve with the function as a buffer to support the fluctuation, especially during the high demand period. There are many factors that can stimulate the source-sink imbalance that may lead to the reducing of non-structural carbohydrate level. These factors include the fruit filling period, environmental stress such as drought and the morphological structure of the plant itself. Thus, a study on the mechanism of accumulation non-structural carbohydrate content related to above factors is crucial to approach our aim to enhance the non-structural carbohydrate concentration naturally. The hypothesis of this study:

1. Complete and continuously fruit removal treatment can improve the accumulation of non-structural carbohydrate in the oil palm trunks.
2. Accumulation of non-structural carbohydrate in the oil palm trunk varies depending on the height and climate change.
3. We postulate the accumulation of non-structural carbohydrate occur at the top part of the tree as it is close to the source-sink.

1.6 Significant of the studies

This study is significantly important to understand the mechanism of accumulation of non-structural carbohydrate reserve in oil palm trunk. Information of this study could be used to establish the method to optimize the level of non-structural carbohydrate content naturally. This research work may contribute to the development of scientific knowledge of physiological study specifically for oil palm tree (*Elaeis guineensis Jacq*.). Modification of non-structural carbohydrate reserves in oil palm trunk shows a potential to be utilized for renewable energy especially as a feedstock for in bioethanol production.

CHAPTER 2

LITERITER REVIEW

2.1 The oil palm (*Elaeis guineensis Jacq.*)

2.1.1 Origin of oil palm

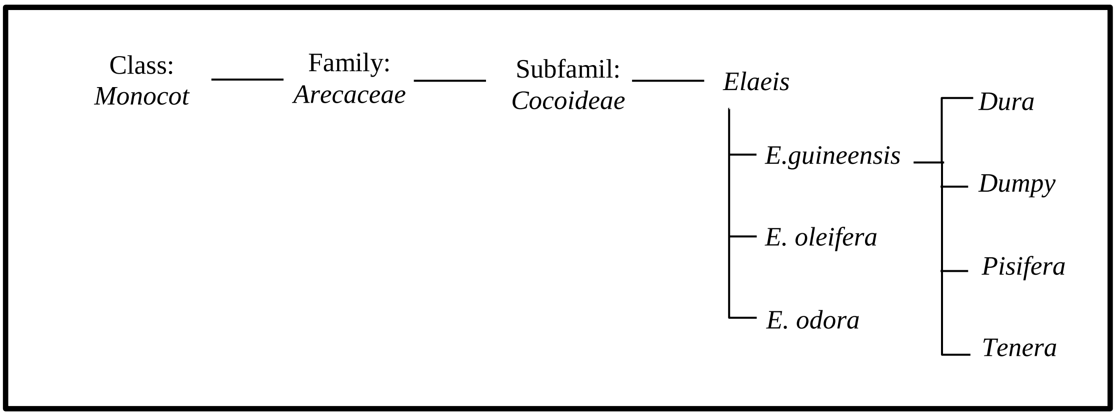
Oil palm (*Elaeis guineensis Jacq.*) is a tropical plant which is coming from the *Arecaceae* family (Fig. 2.1). The name was taken from a Greek word *elaion*, meaning oil (Corley and Tinker, 2003). *Elaeis guineensis Jacq.* was recognized as the first species of genus *Elaeis* followed by *Elaeis Oleifera* and *Elaeis Odora*. All of these species are distinguished by their morphological properties (Tomlinson et al., 2011). Corley and Tinker (2003) found that the classification of the varieties is related to an anatomy of the palm fruit.

Source: Photo taken by Zubaidah Aimi Abdul Hamid (2015).

Fig. 2.1 The oil palm tree (*Elaeis guineensis Jacq*).

Oil palm trees were firstly discovered by local people, and it remains as a domestic plant for centuries. It is quite complicated to allocate the natural habitat of the palm tree. The palm does not commonly grow wild in the forest, but it flourishes in the land that human start to plant it as a crop and use it commercially. The extracted oil from the fruit produces two different types of oil; the pericarp and kernel oil and later it been used as cooking oil by local (Rajanaidu et al., 2000). Owolarafe et al., (2007) indicate that oil palm fruit are distinguished by the thickness of the seed coat with the average fresh component of 62 - 63 % mesocarp, 30 % shell and 7 - 8 % for a kernel.

In Malaysia, oil palm was introduced as an ornamental plant in 1875 before it turns into a commercial crop because of its edible oil. Oil palm in Malaysia began when four seedlings from progeny Dura brought from Botanical Gardens, Bogor in Java were planted in Deli, Sumatra in between 1853 - 1856 and later into Rantau Panjang, Malaysia in 1911 - 1912. The first plantation in Tenmnamaran and Elmina estate, Selangor, Malaysia was opened in 1917 using the Deli seed from Sumatera (Latiff, 2000; Lai et al., 2015). From that point, oil palm industry gain rapidly and contribute to economic growth. Many programs have been developed to improve the quality of the breeding population. The early exchange breeding program was started in 1970, collaborated with Palm Oil Research Institute of Malaysia (PORIM) (now known as the Malaysian Palm Oil Board, MPOB) and Nigerian Institute of Oil Palm Research (NIFOR) in Nigeria (Corley and Tinker, 2003). Through this program, the detailed information on genetic variation from all oil palm breed was collected, and Malaysian successfully established the most comprehensive collection on palm breeding at the different region in Africa and Latin America. The research was emphasized on selecting breeds having a short stem, resistance to disease, high yield of fruit, high oil and kernel content. Four main parents under *Elaeis Guineensis* was chosen based on fruit characteristic namely Dura, Dumpy, Tenera, and Pisifera. Crossed among these chosen main parents were made to produce a satisfaction outcome (Kushairi and Rajanaidu, 2000). Fig. 2.2 shows the lineage of oil palm genus *Elaeis*.

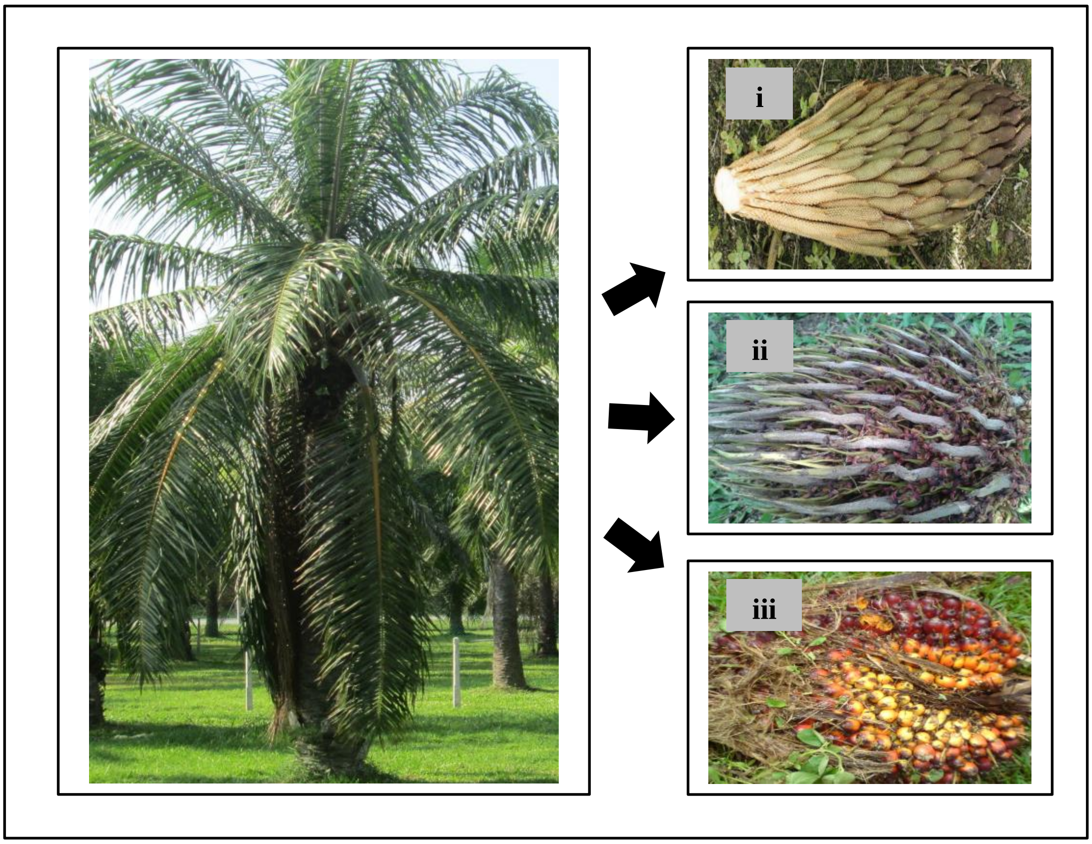


Source: Modified from Latiff (2000).

Fig. 2.2 Lineage of oil palm genus *Elaeis*.

2.1.2 Morphology of oil palm trunks

Oil palm trees are flowering plants where male and female inflorescences flowers grow together in a tree. The leaves have short internode with the linear pinnate arrangement. Fruits and flowers produced in the form of the bunch. The fruit is drupe, and when it ripe, the color will change to reddish and it rich in oil (Fig. 2.3). Different layers of the fruit will produce various types of oils (Lai et al., 2015).



Source: Photo taken by Zubaidah Aimi Abdul Hamid (2015).

Fig. 2.3 Oil palm trees with inflorescences and fruit. (i) Male inflorescences. (ii) Female inflorescences. (iii) Ripe fruit bunch.

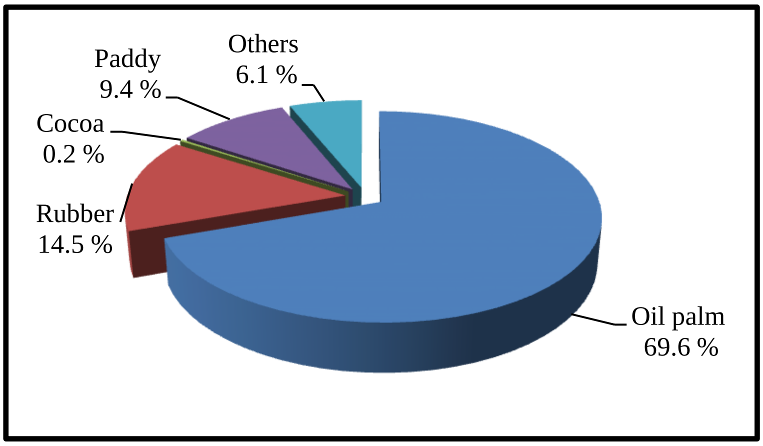
Under the unfavorable condition of low temperature and insufficient sunlight exposure, expansion of trunks and leaves is very slow. The growth of trees will depend on the carbohydrate produced during photosynthesis process which performed inside the chloroplast in the leaves. At the age of 9 – 25 years, the oil palm trees have reached a mature phase (Papong et al., 2010). The height of the tree will indicate the age and for the oil palm tree, logging will take place when the tree reaches an average height of more than 10 m usually after 25 years onward. The elongation rate of the trunk is varying, and it depends on environmental and genetics factors (Corley and Tinker, 2003).

2.1.3 Development of oil palm plantation and industry in Malaysia

Starting from 400 hectares in 1920, the number of new oil palm planted area has dramatically increased up to 54 000 hectares in 1960 (Basiron, 2000). During this time, rubber is still the main crop, but the major problem faced by rubber industry is the low level of productivity and rubber supply is inconsistent. The old and uneconomical rubber trees need to be replaced and the process took a long time and required a high cost. Synthetic rubber was used as substitute natural rubber also caused rubber prices to fall. Rubber wood farmers began to shift their crops toward oil palm for better returns (Fuad et al., 1999).

The potential and suitability of oil palm in oil and fats industry have increased its demand. Encouragement from the government agency has led to the cultivation of oil palm tree on a large scale. The Federal Land Development Authority (FELDA) was established to explore new lands for large plantation of oil palm (Corley and Tinker, 2003).

Currently, palm oil is the dominant agricultural sector in Malaysia. It is now second largest producer after Indonesia. Malaysia plants more than 5.64 million hectares of the 32.86 million hectares of total land area for oil palm cultivation. Around 83.08 % from oil palm plantation was managing by large estate while the rest was managed under smallholder schemes (Department of Statistics Malaysia, 2013; Malaysian Palm Oil Board, 2015). Fig. 2.4 summaries land used for selected crops in Malaysia.



Source: Department of Statistics Malaysia, 2013

Fig. 2.4 Land used for selected crops in Malaysia.

The palm oil industry in Malaysia has entered the mature phase. Expansion of new lands for oil palm plantation starts to slow down to balance the needs of development and conservation biodiversity. Establishment of agro-based government agencies such as Federal Land Development Agency (FELDA), Federal Land Consolidation and Rehabilitation Authority (FELCRA), Palm Oil Research Institute of Malaysia (PORIM) and Rubber Industry Smallholders Development Authority (RISDA) and private agencies such as Sime Darby and GUTHRIE had successfully improve the quality and enhance quantity of oil palm into a higher level (Ministry of Plantation Industries and Commodities, 2013).

2.1.4 Oil palm trunks as a biomass

Oil palm trunks biomass was created throughout the harvesting and processing activities. Oil palm tree typically is removed from production depending on the economically harvestable height and low-productivity of oil palm fruits. Oil is the main commercial product of the oil palm tree. However, it just contains 10 %

from the total oil palm tree while the rest is remaining as a residue (Husin, 2000; Lim et al., 1997). Currently, oil palms become the important source of consumer goods such as for the production of soap, margarine, candles, lubricant for machinery and industrial processes (Corley and Tinker, 2003). Traditionally, during harvesting activities, the old and rejected tree was chopped down before it being burned on the plantation to reduce the volume or relinquish on the ground as a natural fertilizer. However, this activity will cause significant losses of organic material and contribute to an environment problem such air and underground water pollution (Suhaimi and Ong, 2001).

Biomass in term of lignocellulose material is defined as an organic material obtains from plant crop. (Sumathi et al., 2008). Exploitation of this biomass as an alternative material in the non-wood industry has to expand progressively in this recent year. However, utilization of this biomass as whole only a small portion from the total biomass amount. From this small portion of biomass, it has been widely used in the manufacture of medium density fiberboard (MDF) and plywood as a based material for construction although its use is not yet widespread (Sulaiman et al., 2008; Shinoj et al., 2011). Recently, a new invention of this biomass in a production of a binderless board without using any resin has been developed. This green product shows a suitability to be used for internal purposes (Hashim et al., 2011; Hashim et al., 2010). Furthermore, oil palm fiber also been used as automobile absorption in air conditioning system (Abdullah et al., 2011), papermaking (Daud, 2010), food packaging (Ng et al., 2012) and activated carbon to treat toxic waste (Hameed et al., 2008).

2.2 Carbohydrate in oil palm trunks

2.2.1 Photosynthesis and its product

Photosynthesis is the process involving the reaction between water and carbon dioxide in the presence of sunlight. This process takes place in the chloroplast-containing green pigment of chlorophyll which it plays a significant role by absorbing the light energy and converted it into chemical energy in the formed of carbohydrate (Wu et al., 2006). The basic reaction can be summarized as:

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} C_6H_{12}O_6 + 6O_2 + 6H_2O \quad (2.1)$$

Source: Kozlowski et al., 2012.

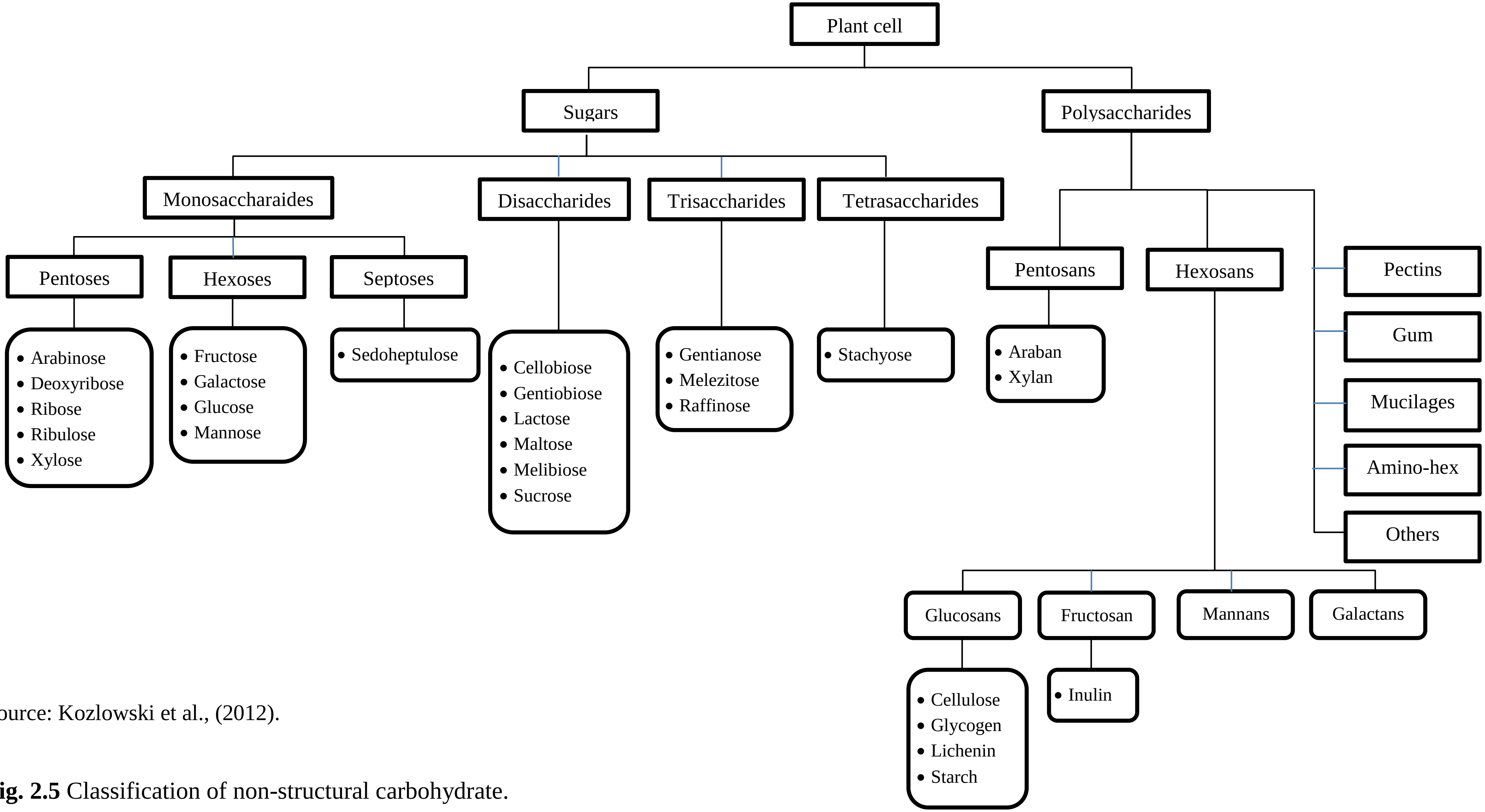
A carbohydrate is a major source of natural energy reserved in the most of the plant trees (Hopkins and Hüner, 1995). Interaction among environmental, hereditary and plant is the primary factor that influences the rate of photosynthesis. The rate of photosynthesis is used to determine the index of the growth potential of the tree which indirectly dependent on the carbohydrate content and accumulation of this reserve. Carbohydrate was made up from carbon (C), hydrogen (H) and oxygen (O) with ratios two hydrogen for every oxygen atom. As a poly-hydroxyl compound, carbohydrates can be classified into aldehyde or ketone group depending on the arrangement, number and chiral handedness of carbon atoms to the hydroxyl group (Scott, 2008). Accumulation of carbohydrate produced in photosynthesis process may be faster than the rate of being assimilated which is used for respiration and translocation out of leaves. Sometimes under certain condition rate of photosynthesis can be reduced and resulted reduction in the accumulation of carbohydrate such as low accumulation in the afternoon compared to the morning. This might explains the water deficit can affect the rate of photosynthesis.

Carbohydrate can be divided into two main category namely non-structural carbohydrate and structural carbohydrate. Non-structural carbohydrate is a term often used to describe the reserve carbohydrate in the plant which is readily degraded either by water, chemical or enzymatic hydrolysis. It also serves as a temporary storage reserves and functional as energy reserves to sustain the survival of living tree. Structural carbohydrate is also a product of photosynthesis with insoluble and high resistance properties to both organic solvent and enzymatic degradation. These notable features make it enable to form a structure for a woody plant. Cellulose is an example of structural carbohydrate (Pallardy, 2010).

2.2.2 Non-structural carbohydrate

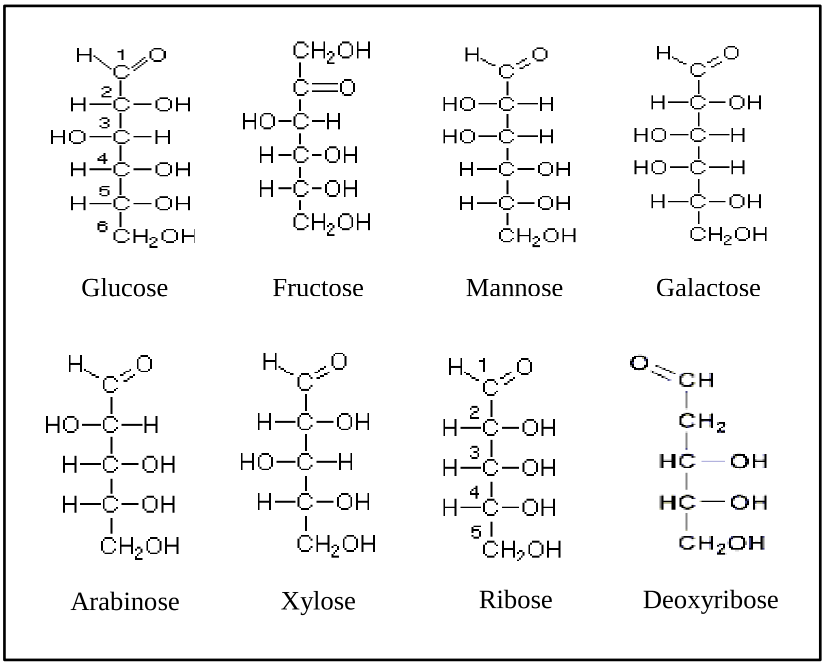
2.2.2(a) Classification of Non-structural carbohydrate

Non-structural carbohydrate can be divided into three main classes namely monosaccharide, oligosaccharide, and polysaccharides. Fig. 2.5 shows classification of non-structural carbohydrate. A monosaccharide is a single sugar and a basic building block of other sugar chains such as disaccharides, trisaccharides, tetrasaccharides, and polysaccharides. It can easily be identified by referring to the attached hydrogen atoms to carbon atoms either aldehyde (RCHO) or ketone (RCOR). The number of carbon atom contain in the structure is varies with the most common atom of pentose ($C_5H_{10}O_5$) and hexoses ($C_6H_{12}O_6$) occur in nature (Kozlowski et al., 2012). Fig. 2.6 illustrated the structure of monosaccharides.



Source: Kozlowski et al., (2012).

Fig. 2.5 Classification of non-structural carbohydrate.



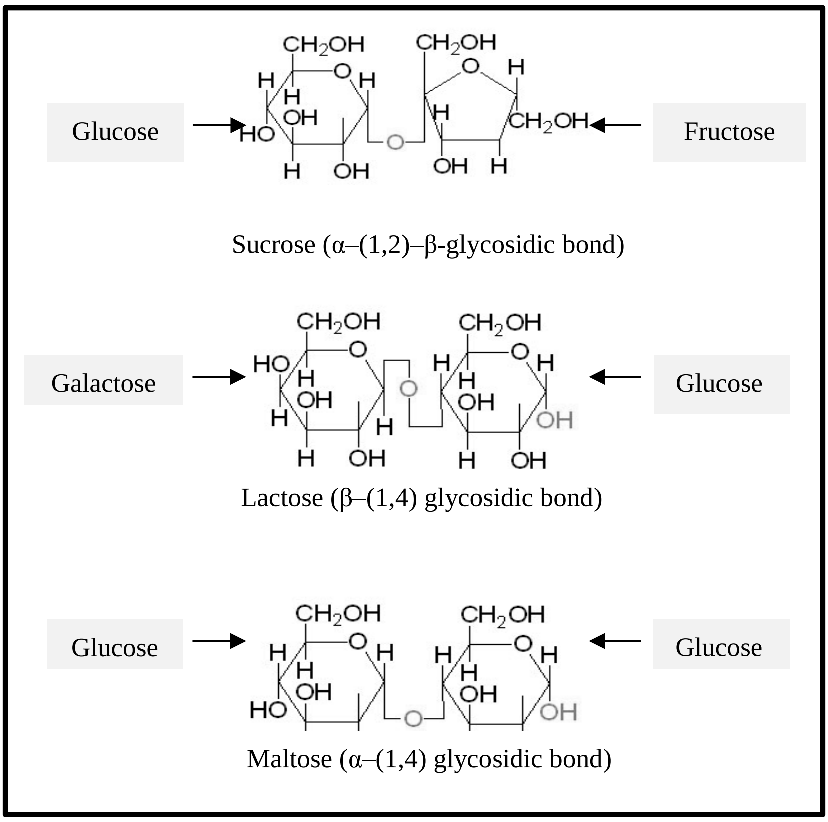
Source: Kozlowski et al., (2012).

Fig. 2.6 Structure of monosaccharides.

Hexoses sugar such as glucose and fructose is important during the early stage of the metabolic or beginning substrate for respiration process in the plant trees. Glucose is a basic unit of cellulose and starch and found abundance in every living cell. Other hexoses sugars like galactose and mannose occurred during germination of seed by degradations of their polymeric linkage of galactan and mannans. The pentose sugars like arabinose and xylose are the important component in hemicellulose which presents in a polymeric form of arabans and xylans. It plays a vital role in the constituent of a cell wall in the plant trees. Ribose also is a common in pentose sugars that are translocated in the part of ribonucleic acid while deoxyribose exists in nucleotides as long chain that constituent of deoxyribonucleic acid (DNA) in the plant tissue (Scott, 2008).

Disaccharides consist of at exactly two monosaccharides sugars link together by the glycosidic bond to form di-, tri-and tetra. The structural of disaccharides is shown in Fig. 2.7. Sucrose is a one of the important disaccharides sugar where it can be found abundantly in the higher part of the plant. It functions as a primary transport carbohydrate reserves by translocating the concentrated solute through the phloem. Hydrolysis of this non-reducing sugar yields a fructose and glucose. Other disaccharides sugars are a maltose where it is widely distributed in the plant but seldom present (Balat et al., 2008). It is produced by the action of amylase enzyme on starch and a primary product of starch hydrolysis. Hydrolysis of maltose release two monosaccharides of glucose linked through α-(1-4) o-glycosyl bond (Kozlowski et al., 2012).

The disaccharides cellobiose is a reducing sugar produced from hydrolytic of cellulose consisting two glucose linked together by β - (1-4) o-glycosyl bond. Contrasting from mannose, this sugar is produced from cleaved cellulose chain by the action of cellulase enzyme. Trehalose, another non-reducing sugar formed by a two glucose unit linked in α-(1-1) oxygen ether bond. It provides a protection against freezing, desiccation and heat stress (Kozlowski et al., 2012). A study by Schluepmann et al. (2003) suggested manipulation on that trehalose metabolism may result to enhance the photosynthesis and the storage reserve in the plant as well.



Sucrose (α–(1,2)–β-glycosidic bond)

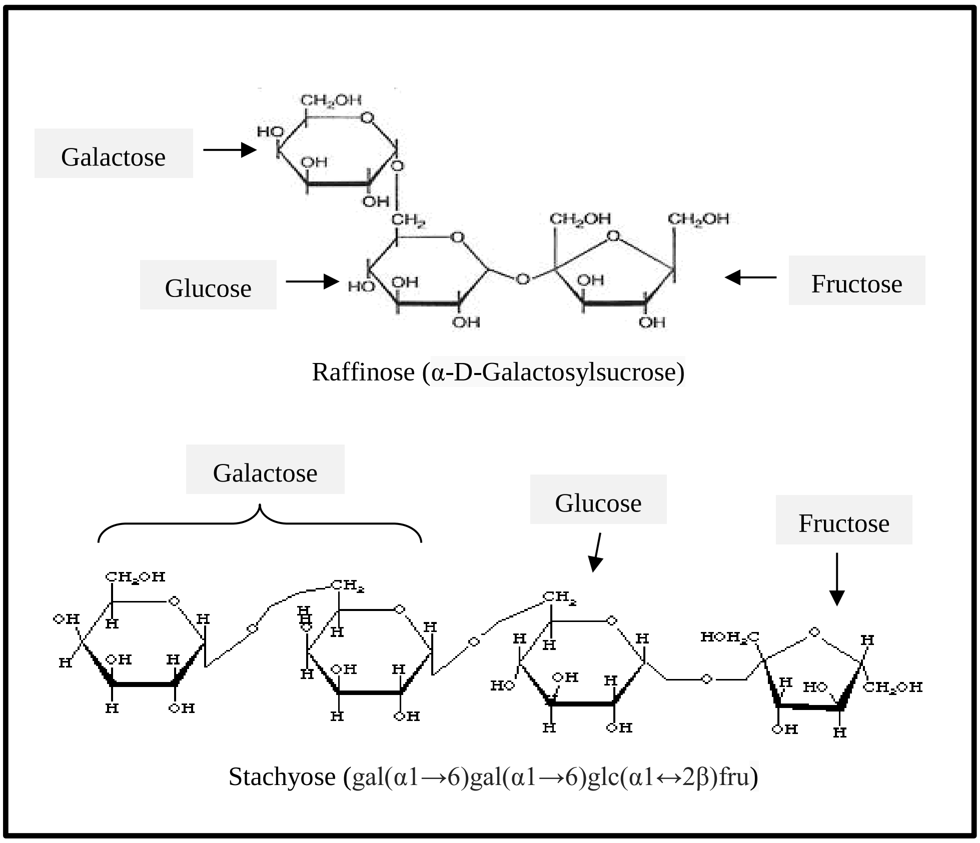
Lactose (β–(1,4) glycosidic bond)

Maltose (α–(1,4) glycosidic bond)

Source: Kozlowski et al., (2012).

Fig. 2.7 Structure of disaccharides

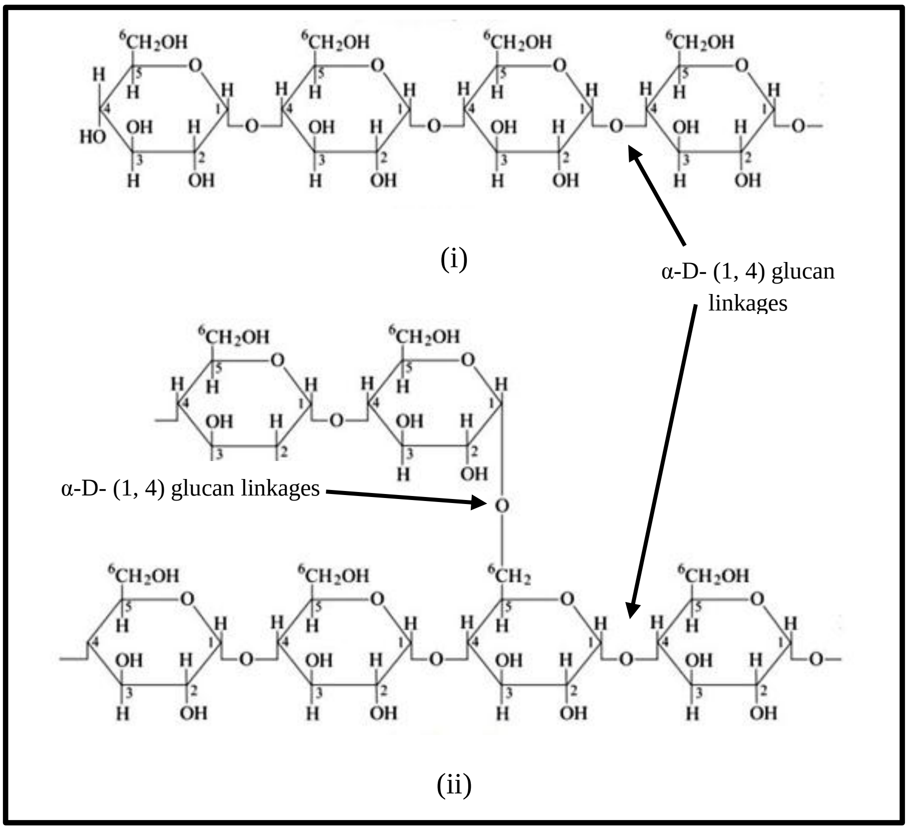
Apart from disaccharides, a small number of trisaccharides raffinose, tetrasaccharides stachyose, and many more sugars are also found in the phloem of some plants and has an important role to ensure sustainability of plant life. The structure of raffinose and stachyose are shown in Fig. 2.8.



Source: Kozlowski et al., (2012).

Fig. 2.8 Structure of trisaccharides raffinose and tetrasaccharides stachyose.

Polysaccharides are the complex mixture of linear or branched long chains of a polymer formed by three or more basic unit of monosaccharide bonded through glycosidic linkage. One of the most common polysaccharides that can be found in the plant is a starch. It exists abundantly and serves as a temporary storage carbohydrate. Unlike cellulose, starch was developed from numerous amount of glucose molecule are joined by α – linkage to formed long and regularly in spiraled chain. Present in the grains form, starch cannot pass through the cell to cell and it must be synthesized by hydrolysis process in the tissues in which it is found. Normally the mature starch is insoluble in water because of it was coated with a layer of lipid. Thus, degrading the starch into solute of glucose needs aid of enzyme and once it degraded, it can be used directly in metabolic and growth process of the tree (Tester et al., 2004). Fig. 2.9 described the structure of starch.



Source: Tester et al. (2004).

Fig. 2.9 The structure of starch linkages. (i) Amylose. (ii) Amylopectin.

As a main product in the plant, starch accumulated in the living tissues of parenchyma cells and stored in the grain form. Starch is a homopolymer composed of two types of polymers, namely amylose and amylopectin. Amylopectin is a most abundant component in a starch structure which consists about 95 % of the total starch content. It is build up from the basic unit of glucose bonded together by α-D- (1, 4) glucan linkages giving the high branches chain. It is different with amylose, where it is derived from α-D- (1, 4) glucan chain with a 4 to 6 % of α-D- (1, 6) glucan linkages from total starch contain and giving the linear form to a chain