Khalid Rehman Hakeem
Mohammad Jawaid
Umer Rashid *Editors*

Biomass and Bioenergy

Processing and Properties

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Foreword

The present volume is a well-written account of highly important aspects of Biomass and Bioenergy. The book comprises of 20 chapters from distinguished scientists/researchers around the tropics, reporting the diversity of untapped biomass resources and their value added as a bio-based feedstock in a sustainable economy. This book eloquently highlighted the usefulness of biomass residues that are mostly known in the tropical world. By doing so, the present volume achieved one of the very important objectives of a book, which is to reach out to a large community comprising of academic, industrial, and social-economic experts. This distinct nature of the contribution of numerous authors from their own community based biomass resources made this book unique and one-of-a-kind.

The editors have noticed the gap existed in the systematic reporting of tropical biomass and agricultural residues in the production of potential materials and made a very compelling case in editing this book with 20 chapters. In this book, the inclusion of a broad range of bast fibers, for example, Kapok, pine apple leaf, Indian date fiber, mainly existing in tropics with untapped potential of vast and wide range value-addition in an energy-intensive world makes perfect sense.

Last but not the least, the importance of the book as a collective knowledge of many coauthors is a result of their collaboration with editors and the publisher. Fully committed to rural and local economic development in the greater part of the globe, the editors and authors are fully devoted to providing their readers a rich knowledge of rural and tropical biomass residue solutions.

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Preface

Since the early times of human civilizations, biomass has been a major source of energy for the world's people. Biomass energy or bioenergy, the energy from organic matter, is being used by human beings since thousands of years, ever since people started burning wood to cook food or to keep warm. Today still non-wood, forest residues, and agricultural biomass are our largest biomass resources. Biomass includes plants, residues from agriculture or forestry materials. So, the proper utilization of biomass can be environmentally friendly because, it will not only be able to solve the disposal problem but also can create value-added products from this biomass. It is also a renewable resource because plants to make biomass can be grown over and over and certainly as alternative source of energy. The use of agricultural biomass is constantly growing and will likely to continue to grow in future. It is estimated that utilization of biomass can also reduce global warming compared to fossil fuel. Energy crops, such as fast-growing trees and grasses, are called *biomass feedstocks*. The use of biomass feedstocks can also help to increase profits for the agricultural based industries.

Biomass obtained from agricultural residues or forest can be used to produce different materials and bioenergy required in a modern society. As compared to other resources available, biomass is one of the most common and widespread resources in the world. Thus, biomass has the potential to provide a renewable energy source, both locally and across large areas of the world. It is estimated that the total investment in the biomass sector will reach up to $104 billion from 2008 to 2021. Presently bioenergy is the most important renewable energy option and will remain so in the near and medium-term future. Previously several countries try to explore utilization of biomass in bioenergy and polymer composite sector. Biomass has the potential to become the world's largest and most sustainable energy source and will be very much in demand. Bioenergy is based on resources that can be utilized on a sustainable basis all around the world and can thus serve as an effective option for the provision of energy services. In addition, the benefits accrued go beyond energy provision, creating unique opportunities for regional development.

The present book "Biomass and Bioenergy," volume 1, provides an up-to-date account of processing and properties of non-wood, forest residues, agricultural biomass (natural fibers) and its composites and bioenergy to ensure biomass utilization and reuse.

We wish to express our gratitude to all the contributors from all over the world for readily accepting our invitations and sharing their knowledge and expertise. We are thankful to authors for helping us to formulate diverse fields and also admirably integrating their scattered information from diverse fields in composing the chapters and enduring editorial suggestions to finally produce this venture that we hope will be a success. We greatly appreciate their commitment.

We are highly thankful to Springer-Verlag team for their unstinted cooperation at every stage of the book production.

Selangor, Malaysia

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Dr. Umer Rashid, Ph.D. is working as a Senior Fellow Researcher at Universiti Putra Malaysia, Malaysia since 2011. He has obtained his M.S. in Chemistry in 2003, from the University of Agriculture, Faisalabad, Pakistan and then completed his Ph.D. degree also from the University of Agriculture, Faisalabad, Pakistan in 2009 in the field of Analytical Chemistry. During his Ph.D. he worked as a Visiting Scientist in the Food and Industrial Oil Research Group at the USDA in Peoria, IL, USA. He is also the recipient of 2007 The Industrial Oil Products Division Student Excellence Award by Industrial Oil Products Division of the American Oil Chemist's Society (AOCS), USA. He completed his Post Doctorate in the field of Green Chemistry from Universiti Teknologi PETRONAS, Malaysia from 2010 to 2011. The focus of his research has been on the production and characterization of novel feedstocks for biodiesel production. He has produced 92 research papers in internationally recognized ISI journals, including 5 book chapters with international publishers. Currently, he is working on the synthesis of heterogeneous catalyst from carbon based sources for the utilization of high free fatty acid feedstocks for biodiesel production.

Chapter 1
Processing and Properties of Date Palm Fibers and Its Composites

Faris M. AL-Oqla, Othman Y. Alothman, M. Jawaid, S.M. Sapuan, and M.H. Es-Saheb

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Abstract Date palm (*Phoenix dactylifera*) fibers are considered as one of the most available natural fiber types worldwide. Large quantities of date palm biomass wastes are annually accumulated without proper utilization. These quantities are of potential interest to support the industrial sustainability by producing alternative cheap eco-friendly materials. The competitiveness of the date palm fibers in several applications particularly in automotive industrial sectors was illustrated. Date palm fiber can be considered the best regarding several evaluation criteria like specific strength to cost ratio if compared to other fiber types. The effects of using date palm fibers in natural fiber composites with different polymer matrices were demonstrated. Criteria that can affect the proper selection and evaluation of the natural fibers as well as the composites for particular applications were discussed. The benefit of natural fibers' modifications on physical, mechanical, and other properties were also explored. Selecting the proper date palm fiber reinforcement condition can dramatically enhance its future expectations and widen its usage in different applications.

Keywords Date palm fibers • Natural fiber composites • Composites performance • Evaluation criteria

1.1 Introduction

Date palm cultivation and their fruit utilization had been investigated by several studies and works. Unfortunately, little information and details are available regarding the utilization and implementation of the date palm fibers and wastes in producing desirable commercial natural fiber composites. Consequently, the intention of this chapter is to introduce a comprehensive discussion on the value of the date palm fibers and their composites in addition to their properties and competitiveness from different physical, chemical, mechanical, and engineering point of views. This is presented here to focus a light on one of the most important fiber types that can be utilized as an eco-friendly raw alternative material for different engineering applications.

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Table 1.1 Characteristics of the date palm production system (Dakheel 2003; Jain 2007)

1	Its sustainability in harsh climatic
2	High efficiency in resource utilization
3	High productivity
4	High nutritional value of date fruit
5	Long productive life
6	Enhance agriculture development by creating equable microclimate within oasis ecosystems
7	Helpful in reducing desertification risks

Date palm (*Phoenix dactylifera* L.) trees as one of mankind's oldest cultivated plants belong to the family of Palmae (Arecaceae). It has played a vital role in daily life activities in the Middle East particularly the Arabian Peninsula since 7,000 years (Ahmed et al. 1995). Recently, the worldwide production of date palm fruits is continuously increasing which indicates the importance of the date palm trees. The utilization and industrialization of dates are distributed among several countries such as Egypt (1,352,950 metric tons), Saudi Arabia (1,078, 300 metric tons), Iran (1,023,130 metric tons), UAE (775,000 metric tons), and Algeria (710,000 metric tons) (Chandrasekaran and Bahkali 2013).

Date palm trees have government support, social acceptance, and positive view in most countries (Al-Oqla and Sapuan 2014). Such reasons can sufficiently express why there are more than 120 million date palm trees in different countries worldwide. Over two-thirds of such trees are in Arab countries. Each tree has the ability to grow and produce fruits for more than 100 years (Al-Khanbashi et al. 2005). For instance, date palm trees have positive points of view and government support due to several reasons such as to produce the raw materials for local industries (furniture and home accessories), and produce valuable food for human beings (Jain 2007). Moreover, date palm trees can contribute to the national economy of several countries. For instance, the income for Saudi Arabia from the date fruit production was about $2.12 billion according to the base price of 2006 (Alshuaibi 2011). Due to the unique characteristics of date palm it is usually called the tree of life (Jain 2007). That is, it is very beneficial and connected with the survival and well-being of humans living particularly in hot arid environments under harsh climatic conditions. The date palm production systems have several distinguished characteristics as shown in Table 1.1. Moreover, the rich date fruit plays a crucial role in providing nutrition to human kinds under hot and arid conditions. Date fruits are rich source of fructose, sweeteners, fat, proteins, glucose, and vitamins (Al Eid 2006; Jain 2007) in addition to other minerals. Therefore, date palm fruits are considered as an ideal food for human beings as it provides several kinds of essential nutrients and potential health benefits. In addition, date palm trees are usually utilized for garden decorations in Arabian Peninsula. Consequently, it can be deduced that such reasons can ensure the continuous availability of the date palms and their residuals and fibers as renewable raw materials with low prices to be used in different industrial applications.

1.2 Natural Fiber Composites

Materials have critical roles in engineering design and applications that can lead to successful sustainable products. The proper compatibility between the material and products' functions, performance, and recyclability became critical for engineering applications. Moreover, finding new materials with desirable distinctive characteristics can expand new design possibilities (Ashby 1992). On the other hand, several criteria and limitations usually affect the usage of a specific type of material in a particular application (Ashby 1992). Thus, selecting a proper material type for a particular application is a matter of multi-criteria decision making problem (Dweiri and Al-Oqla 2006) where proper decisions have to be carried out based upon several factors.

Recently, due to the tremendous need and awareness of environmental impact and as a result of the governmental emphasizing on the new regulations regarding the environmental impact issues and sustainability concepts as well as the growing of social, economic, and ecological awareness (Faruk et al. 2012; Kalia et al. 2011a, b), the utilization of natural resources was strongly encouraged (Govindan et al. 2014). Consequently, the natural fiber reinforced polymer composites (NFRPC), (simply NFC), became a valuable alternative material type for wide range of applications. In this NFC, natural fibers (such as jute, hemp, sisal, oil palm, kenaf, and flax) are utilized to be fillers or reinforcing material for polymer-based matrices. Such utilization of natural fibers can decrease the amount of waste disposal problems, and enhance reducing in environmental pollution (Kalia et al. 2011b). Such materials are attractive from environmental point of view where they can be used as an alternative to the traditional glass/carbon polymer composites (Faruk et al. 2012; Kalia et al. 2011a, b). They can be used in different applications such as packaging, disposable accessories, furniture, building, insulation, and automotive industries (Al-Oqla and Sapuan 2014). Moreover, these NFC have several advantages over the traditional types of materials like the low costs and density as well as acceptable specific strength and modulus (Alves et al. 2010; Faruk et al. 2012; Kalia et al. 2011b) which can lead to low weight products.

Furthermore, natural fiber composites are acceptable from environmental points of view because they can participate in producing recyclable and biodegradable products after use (Alves et al. 2010; Kalia et al. 2011a; Mir et al. 2010). Comparable to synthetic fiber composites, NFC are much cheaper, good thermal as well as acoustic insulating properties that can widen their industrial applications (Alves et al. 2010; Faruk et al. 2012). On the other hand, natural fibers have several advantages over the traditional glass fibers such as: availability, CO_2 sequestration enhanced energy recovery, reduced tool wear in machining, and reduced dermal and respiratory irritation (Al-Oqla and Sapuan 2014; Faruk et al. 2012; Kalia et al. 2011b; Sarikanat 2010). Despite of that, natural fibers have some considerable drawback demonstrated in poor water resistance, poor bonding with the matrix, and low durability, The weak interfacial bonding between natural fibers and the polymer matrix can lead to undesirable properties of the composites and thus limited their industrial usage. Therefore, different ways have been performed to improve their compatibility

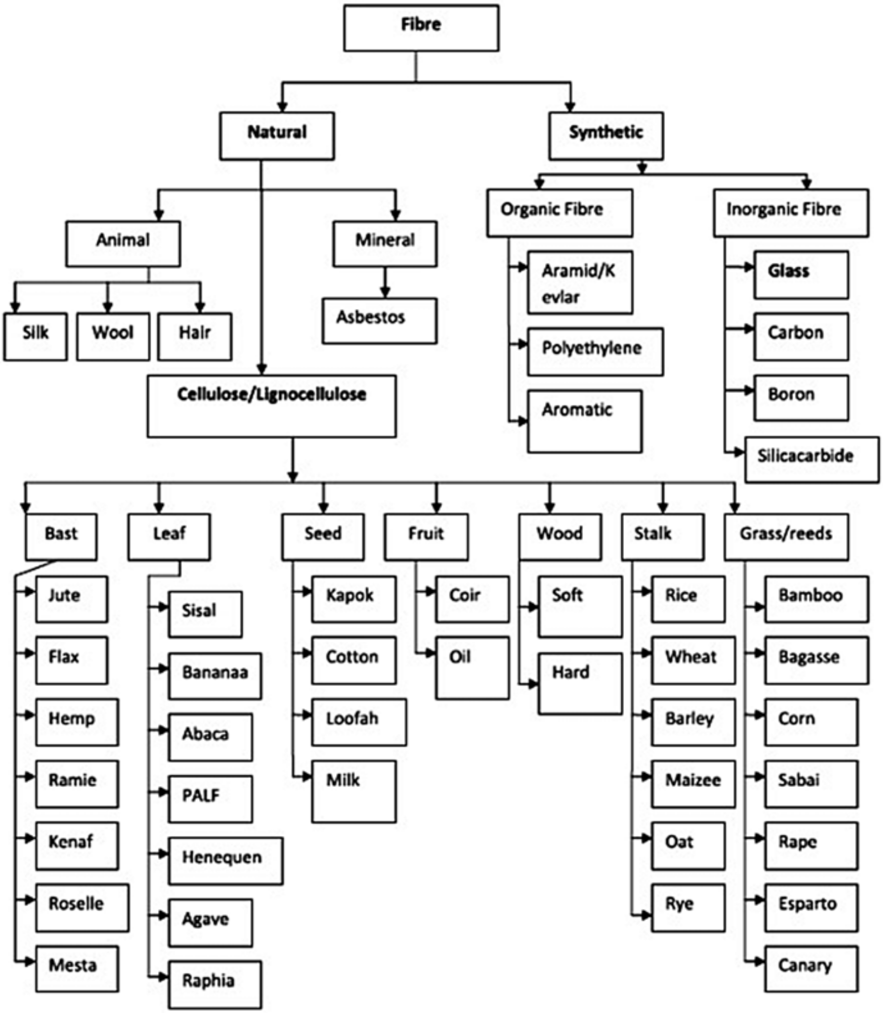

Fig. 1.1 General classifications of fibers (Jawaid and Abdul Khalil 2011)

and bonding. Consequently, the usage of the coupling agents and surface treatments via mechanical, chemical, and/or physical modifications was implemented (Al-Khanbashi et al. 2005; Arbelaiz et al. 2005; Faruk et al. 2012). A general classification of the natural fibers can be classified based upon their origin as bast fibers, leaf fibers, fruit, and seed-hair fibers as seen in Fig. 1.1. Wide different natural fiber types had been used to reinforce different polymer matrices. Such fibers include wood, cotton, bagasse, rice straw, rice husk, wheat straw, flax, hemp, pineapple leaf, coir, oil palm, date palm, doum fruit, ramie, curaua, jowar, kenaf, bamboo, rapeseed waste, sisal, and jute (Jawaid and Abdul Khalil 2011; Majeed et al. 2013). A schematic diagram of the general classifications of natural fibers is shown in Fig. 1.1.

1.3 Date Palm Fibers

The date palm biodiversity is obvious all around the world where about 5,000 date palm cultivars can be found (Jaradat and Zaid 2004). Based on botanical descriptions, about 1,000 cultivars can be found in Algeria, 400 in Iran, 370 in Iraq, 250 in Tunisia, 244 in Morocco, and 400 in Sudan, as well as many additional cultivars in the other countries (Benkhalifa 1999; Osman 1983; Zaid and De Wet 1999). The date palm trees (*Phoenix dactylifera* L.) is the tallest *Phoenix* species, it can be found with heights of more than 30 m and has fruit reaching up to 100 mm × 40 mm in size. The fruits are very tasty and nutritious (Jaradat and Zaid 2004). Date palms have characteristics that adapt them to varied conditions. Date palm trees can grow well in sand, but it is not arenaceous. It can also grow well where soil water is close to the surface because they have air spaces in their roots. Although date palm tree can grow well in saline conditions, it can do better in higher quality soil and water. The leaves of the date palm are adapted to hot and dry conditions, but it is not a xerophyte and requires abundant water (Benkhalifa 1999; Jaradat and Zaid 2004).

The date palm tree is characterized by numerous offshoots produced at its trunk's base. The trunk of the date palm tree is covered with persistent grayish leaf bases. It is surmounted by a handsome array of pinnate divided long leaves and needle sharp fronds. Usually, around 10–20 new leaves are produced annually. The leaves of the date palm are subtended by a cylindrical sheath of reticulate mass of tough, fibrous material, at their bases. These together form a tight protective envelope for the terminal bud (Benkhalifa 1999; Dakheel 2003). A young actively bearing date palm tree showing offshoots is shown in Fig. 1.2 and fruit of the date palm is seen in Fig. 1.3. Detailed morphological traits of date palm tree leaf can be shown in Fig. 1.4, where different parameters of the leaf can be demonstrated like the leaf length, thickness, angle, length of leaflet part, rachis thickness, leaf lets number as well as others (Salem et al. 2008).

Once the date palms' fruit are harvested, large quantities of date palm rachis and leaves wastes accumulated every year in agricultural lands of different countries. These amounts of important and valuable biomass wastes are of potential interest in different countries since they can be considered as new cellulosic fiber sources. Thus, innovative ways of valorizing this abundant renewable resource should be found (Chandrasekaran and Bahkali 2013). One of these ideas is to use such natural fibers in natural fiber composites suitable for different industrial applications. This can be one way of meeting the increasing demand in renewable and biodegradable materials. Therefore, the agricultural residues of date palms mainly rachis and leaves can be viewed as sources of reinforcing fibers for polymeric matrices in composite. The competitiveness of the date palm fibers in forming natural composites suitable for automotive industrial applications was demonstrated (Al-Oqla and Sapuan 2014). On the other hand, several studies proved that date palm fibers have the potential to be an effective filler in both thermoplastics and thermosetting materials to be used in different industrial applications (Abdal-hay et al. 2012; Agoudjil et al. 2011; Al-Oqla and Sapuan 2014).

Fig. 1.2 Date palm tree

Fig. 1.3 Date palm fruit

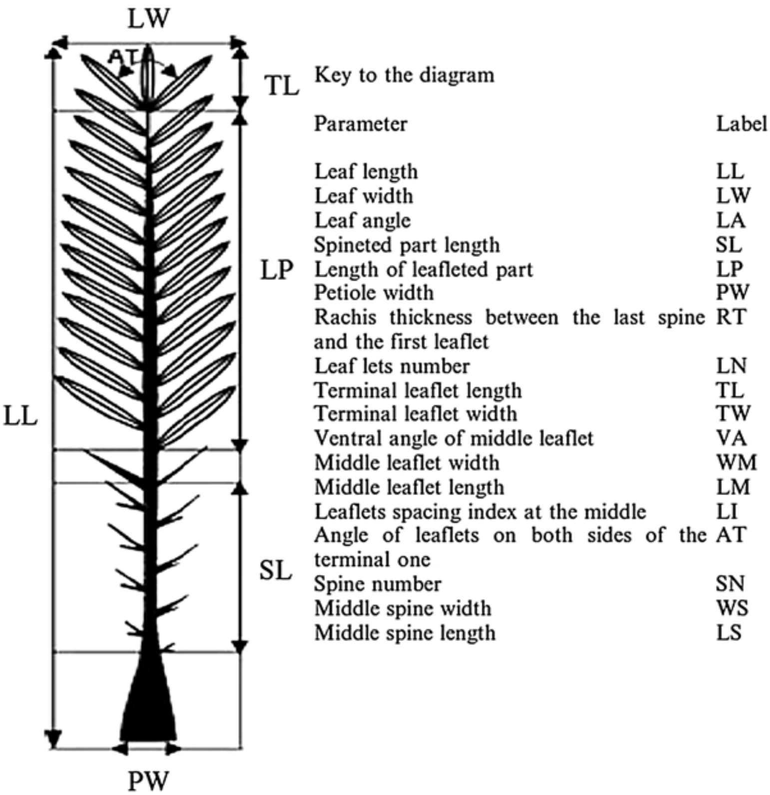

Fig. 1.4 Detailed morphological traits of date palm tree leaf (Salem et al. 2008)

Date palm tree can produce annually large number of natural fibers that can be utilized in different industries. It is estimated that the annual date palm agricultural wastes are more than 20 kg of dry leaves and fibers for each date palm tree (Al-Oqla and Sapuan 2014). Moreover, the date palm tree produces another type of wastes as date pits which are about of 10 % of the date fruits (Barreveld 1993). Unfortunately, these agriculture wastes are not properly utilized in any biological process or industrial applications, in most of countries, despite of their contents of potential amount of cellulose, hemicelluloses, lignin, and other compounds. Typical date palm fibers can be seen in Fig. 1.5.

1.3.1 Chemical Composition of Date Palm Fiber

It is known that the chemical composition of the natural fibers is of paramount in determining their suitability for different industrial applications particularly for NFRPC. That is, several characteristics of these composites like degradability and

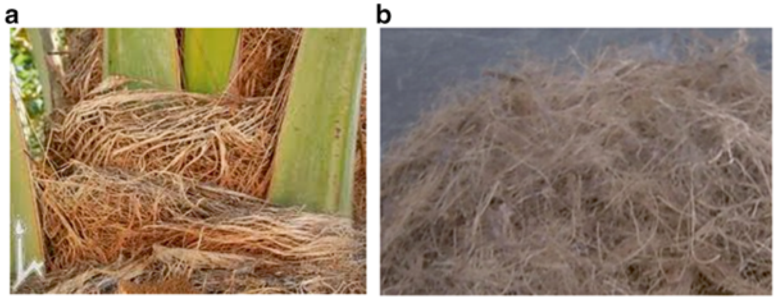

Fig. 1.5 Date palm fibers (**a**) on the tree, (**b**) separated

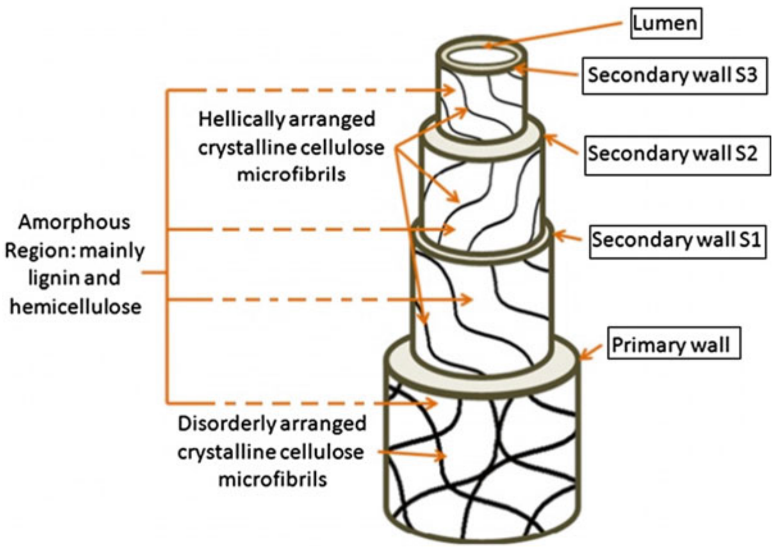

Fig. 1.6 Structure of bio-fiber. Adapted from Azwa et al. (2013)

recyclability, weather resistance, fungi attack, etc., strongly depend on the chemical composition of filler (fiber) (Al-Oqla and Sapuan 2014; Azwa et al. 2013). Actually, a variation in the fiber quality can be achieved for the same fiber type due to several factors. Some of these factors are: soil quality, fiber location on the plant, weather conditions, crop variety, fertilization, climate, and harvest timing (Dittenber and GangaRao 2011; Kalia et al. 2011b). In addition, extraction processing methods, fibers cross-sectional area variation, and the differences in drying processes will also affect the quality of the natural fibers (Dittenber and GangaRao 2011). Consequently, differences of natural fiber chemical and physical properties can be found in literature. Plant fibers consist mainly of cellulose fibrils embedded in lignin matrix. The bio-fiber structure is shown in Fig. 1.6. A primary cell wall and other

Table 1.2 The average weight percentage of chemical composition of the date palm fibers from leaf (leaflet and rachis) (Mirmehdi et al. 2014; Sbiai et al. 2010)

Constituents		Cellulose		Hemicelluloses		Lignin		Ash		Extractive	
Leaflet	Leaf[a]	40.21	54.75[a]	12.8	20.00[a]	32.2	15.30[a]	10.54	1.75[a]	4.25	8.2[a]
Rachis		38.26		28.17		22.53		5.96		5.08	

[a]Values are from Sbiai et al. (2010)

three secondary walls form the fiber's complex layered structure whereas secondary thick middle layer of the cell walls consists of a series of helically wound cellular micro-fibrils formed from long chain cellulose molecules can determine the mechanical properties of fiber. Each cell wall is formed from three main components which are cellulose, hemicelluloses, and lignin. The lignin-hemicelluloses have a matrix-like role while the micro-fibrils which are made up of cellulose molecules act as fibers (Dittenber and GangaRao 2011; John and Thomas 2008). Pectin, oil, and waxes can be found as other components (John and Thomas 2008; Wong et al. 2010). Due to the existence of Lumen, the natural fiber has a hollow structure unlike synthetic ones (Liu et al. 2012).

Cellulose and lignin are the most important structural components in many natural fibers. In plants, cellulose is usually found as a slender rod like crystalline micro-fibrils and aligned along the fiber's length (Azwa et al. 2013). Although Cellulose is resistant to hydrolysis, strong alkali, and oxidizing agents, it is degradable to some extent when exposed to chemical treatments (Azwa et al. 2013). Lignin is a complex hydrocarbon polymer. It usually gives rigidity to plant and assists in water transportation. It is hydrophobic, resists most of microorganisms attacks as well as acid hydrolysis, it is usually soluble in hot alkali, readily oxidized, and easily condensable with phenol. The nature of cellulose and its crystallinity can determine the reinforcing efficiency of natural fibers (John and Anandjiwala 2007). Filaments are bonded into a bundle by lignin and are attached to stem by pectin. Lignin and pectin are weaker polymers than cellulose. They have to be removed by retting and scotching for effective composite reinforcements (Dittenber and GangaRao 2011). The average weight percentage of chemical composition of the date palm tree frond and their fiber properties (Mirmehdi et al. 2014; Sbiai et al. 2010) are shown in Table 1.2.

It can be noticed that there are some variation in the measured values of the date palm fiber's chemical composition due to inherent parameters mentioned previously. A comparison between average values of both cellulose and lignin for the date palm fiber with other natural fibers can demonstrate the appropriateness and competitiveness of the date palm fibers for being potential type of fillers for natural fiber composites. Such comparison is demonstrated in Fig. 1.7.

It can be seen from the comparison that the date palm fiber has an added value over both hemp and sisal, because it has less cellulose content than they do which reduces the ability of the date palm fiber to absorb water comparing with hemp and sisal (Al-Oqla and Sapuan 2014). On the other hand, this can give the date palm fiber more desired mechanical properties over the coir one. Moreover, the cellulose content in date palm fiber is greater than that of lignin, which allows it to be competitive for automotive applications (Al-Oqla and Sapuan 2014).

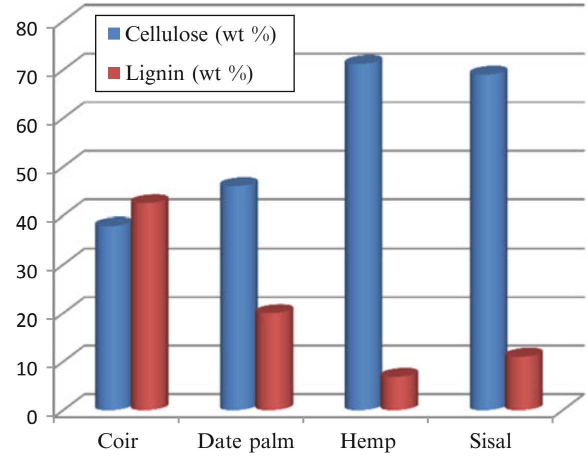

Fig. 1.7 Comparing the date palm's cellulose and lignin contents with other natural fiber types. From Al-Oqla and Sapuan (2014)

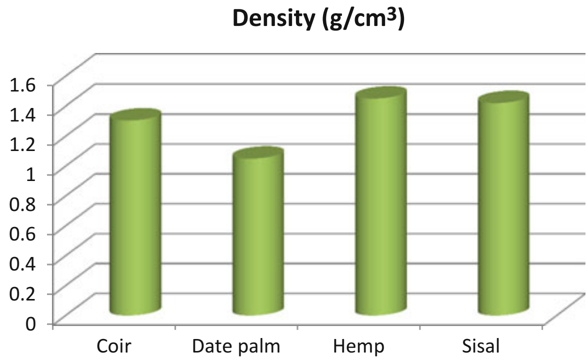

Fig. 1.8 Date palm fiber's density compared with other natural fibers types used in automotive industry. From Al-Oqla and Sapuan (2014)

1.3.2 Physical Properties of Date Palm Fiber

Physical properties of the natural fibers are crucial in determining their suitability for different industrial applications as well as natural fiber composites. Fiber's length, diameter, and density as well as aspect ratio, thermal conductivity, cost, and availability are considered as key criteria and properties that can determine the potential usage of any natural fiber type in different industrial applications (Al-Oqla and Sapuan 2014; Al-Khanbashi et al. 2005; Alves et al. 2010). Date palm fiber can be considered as one of the most available natural type comparing to other natural fiber used in polymer composites for automotive industry. It can be estimated that the annual world production of the date palm fiber is about 42 times more than that of coir and about 20 and 10 times more than hemp and sisal production respectively. On the other hand, the fiber density is one of the most important physical properties that contribute implementing natural fibers in different applications. That is, it can lead to lower weight composites suitable for automotive and space applications. A comparison between the date palm fibers with other natural types regarding the density property is demonstrated in Fig. 1.8. It is noticed that date palm fiber have a lower density as compared to other natural fibers which give it an added value in the field of natural fiber composites.