Khalid Rehman Hakeem
Mohammad Jawaid
Umer Rashid *Editors*

Biomass and Bioenergy

Applications

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Foreword

There are many global resources available to meet the growing energy demand. Global reserves of petroleum lie around 1.033.2 billion barrels, natural gas around 5.141.6 trillion cubic feet, and coal around 1.087.2 billion tons. The energy sources used for generating electrical power on global basis are nuclear (17.7 %), natural gas (14.8 %), coal (38.4 %), oil (9.3 %), hydro (18.4 %), and wood + refuse + renewable (1.4 %). The common renewables are solar, wind, biomass, energy from waste, geothermal, hydro, wave and tidal, and ocean thermal. Out of these energy sources, renewable energy is among the fastest growing. Annual turnover has reached 30 billion Euros or about 50 % of the world market. Recycling, energetic valorisation, prevention and organic valorisation are attracting great attention worldwide. One of the sources of renewable energy is biomass. In many developing countries these sources of fuel are a large proportion of the energy available.

A substantial increase in the production of bioenergy from biomass originating from different sources offers opportunities to reduce greenhouse gas emissions and helps to diversify use of resources in order to provide more secure energy supply. It can create additional income for agricultural land owners, thereby paving way for promoting new economic perspectives among rural communities. A greater production of bioenergy can provide incentives for greater use of agrilands as well as forests, which can counteract the aims of waste reduction policies. However, increase in bioenergy production can at the same time pose a risk of additional environmental pressure on plant diversity, soil use, and water resources. There are ways to overcome these disadvantages by growing low-impact bioenergy crops, forbidding ploughing of pastures, and bringing down the intensity of residue extraction depending upon the soil conditions. Application of sustainably fit environmental regulations is important if we want to increase bioenergy production. There is a great need for an assessment of economics and logistics in this direction.

This book provides detailed insight covering selected chapters on topics like non-wood renewable materials such as oil palm, bamboo, rattan, bagasse, and kenaf; upgrading of oil palm as added product a long-identified sustainable source of renewable energy which can reduce the dependency on fossil fuels as the main source of the energy supply; biodiesel synthesis using transesterification of triglycerides in the presence of catalyst and alcohol, and application of single-step process for biodiesel synthesis from microalgae; electrochemically active biofilms as fascinating biogenic tools for microbial fuel cells, nanomaterial synthesis, bioremediation, and bio-hydrogen production as synthesis of these nanoparticles as well as nanocomposites and bio-hydrogen production does not involve any energy input which make these approaches highly efficient; microalgal biomass as a source of renewable energy; critical analysis of the current situation and future needs for technological developments in the area of producing liquid biofuels from lignocellulosic biomass as a future alternative for bioethanol production; utilisation of sawmill by-product for making cellulose and its valuable derivatives which is normally used for direct combustion; ultimate valorisation of oil palm biomass in relation to biorefinery approach; polylactic acid-based kenaf biomass synthesised via ring opening polymerisation for a production of eco-friendly products which can replace the petroleum-based products; chemical functionalisation of natural cellulosic fibres through free radical-induced graft copolymerisation technique for green polymer composites applications so as to overcome the disadvantages associated with these fibres; recent applications of kapok fibre and its use as a desirable template material or supported candidate such as for catalyst carriers; abaca fibre as a renewable bioresource for industrial uses and other applications in environmental protection specifically for soil conservation and control of soil erosion as well as for the preparation of cellulose nanocrystals as components of the composites; recent advances in the realm of the extraction of nanofibrillated cellulose from lignocellulosic fibres as sustainable nanofillers with broad potentials use; termites from pest to biopolymer derivatives extractor as efficient converters of wood into sugars and for making numerous biochemicals and biofuels, with recent conversion methods of biochemicals from lignocellulosic biomass for application enablement and commercialisation, laying special emphasis on termite lignocellulolytic system; and last but not least applications of biomass-derived catalyst.

I am sure that the chapters presented in this book will encourage further discussion and research and development on biomass and biofuel production for human use, taking into account the environmental sustainability. It is a welcome addition to the existing information available on this topic. The main focus has been on Indonesia, Malaysia, Philippines, Thailand, Bangladesh, India, and Pakistan where large populations have been and are still using biomass as a source of energy. The authors and the editors of this book have done a good job in covering the diverse aspects of biomass/biofuel production and multiple uses of cellulosic materials.

Izmir, Turkey — Münir Öztürk

Preface

Recently technological advances, consumer demands, and environmental consciousness lead to better application of available biomass for environmental sustainability. Biomass is abundantly available worldwide as a cheap and extremely important renewable energy source of materials for producing energy which can be used for different applications at the cost competitive rates. In recent years, the use of biomass and bioenergy has been widely adopted worldwide to produce biofuels, biogas, biocatalyst, bio-composites, bioplastics, green chemical products, cellulose textiles, etc. However, there are still important issues and applications of biomass to be explored. The number of biomass energy applications is expanding rapidly which motivated us to work in this area to compile resources in the form of the present book.

This volume (second of the book series *Biomass and Bioenergy*) attempts to give an overview of the current applications of biomass and bioenergy to scientists, researchers, and industrial people in the field of material science, chemical engineering, forestry, and mechanical engineering to understand where and how biomass and bioenergy can be utilised, how it works, and the advantages as well as the limitations. Overall, biomass is seen as a potential material, and this book covers the utilisation of biomass in different applications such as hydrogen production, bioethanol, biodiesel, biofuel, bioenegry, biofilms, renewable energy, nanocellulose, green composites, and catalysts. With this book we tried to provide some new insights into the readers about applications of biomass and bioenergy, which were not explored in previous published works.

We are highly thankful to all the contributors from around the world, who helped us to shape our idea in the form of a much needed volume by following our instructions and feedback. We greatly appreciate their commitment.

We thank Springer-Verlag team for initiating and supporting our book idea and their unstinted cooperation at every stage of the book production.

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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 characterisation of novel feedstocks for biodiesel production. He has produced 92 research papers in internationally recognized ISI journals, including five book chapters with international publishers. Currently, he is working on the synthesis of heterogeneous catalyst from carbon based sources for the utilisation of high free fatty acid feedstocks for biodiesel production.

Chapter 1
Non-wood Renewable Materials: Properties Improvement and Its Application

Rudi Dungani, H.P.S. Abdul Khalil, Ihak Sumardi, Yoyo Suhaya, Endah Sulistyawati, Md. Nazrul Islam, N.L.M. Suraya, and N.A. Sri Aprilia

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Abstract Plant biomass are woody and non-wood materials (e.g., oil palm, bamboo, rattan, bagasse, and kenaf) and are abundant and renewable resource. Unfortunately, the heavy reliance on this resource is a threat to forest ecosystems and a recipe for accelerated land resource degradation. Due to the increasing scarcity of wood resources, many rural communities have shifted to utilization of crop residues for many different applications. The non-wood biomass is readily available, environmental friendly, and technologically suitable, and therefore, an excellent raw material for the future. The non-wood materials like bamboo, rattan, oil palm, and bagasse have superior properties and durability, which can be further prolonged by the modification treatment. The modification treatments increase the performance of the non-wood and could make it suitable for applications in many fields ranging from construction industry to automotive industry. This chapter deals with the properties improvement techniques of the selected non-wood biomasses and evaluates its applications for various purposes. The new developments dealing with the improvement of non-wood properties have also been presented in the chapter. The performance of non-wood biomass materials has been compared to the wood-based materials. Recent studies pertaining to the above topics have also been cited. Finally, the advanced applications of the improved non-wood biomasses have been highlighted.

Keywords Non-wood biomass • Biocomposites • Properties improvment • Fibers

1.1 Introduction

Fossil resource-based industry has serious negative impact on the global environment due to the increase in the atmospheric concentration of carbon dioxide, along with a number of other pollution problems. Non-wood biomass (agricultural waste) is the most abundant resource and one that is also renewable. However, it also has various advantages of a techno-economical. Utilization of non-wood biomass has been based on the paradigm of a fossil resource-based society, and thus, it is critically important to establish sustainable production and utilization system for material, especially those in tropical regions where resources and biodiversity are plentiful.

In subtropical and tropical region, non-wood biomass are natural resources which plays very important role in the daily life of millions people. Traditionally, the main uses of non-wood biomass in ropes and twines mainly produced through cottage industries. Non-wood, especially, in a form of fibers is converted into yarn, string, ropes, floor mats, bags, floor and wall coverings, and different handicrafts. Meanwhile, the modern processing techniques have considerably extended their usefulness. Non-wood biomass are very promising alternative material because it is economical, renewable, and processable material that has been shown to exhibit equal or better physical and mechanical properties and comparable to some commercial wood species. Therefore, it is becoming more important to establish sustainable and renewable resources for societies. In addition, establishment of basic science and technology dealing with lignocellulosic materials, including bamboo, oil palm, rattan, and bagasse, is indispensable to the promotion of non-wood industries of tropical countries.

Polymers and reinforcing fibers from renewable resources, e.g., annual plants or non-wood, is one way to produce renewable and biodegradable composite materials for various applications such as furniture, automotive components, structural, and others. In the composite industry, non-wood fibers are used to produce a wide variety of products with different properties: fiber as filler reinforcement, biofiller, fiber for polymer composite, upholstery material, packaging materials such as board and corrugated board, and fluff products for diapers.

The declining supply of raw material causing concern and in this context the natural fiber material can be seen as a good alternative material for the local timber industry to produce value-added biocomposite product in tropical countries. Biocomposite product needs further development as a long-term strategy to develop the tremendous wealth of non-wood (natural plant) fiber that is currently under utilized. Interest in using non-wood biomass, which is predominantly lignocellulosic materials, in the production of biocomposites has gained momentum in recent years. The non-wood biomass has not been fully exploited as source cellulosic fiber, principally to biocomposites technology development. Lignocellulosic, in this context, is referring to a non-wood biomass fibers which have different properties due to differences in chemical composition and morphological of fibers (Abdul Khalil et al. 2012).

Malaysia and Indonesia produce total of over 90 % of lignocellulosic material from oil palm industry only (Yuliansyah et al. 2009). Other lignocellulosic source mentioned was sugar cane bagasse, bamboo, rattan, and natural fibers (kenaf).

1.2 The Overview of Selected Non-wood Biomass

The biomass development through intensification use of non-conventional raw material (kenaf, oil palm, bamboo, rattan, bagasse, and another non-wood) was technically and economically feasible. They can play an important supplementary role, especially in the form of fibers. The non-wood materials were identified suitable for the production of paper, composites, and engineered material. There are several non-wood fiber sources other than those of agricultural residue origin. While some of them are of forest origin, others are cultivated in view of their suitability for biocomposites production. Malaysia and Indonesia are world's largest producers of oil palm. But the situation is not as impressive with regard to their utilization.

The most important properties of fiber in utilization to biocomposites product are fiber dimension (length, thickness, and width), crystallinity, and permeability. Therefore, fiber produced by agricultural waste (oil palm waste and bagasse), and natural fiber plants (kenaf, jute, pineapple, abaca etc.) are seen as promising lignocellulosic raw material for the manufacturing of natural fiber reinforced/filled composites for different application. These fibers have tremendous variations in chemical and physical properties as compared to wood fiber. Products produced using natural fiber improved their homogeneity and quality (Abdul Khalil et al. 2012). Non-wood biomass offers numerous advantages; they are abundantly available, have high specific mechanical properties, low in cost, low density, safe to handle, not a threat to environment, and also renewable and biodegradable (Abdul Khalil et al. 2008a; Bachtiar et al. 2011). Oil palm, bamboo, bagasse, rattan, and kenaf biomass which used as raw material to produce fibers are shown in Fig. 1.1.

1.2.1 Properties of Non-wood Biomass and Fibers

The properties and characteristic of physical fiber, chemical (lignin, hemicellulose, and cellulose) content of various non-wood and agricultural residues were examined to assess their suitability for biocomposites production. The fundamental characterization and properties will not only help in open up a new avenue for this fiber, but also emphasize the importance of this biomass as future material. In order to determine the applicability of biomass as raw materials for the production of biocomposites, the properties of the raw materials have first to be examined and determined.

The physical, mechanical, and morphological properties on performance of non-wood fibers depend on cellulose content, fiber orientation, crystal structure, and diameter/cross-section area of the fiber. The fiber cross-section area strongly influences the evaluation of fiber strength. Hence, as a natural material, non-wood biomass fiber is strongly influenced by the strength of its constituent cells, namely affected by thickness of fiber wall (Rowell et al. 2000).

1.2.1.1 Chemical Properties

The major chemical component of non-wood biomass and fiber is composed of cellulose and hemicelluloses that are combined with lignin with lesser amounts of extractives, protein, starch, and inorganics. The three-dimension polymeric components determine most of the properties of non-wood biomass and fibers (Ndazi et al. 2006). The distribution of chemical components pass through the cell wall which is composed of primary and secondary wall layers. Variation and contribution of chemical composition from non-wood biomass to other non-wood biomass are different from parts of the same non-wood biomass. Table 1.1 shows the chemical composition of different non-wood biomass and fibers.

1.2.1.2 Physical and Mechanical Properties

The physical properties of non-wood fiber are important to know in order to reach its highest potential in the utilization. As depicted previously, the physical properties of fibers such as defects, strength, fiber dimensions, variability, crystallinity, and structure are some of the important considerations in utilization for production of high-performance structure fiber/polymer composite.

Fig. 1.1 Non-wood biomass fibers

Table 1.1 Chemical composition of some non-wood biomass and fiber

Type of biomass	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)	Extractive (%)
Oil palm	14.3–65.2	12.5–38.7	17.3–26.5	2.0–3.5	0.9–3.0
Bamboo	20.3–61.5	19.3–21.4	11.1–32.2	1.7–5.1	1.3–2.8
Bagasse	55.6–57.4	23.9–24.5	24.35–26.3	1.5–5.3	2.65–3.25
Rattan	35.6–52.9	22.8–34.7	21.0–22.0	1.3–2.0	0.3–2.0
Bast kenaf	44.3–57.8	15.6–19.2	22.0–23.2	2.0–5.0	0.1–0.25
Core kenaf	37.5–49.6	15.1–21.4	18.0–24.3	2.3–4.3	0.12–0.3

Sources: Law et al. (2007), Abdul Khalil et al. (2006), Shibata (2012), Wang et al. (2010), Muniandy et al. (2012), Hemmasi et al. (2011), Zaini et al. (2013), Li et al. (2007)

Table 1.2 Dimension of selected non-wood biomass fibers

Type of fiber	Fiber length (mm)	Width fiber (μm)	Width lumen (μm)	Wall thickness (μm)
Oil palm	0.33–50.31	8.3–20.5	7.90–17.3	1.8–8.3
Bamboo	2.98–5.63	12.9–42.5	1.6–31.1	2.4–13.3
Bagasse	1.22–1.59	19.35–20.96	9.12–9.72	4.95–5.62
Rattan	1.23–1.92	1.04–2.13	0.8–1.12	1.9–3.8
Bast kenaf	2.27–2.51	25.74–26.59	13.05–13.75	6.35–6.42
Core kenaf	0.72–0.88	36.10–36.78	23.58–27.48	4.31–6.60

Sources: Abdul Khalil et al. (2008a), Sreekala et al. (2004), Tamizi (2010), Abdul Khalil and Suraya (2011), Phukringsri and Hongsriphan (2013), Shibata (2012), Hemmasi et al. (2011)

Non-wood biomass of bamboo, rattan, and oil palm in the form of stem have different physical and mechanical properties which are affected by variety of species, age, and locality. The fiber length and width is very important in non-wood biomass-based fiber composites as it give an indication of possible strength properties (Rowell et al. 2000). The fiber characteristics of biomass indicate a wide range of fiber length, width, and thickness. The average values are obtained by different workers on each type of biomass (Tamizi 2010). The dimensions of some common non-wood biomass fibers are shown in Table 1.2.

On the other hand, fiber strength can be an important factor in selecting a specific non-wood biomass fiber for a specific application. Non-wood biomass fibers also vary in mechanical properties depending on what part of the plant the fiber came from and the age of the plant. The variation of value for mechanical properties shows that results reported by researchers are not identical because of variation in the type fiber and also the irregular sectional area which fluctuates along the length of non-wood biomass fiber (Virk et al. 2012). Table 1.3 gives data on physical and mechanical properties of several non-wood biomass and fibers. It can be seen that physical and mechanical properties vary widely depending on the type of non-wood biomass and fiber.

1.2.1.3 Morphological and Fiber Ultrastructure

The lignocellulosic of fibers non-wood biomass, multi-cellular with single cells embedded in a matrix composed of non-cellulosic matters, and lignin constitutes one of the main components in the system. The fiber will change in physical properties

Table 1.3 Physical and mechanical properties of selected non-wood biomass and fibers

Type of non-wood biomass and fiber	Tensile strength (MPa)	Elongation at break (%)	Young's modulus (GPa)	Density (gr/m^3)
Oil palm	227.5–278.4	2.1–5.0	2.7–3.2	0.7–1.55
Bagasse	257.3–290.5	6.2–8.2	15–18	0.31–1.25
Bamboo	330.5–400.3	15.4–30.0	45.6–65.5	0.51–1.13
Rattan	280.3–500.5	19.32–31.3	40.9–66.4	0.25–0.59
Bast kenaf	895.1–930.3	1.46–1.76	49.3–56.2	0.22–0.40
Core kenaf	898.5–938.7	1.43–1.69	50.5–56.8	0.10–0.20

Sources: Muniandy et al. (2012), Tamizi (2010), Abdul Khalil and Suraya (2011), Abdul Khalil et al. (2008a), Gassan et al. (2001), Hemmasi et al. (2011)

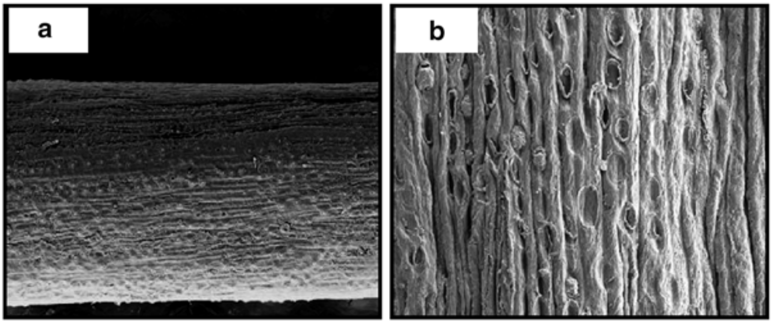

Fig. 1.2 Scanning electron micrograph of oil palm EFB fiber: (**a**) Longitudinal surface view at magnification 500× (*photo by* Abdul Khalil et al. 2006); (**b**) Surface of oil palm fiber with silica bodies (*photo by* Bhat et al. 2011)

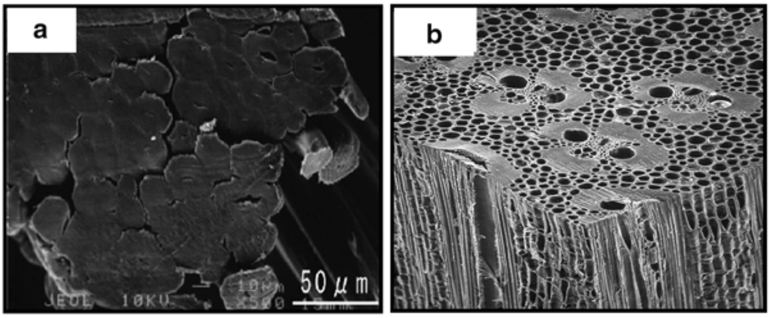

Fig. 1.3 Scanning electron micrograph of bamboo fiber: (**a**) Cross-section structure bamboo fibers (*photo by* Shibata 2012); (**b**) vascular bundle of bamboo fibers (*photo by* Liese 2004)

because of differences in its morphology. The ultrastructure of non-wood biomass fibers by scanning electron micrographs (SEM) is shown in Figs. 1.2, 1.3, 1.4 and 1.5. Generally, the natural fiber has major differences in structure (density, cell wall thickness, tracheid length, and diameter) that result in differences in physical properties (Rowell et al. 2000).

Figure 1.2a shows the longitudinal surface view at magnification 500× and Fig. 1.2b shows closer and clearer view of silica bodies on oil palm fiber. As depicted

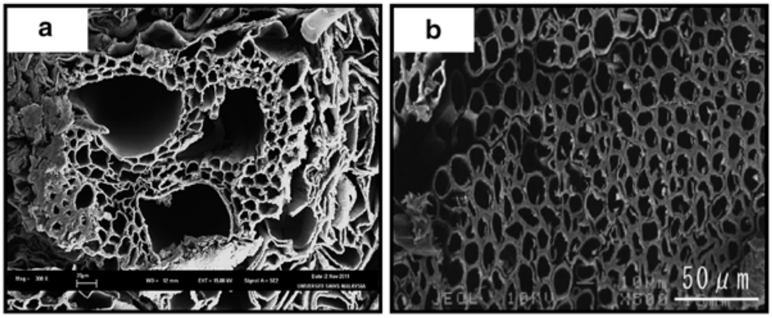

Fig. 1.4 Scanning electron micrograph of a bagasse fiber: (**a**) bagasse fiber at magnification, 300×; (**b**) Cross-sectional structure bagasse fiber (*photo by* Shibata 2012)

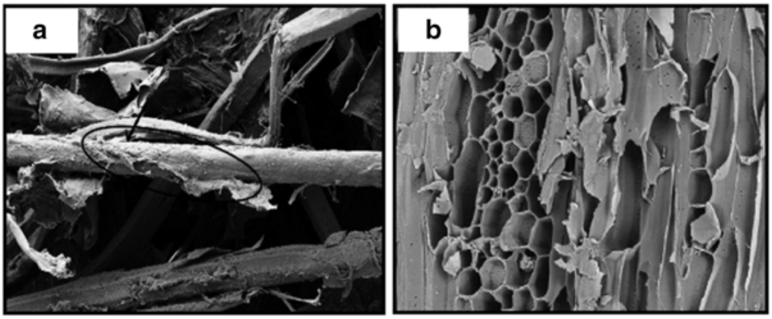

Fig. 1.5 Scanning electron micrograph of kenaf fiber: (**a**) bast kenaf fiber (*photo by* Abdul Khalil and Suraya 2011); (**b**) longitudinal section of core kenaf fibers (*photo by* Abdul Khalil et al. 2010c)

in Fig. 1.2b, silica bodies are found in great numbers on oil palm EFB strand (Law et al. 2007). Furthermore, Law et al. (2007) reported that, silica bodies seem to attach themselves to circular crater which spread relatively uniform over the strand's surface. They also investigated that the silica bodies looked like rounded-shape and are measured about 10–15 μm in diameter.

The bamboo fiber is often brittle because their fibers contain higher lignin compared to other natural fibers. The lignin components are covering in fibers resulting in great difficulties in delignification (Okubo et al. 2004). Therefore, it is impossible to remove the lignin clearly. The fiber morphology for each species has a different measure of size in terms of fiber length, fiber diameter, lumen diameter, and wall thickness. Study by Tamizi (2010) showed that there were differences in fiber dimensions of bamboo at different locations (node and internode) and positions (outer, middle, and inner layer) in the same species. He observed fiber length was found to be longer at the internode. However, the middle layer has the longest fiber length compared to the outer and inner layer (Fig. 1.3).

Figure 1.4a, b show cross-section structure of bagasse fiber under SEM. Bagasse fibers were found to be porous in structure (Shibata 2012). The structure of the bagasse fibers has a fairly high length (1,590 μm), an acceptable wall thickness (5.64 μm), and

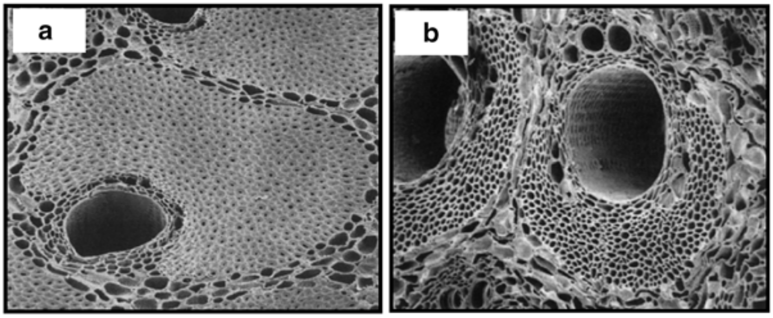

Fig. 1.6 Scanning electron micrograph of rattan: (**a**) Vascular bundle of *C. thwaitesii* with thicker-walled fibers in the periphery and thinner-walled fibers (*photo by* Bhat et al. 1990); (**b**) Vascular bundle of C. *thwaitesii* with thicker-walled fibers in the center of basal internode (*photo by* Bhat et al. 1990)

small cell diameter (20.96 μm). The ratio cell length to diameter is around 75.85 (Hemmasi et al. 2011). It is very well suited for papermaking. The comparison of length fiber showed that the bagasse fibers are shorter than bamboo (Deniz and Ates 2002).

In Fig. 1.5a, it can be seen that the diameters of kenaf fibers ranged from 20 to 90 μm (Abdul Khalil et al. 2006). The individual fibers showed smooth surface and the fiber diameters reduced to an average value of 11 ± 3 μm after bleaching (Zaini et al. 2013). Longitudinal section at tangential surface of core with very small pits in the fibers and parenchymatous cells is shown in Fig. 1.5b. Kenaf fibers have similar cell dimensions to jute fiber; however, the cells in kenaf fiber are much longer (range 20–25 mm). In the cross-sectional area, the single kenaf fibers are much finer than those of jute (Rowell and Stout 2007).

The percentage of wall thickness and fiber of rattan decrease significantly from the basal to the top internodes of the stem and from the periphery to the center at a given internode. Phukringsri and Hongsriphan (2013) suggested that, the increasing of wall thickness will increase stem density due to the deposition of additional lamellae. They considered that, difference of the number and thickness of lamellae in a fiber wall often vary from fiber to fiber even within a given vascular bundle. As depicted in Fig. 1.6a, b, the structure of rattan at transverse section consisted of scattered vascular bundles and ground parenchyma cells.

1.2.2 *Availability of Non-wood Biomass and Fibers*

The establishment of wood industries has to be based on availability of raw materials. Specifically, raw materials from natural forests that are utilized for products with high value-added function, raw materials from non-wood materials (bamboo and rattan) are utilized to replace wood from natural forests and agricultural wastes (postharvest fruits for oil palm and sugarcane production) and natural fiber utilized to replace wood fiber or wood particle otherwise obtained from natural forests.

1.2.2.1 Oil Palm

Oil palm waste is among the most abundantly non-wood biomass all over the world. Oil palm plantations are established primarily in tropical regions, where they are produced in 42 countries worldwide on about 27 million acres (Abdul Khalil et al. 2010a). Oil palm production has nearly doubled in the last decade, and this plant has become the world's foremost fruit crop, in terms of production, for almost 20 years. Biomass of oil palm includes empty fruit bunches (EFB), oil palm trunks (OPT), oil palm fronds (OPS), palm shells, and palm oil mill effluent palm (POME). Malaysia and Indonesia are two main countries which produced roughly around 85 % of the world oil palm.

Sumathi et al. (2008) reported that the oil palm industry in Malaysia, with its six million hectares of plantation, produced over 11.9 million tons of oil and 100 million tons of biomass. The amount of biomass produced by an oil palm tree, inclusive of the oil and lignocellulosic materials, is on the average of 231.5 kg dry weight/year. Prediction based on a planted area of 4.69 million ha and a rate of production dry oil palm biomass of 20.34 tons per ha per year shows that the Malaysian palm oil industry produced around 95.3 million tons of dry lignocellulosic biomass in 2009 (Abdul Khalil et al. 2012). Meanwhile, Indonesia produced 143 million tons of the oil palm biomass annually (Yuliansyah et al. 2009; Hambali et al. 2010).

Therefore, oil palm biomass in the form of lumber or conventional composites such as plywood (Abdul Khalil et al. 2010b), oriented strainboard (Hashim et al. 2011) and medium density fiberboard (Ibrahim et al. 2013), and polymer composite (thermoset and thermoplastic) (Abdul Khalil et al. 2008b) can be produced from the parts of oil palm trunk and their fibers. Figure 1.7 showed lumber and fibers product from oil palm biomass as raw material.

A great potential has been depicted by oil palm wastes fibers as a reinforcing material in polymer composites. Many researchers reported the good physical and mechanical properties of this fiber have led to diversify in its applications in the composites material area. Oil palm-producing countries can generate revenue out of this waste and this utilization can also reduce the disposal problem facing by many industries.

1.2.2.2 Bagasse

Bagasse is biomass fiber remain after sugarcane stalks are crushed to extract the juice. It accounts for 9–18 % of the stalk weight in commercial variety (Fig. 1.8). Normally 30 % of bagasse fiber are produced from a sugar factory out of total crushing. The researcher study has attempted to use bagasse as a renewable raw material for power generation and for the production of non-wood biomass material (Mustafa Al Bakri et al. 2013). Typically, the processing of one ton of sugarcane yields about 300 kg of bagasse (Vandamme 2009). In the producer countries, the utilization of sugarcane bagasse becomes more important as it is utilized for manufacturing paper, board or panels, and fuel sources that supply electricity and steam for consumers and mill boiler. World's top producer of sugarcane is Brazil which earns billion

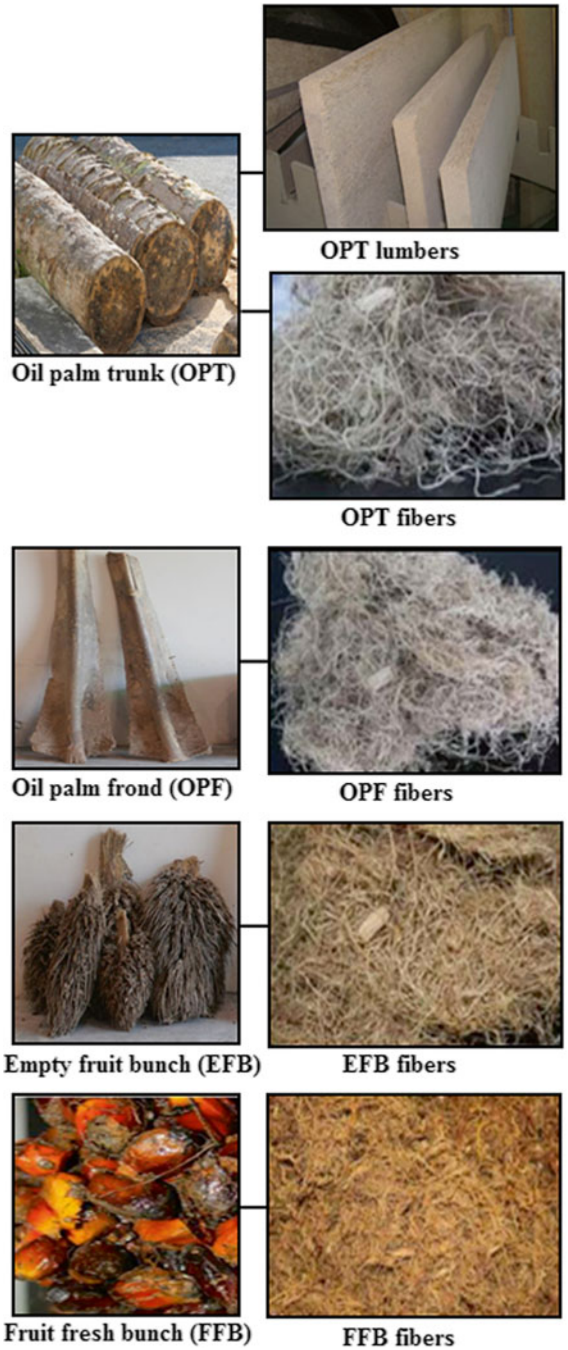

Fig. 1.7 Oil palm biomass waste

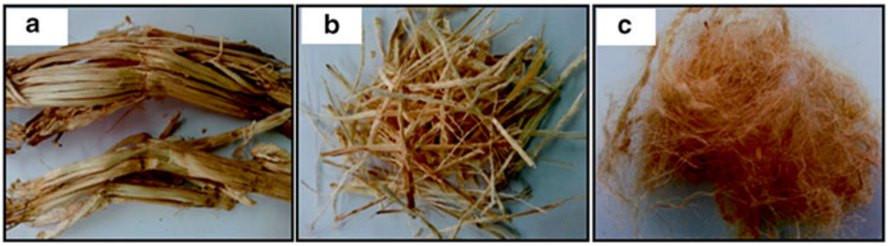

Fig. 1.8 Bagasse waste: (**a**) raw material; (**b**) flakes; (**c**) fibers

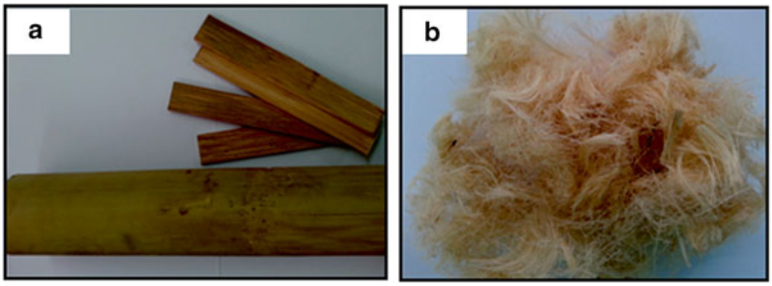

Fig. 1.9 Bamboo biomass: (**a**) Culm and strips; (**b**) fibers

dollars annually by producing sweeteners, ethanol, and alcohols. Fermentation of sugarcane bagasse is the main process in the ethanol production. During this process, sugar or sugar-based ethanol production is a solid residue generated in the form of a dried pulp known as sugarcane bagasse. For example, 28 billion liters of Brazilian ethanol production will yield around 350 million tons of bagasse (Alves et al. 2012). Bagasse are widely utilized and become more important in many industries such as paper and board manufacturing, polymer composites, and also as fuel sources that supply electricity. Many research and development efforts have been done towards the technologies to reduce the pollution and cost of value-added products by the use of agricultural wastes.

The present review by Verma et al. (2012) reported the use of bagasse fibers as reinforcements in polymer matrix. This review reports some selected works in the field of bagasse fibers.

1.2.2.3 Bamboo

Bamboo fiber is also a good candidate for non-wood fibers and can be exploited for the design and development of polymer composites (Fig. 1.9). This material is the most important material for socio-economical status of society and it takes several months to grow up. Traditionally, various living facility such as floor mats, bags and different handicrafts has been use from bamboo, mainly produced through cottage industries. Their properties is brittle compared to other natural fiber because of the

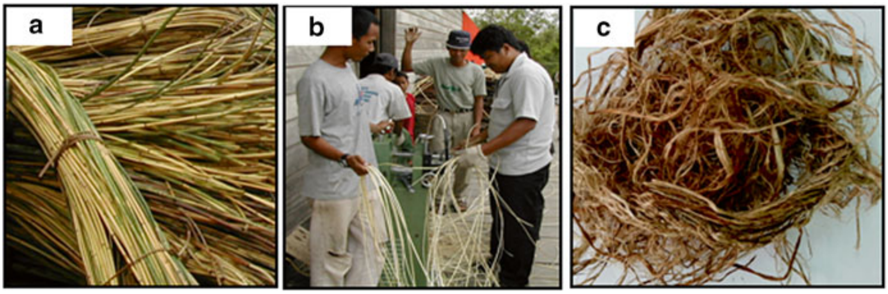

Fig. 1.10 Rattan: (**a**) raw material; (**b**) fibers preparation; (**c**) fibers

high lignin content which covering the bamboo fibres, but still possessed better in mechanical properties (Abdul Khalil et al. 2012). It can also be used in manufacturing reinforced composite for application in building construction.

Six countries in Asia, which are India, China, Indonesia, Philippines, Myanmar, and Vietnam, occupied largest area of bamboo. Almost 11.4 million hectares are from India and 5.4 million hectares are from China and two million hectares are from Indonesia. India and China are reported as the largest area which approximated 70 % of total area of bamboo in Asia. The bamboo area in Asia has increased by 10 % over the last 15 years, primarily due to large-scale planting of bamboo in China and to a lesser extent in India (Lobovikov et al. 2007).

1.2.2.4 Rattan

Rattans are climbing palms belonging to the palm family (Palmae or Arecaneae). Rattans have about 610 different species belonging to 13 genera found in the world and these are mainly distributed in Southeast Asia and its neighbouring areas. There are about 20 species distributed in Africa and China. The rattan canes being aesthetically beautiful materials, malleable yet strong and durable, are in great demand particularly in the furniture and handicraft industries and are used either in whole or round form, especially for furniture frames, or split, peeled, or cored for matting and basketry. Rattans were also cultivated for edible shoots production in a past few decades, especially in Thailand and Laos. It is because planting is spreading rapidly without needing special policy support because shoot-producing plantations offer a rapid and proven return on both the domestic and export markets (Fig. 1.10).

1.2.2.5 Kenaf

Kenaf is one of the most widely used as non-wood fibers in various applications. Kenaf (*Hibiscus cannabinus* L) is a warm season annual fiber crop. It is among the most versatile, natural, ecofriendly, antistatic non-wood fiber available, durable, and spread widely in many countries such as Africa and Asia (Summerscales et al. 2010). Kenaf plant has an outer fibrous bark surrounding the core and an inner