Chapter 5
Agricultural Biomass Raw Materials: The Current State and Future Potentialities

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Abstract Nowadays, the depletion of natural resources, growing population and raising environmental concerns have raised a tremendous interest in finding a sustainable alternative for creating new materials that are environmental friendly. Agricultural biomass is the plant residue left in the plantation field after harvesting. This lignocellulosic material possesses a composition, structure and properties that make them suitable to be used in various conventional and modern applications. This renewable plant waste is abundant, biodegradable, low cost and low density that could be a principal source for production of fibres, chemicals and other industrial products. The uses of these materials are not only limited to composite, paper and textile applications, but are also progressing immensely to many other unlimited applications such as medical, nano technology, biofuel and pharmaceutical. These expanding applications of agricultural biomass would not only help in reducing the environmental pollution but also provide an opportunity in developing renewable and sustainable material to be used in various advanced applications in the future. This would also help in generating employment and contributing to the improvement of people's livelihood. The aim of this chapter is to discuss different types of agricultural biomasses with its present applications and future potentialities.

Keywords Agricultural biomass • Properties • Fibre design • Fibre network • Applications

5.1 Introduction

The widespread concern over increasing fossil fuel prices, global warming issues, environmental pollution and green house effects have stimulated a tremendous interest in the use of renewable materials that compatible with the environment. A way of addressing this sensitive issue could be through promoting the biomass from agricultural as an important alternative source for raw materials in the composition of various products and applications.

Biomass such as agricultural crops is the largest of cellulose resource in the world. Approximately 2×10^{11} tons of lignocellulosics is produced annually compared to 1.5×10^{8} tons of synthetic polymers (Pandey et al. 2010). Biomass is a clean source of energy as it releases carbon dioxide (CO_2) as it burns but the gas released is recaptured by the growth of the same materials. This material considered as the most abundant waste after harvesting. After harvesting the fruit for food, most of the biomass is traditionally wasted for which it is normally left in the plantation field as organic fertilizer, mixed with the rejected fruits to make animal feed or is open-burnt. Utilization of these wastes could solve the disposal problem and reduce the cost of waste treatment (Goh et al. 2010).

Compared to glass fibre, biomass offers many advantages due to their unique characteristic such as low cost, low energy consumption, zero CO_2 emission, low abrasive properties, low density, biodegradability, non-toxicity and their continuous availability (Guimarães et al. 2009). However, biomass fibres also have certain drawbacks especially when considering its application in composite. They have high moisture absorption and poor compatibility with polymer matrix which is responsible for poor mechanical and thermal properties. Modification or treatment of the fibre is needed to enhance the performance of biomass in different multiple applications (Pandey et al. 2010).

In the past few decades, the development of new materials that involve natural resources as the raw material, especially as a composite material, has accelerated. Nowadays, a large number of interesting applications are emerging for these materials due to recent progress in technological advances, biomass material development, genetic engineering, and composite science technology that offer significant opportunities for an exploration and development of improved materials from renewable resources which can be used in various applications such as biocomposites, pulp and paper, construction, automotive, medical, packaging, aerospace, pharmaceutical and biomass energy production (Lau et al. 2010).

5.2 Classification of Agricultural Biomass Raw Materials

Agricultural biomass, also referred to as lignocellulosic are produced in billions of tons around the world every year. There are various types of agricultural biomass across the world that can be a potential candidate as raw material in different applications such as oil palm trunks, bagasse, coconut coir, bamboo and kenaf. Mostly, this biomass is found in the form of residual stalks from crops, leaves, roots, seeds, seed shells, etc. They can be divided into main groups depending on the part of the plant which they are extracted, i.e. bast (stem), leaf, fruit (seed) and straw as shown in Fig. 5.1. The composition of these organic fibres varies from one plant species to another. In addition, the polymer constituent composition in a single plant varies among species and even different parts of the same plant. It depends on the plant age, development growth, environment and other condition (Kumar et al. 2008). The properties of biomass vary considerably depending on the fibre diameter, structure, degree of polymerization, crystal structure and source and on the growing conditions.

Since decades ago, biomass raw materials have been historically used for ancient tools, food source, construction materials and textiles and as a source of energy. However, there has been a dramatic increase in the use of plant fibre recently for the development of environmental renewable materials especially as a reinforcing agent in polymeric composite materials in substitution of synthetic fibres like glass fibres. This situation is largely spurred by environmental awareness, ecological consideration and technological advances. Figure 5.2 depicted an example of different types of agricultural biomass raw materials that has been used in various applications.

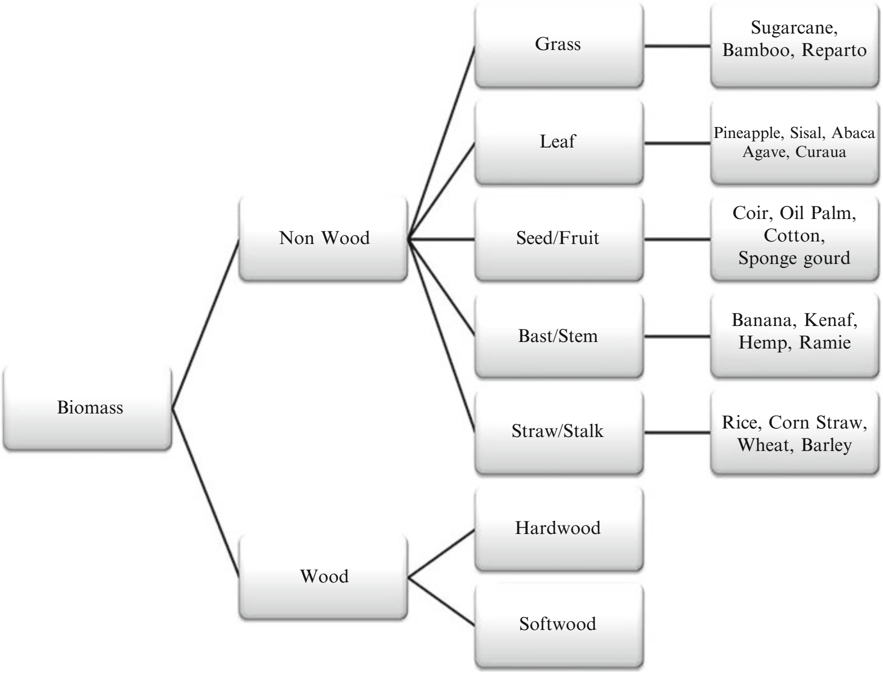

Fig. 5.1 Classification of agricultural biomass

Fig. 5.2 Various types of agricultural biomass

5.3 Agricultural Biomass Properties

The properties of biomass has been studied for decades; however the data were different among cited works because different types of biomass were used, different moisture conditions were present and different methods were employed. Researchers concluded that the overall properties of agricultural biomass are determined by large variables including its structure, chemical composition, cell dimension and microfibril angle. Furthermore these properties are also varying considerably between plant species and even in the same individual plant (John and Anandjiwala 2008).

5.3.1 Chemical Properties

Plant biomass is primarily composed of cellulose, hemicelluloses and lignin along with smaller amounts of pectin, protein and ash (Kumar et al. 2009). Cellulose is a semicrystalline polysaccharide made up of D-anhydroglucose ($C_6H_{11}O_5$) units linked together by β-(1-4)-glycosidic bonds. It provides strength, stiffness and structural stability of the fibre which help to maintain the structure of plants and serves as a deciding factor for mechanical properties. Hemicelluloses are branched and fully amorphous polymers. Meanwhile, lignin is a complex hydrocarbon polymer with both aliphatic and aromatic constituents. Lignin is associated with the hemicelluloses in plant cell wall and plays an important role in the natural decay resistance of the biomass material (Majhi et al. 2010). Table 5.1 shows the variability in cell wall composition in biomass. The table shows that content of the polymers are highly variable depending on the plant species. The composition, structure and properties of biomass depend on plant age, soil condition and other environmental factor including stress, humidity and temperature (Jawaid and Abdul Khalil 2011). The polymer chemistry of these fibres will affect their characteristics, functionalities and properties processing in different applications (Gorshkova et al. 2012).

5.3.2 Physical Properties

Final properties of biomass fibres are strongly influenced by its individual characteristic which played an important factor when considering this material in multidisciplinary applications. Biomass fibre properties that are related to vital variables include fibre structure, cell dimension, microfibril angle and defects (Abdul Khalil et al. 2012b). According to John and Thomas (2008), origin, sources, species and maturity of fibres determined the dimension of single cell in biomass fibres. Table 5.2 shows the physical properties of various agricultural biomasses. The properties of end product such as tensile strength, tear strength, drainage, bonding and

Table 5.1 Chemical properties of agricultural biomass

Type of biomass	Composition (%) Cellulose	Hemicellulose	Lignin	Extractive	Source
Bagasse	40	30	20	10	1
Corn cobs	45	35	15	5	1
Corn stalks	35	25	35	5	1
Cotton	95	2	1	0.4	1
Oil palm empty fruit bunch	50	30	17	3	1
Flax (retted)	71	21	2	6	1
Flax (unretted)	63	12	3	13	1
Hemp	70	22	6	2	1
Jute	71	14	13	2	1
Ramie	76	17	1	6	1
Sisal	73	14	11	2	1
Wheat straw	30	50	15	5	1
Oil palm frond	56	27	20	4	2
Bamboo	73	12	10	3	2
Kenaf (whole)	53	–	21	6.4	3
Kenaf (bast)	55	29	14	5.5	3
Kenaf (core)	49	33	19	4.7	3
Rice straw	34	23	11	17	4
Switchgrass	31	29	17	17	4
Henequen	78	4	13	4	5
Istle	73	4	17	2	5
Sunn	80	10	6	3	5
Banana	50	0.77	17	–	6
Sponge gourd	66	17	15	–	6

Source: (1) Abdul Khalil et al. (2012a), (2) Jawaid and Abdul Khalil (2011), (3) Abdul Khalil et al. (2010) (4) Zhao et al. (2012), (5) Klemm et al. (2005), (6) Guimarães et al. (2009)

stress distribution are highly dependent on the fibre structural characteristic especially on fibre length, fibre width and thickness of cell wall (Rousu et al. 2002; Ververis et al. 2004; Abdul Khalil et al. 2008). Fibre aspect ratio (length/width) is important in determining the suitability of fibre for an exact application in order to reach its maximum potential (Han and Rowell 1997). Biomass fibre cell wall structure is composed predominantly of polysaccharide-rich primary (P) and secondary wall layers (S_1, S_2 and S_3) (Abdul Khalil et al. 2008). This thick multilayered and sandwich-like structure of bonded cell wall layers provide strength, toughness and collapse resistance to the structure (Smook 1992). Moreover, lumen structure influenced the bulk density of fibres and its size affects the thermal conductivity and acoustic factor of fibre in end product (Liu et al. 2012).

Table 5.2 Physical characteristics of agricultural biomass

Agricultural Biomass	Fibre Length (mm)	Fibre Diameter (µm)	Thickness of single cell wall (µm)	Width of lumen (µm)	References
Oil palm EFB	0.6–1.4	8.0–25.0	–	6.9–9.8	13, 17, 20
Coconut coir	0.3–1.0	12.0–14.0	0.06–8.0	–	1, 4, 7, 8, 19
Banana	0.1–4.2	12.0–30.0	1.2–1.5	13.4–22.4	5, 7, 8, 9, 13
Pineapple leaves	3.0–9.0	5.9–80.0	1.8–8.3	2.4 –3.0	13, 20
Jute	0.8–6.0	5.0–30.0	5.2–11.3	3.4–7.6	8, 13, 15, 21
Sisal	0.8–8.0	7.0–47.0	8.0–25.0	8.0–12.0	11, 13, 19
Flax	10.0–65.0	5.0–38.0	10.0–20.0	–	13, 20, 22
Cotton	15.0–56.0	10.0–45.0	3.6–3.8	15.7–16.4	9, 13, 14, 17
Ramie	30.0–60.4	7.0–80.0	2.8–3.0	12.8–13.0	3, 13, 16
Kenaf (bast)	1.4–11.0	4.0–36.0	1.6–12.6	5.4–11.1	2, 3, 13
Kenaf (core)	0.4–1.1	0.27–37.0	0.5–11.5	14.8–22.7	2, 13, 20
Bagasse	0.7–2.8	10.0–40.0	1.4–9.4	1.0–19.1	3, 12, 13
Bamboo	2.0–3.0	14.0–17.8	3.0–9.0	3.8–8.6	1, 10, 13, 17
Rice	0.4–1.2	8.0–15.5	2.0–5.6	1.1–8.7	12
corn	0.4–1.4	12.1–26.7	2.4–6.5	2.4–20.1	12
Sunflower	0.5–1.4	16.1–36.1	2.2–9.4	3.2–24.6	12
Rapeseed	0.6–1.3	6.2–34.1	1.5–9.3	3.1–27.9	12

Adapted from: (1) Joseph et al. (1999), (2) Rowell et al. (2000), (3) Mohanty et al. 2005, (4) Reddy and Yang (2005), (5) Wathen (2006), (6) André (2006), (7) Abdul Khalil et al. (2007), (8) Satyanarayana et al. (2007), (9) Omotoso and Ogunsile (2009), (10) Yueping et al. (2010), (11) Ahmad (2011), (12) Kiaei et al. (2011), (13) Jawaid and Abdul Khalil (2011), (14) Sadegh et al. (2011), (15) Zimniewska et al. (2011), (16) Abdul Khalil et al. (2012a), (17) Jawaid et al. (2012), (18) Kalita et al. (2013), (19) Shah (2013), (20) Moya et al. (2013), (21) Mershram and Palit (2013), and (22) Nguong et al. (2013)

5.3.3 Mechanical Properties

Table 5.3 provides an overview of mechanical properties of various biomasses. The mechanical properties of the fibre types from different sources and origin clearly show why the large variation of mechanical properties of biomass becomes a crucial concern when it comes to commercial utilization. The large variability of tensile properties is also a drawback for all natural products which is influenced by species, fibre structure and environmental conditions during plant growth. The structural parameters that have been reported by different methods have influences on the tensile properties of plant fibres—chemical composition, cellulose crystallinity, microfibril angle and stiffness of cell wall materials—and the fibre lumen size as well as the presence of defects (Vincent 2000; Alix et al. 2009).

Table 5.3 Mechanical properties of selected agricultural biomass and glass fibres

Types of biomass	Density (g/cm^3)	Young's modulus (GPa)	Tensile strength (MPa)	Elongation at break (%)	Source
Oil palm empty fruit bunch	0.7	3.2	248	2.5	1
Ramie	1.5	44	500	2	1
Banana	1.3	33	355	5.3	1
Cotton	1.5	12	400	3	1
Hemp	1.5	70	550	1.6	2
Coir	1.2	44	500	2	2
Sisal	1.3	38	600	2	2
Kenaf	1.1	53	930	1.6	3
Flax	1.5	58	1,339	3.2	4
Jute	1.5	60	860	2	4
Pineapple leaf	1.4	4.4	126	2.2	5
Abaca	1.5	6.2	764	2.6	6
Bamboo	0.9	35	503	1.4	7
Date leaf	0.9	11	309	2.7	7
Palm	1.0	2.7	377	13	7
Vakka	0.8	15	549	3.4	7
E-glass	2.5	2,500	70	2.5	1
S-glass	2.5	4,570	86	2.8	1

Source: (1) Jawaid and Abdul Khalil (2011), (2) Wambua et al. (2003), (3) Pandey et al. (2010), (4) Summerscales et al. (2010), (5) Arib et al. (2006), (6) Symington et al. (2009), (7) Rao and Rao (2007)

5.4 Biomass Raw Material Design and Network

5.4.1 Biomass Fibre Design

Agricultural fibres are presently a major area of research for various end product applications. The major strength of fibres can be utilized as reinforcement in biodegradable composites and as alternative raw materials for several manufacturing industry. Figure 5.3 shows that the design of fibre biomass varies according to the type of species and sizes. Each size also varies according to each specific application of particle, pulp, fibre, fibrils, micro and nano. In terms of strength per unit weight, the fibres have strength comparable to that of man-made fibres, while the modulus is very high (Chinga-Carrasco 2011a). The micro and nano-microchips invisible to the normal view were widely used in many modern applications for various purposes and is also a very important technology in the future (Chinga-Carrasco 2011b). Several modern and high-tech nano-applications were introduced because of the excellent result as for medical applications, cosmetic, pharmaceutical, aerospace and others. In addition, the successful applications have been demonstrated in military research and development, and by-products have also been explored.

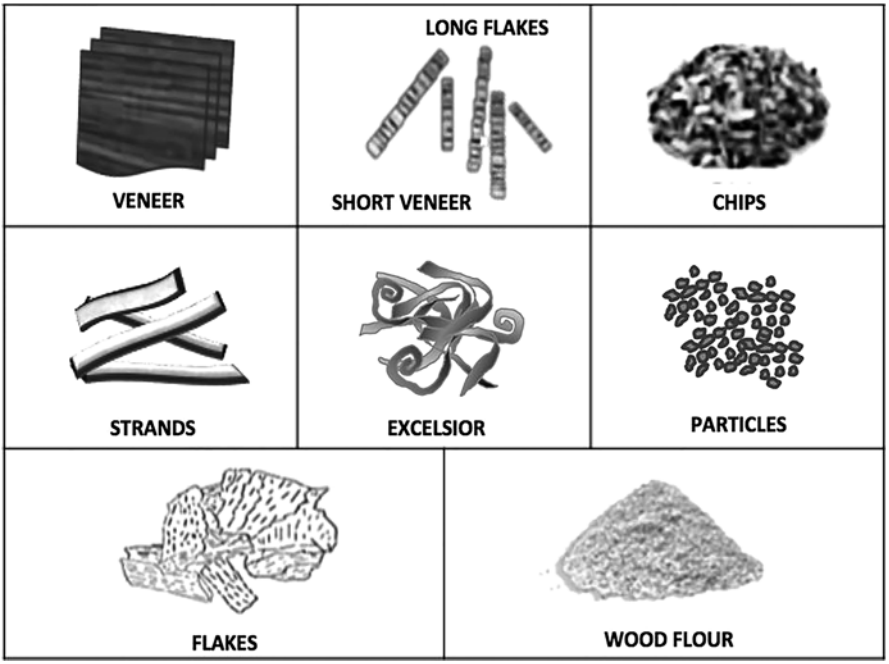

Fig. 5.3 Variations of agriculture raw materials

Agricultural biomass or lignocellulosic fibres can be described as resources comprising primarily cellulose, hemicellulose and lignin (Rowell et al. 2000). Detailed observation of the fine structure of biomass fibre is achieved by using electron microscope that provides a clearer understanding of biomass cell wall structure organization. Figure 5.4 depicted the schematic illustration of biomass fibre cell wall structure which consists of primary and secondary multilayered structure (Abdul Khalil et al. 2006). Each cell wall layer comprises different chemical composition, microfibril alignment which depends on the development and functionalities of the plant that provides mechanical support and stability to the structure. Advanced biocomposite production has dominated the world of manufacturing industry to increase value-added bamboo materials to produce innovative products such as bamboo fibre reinforced, particleboard, pulp, medium density fibre board and composites for the construction industry. The production of green composites derived from renewable sources such as palm trees, bamboo, kenaf, and others have potential to provide positive benefits to the manufacturing industry, consumers and the natural environment (Koronis et al. 2013).

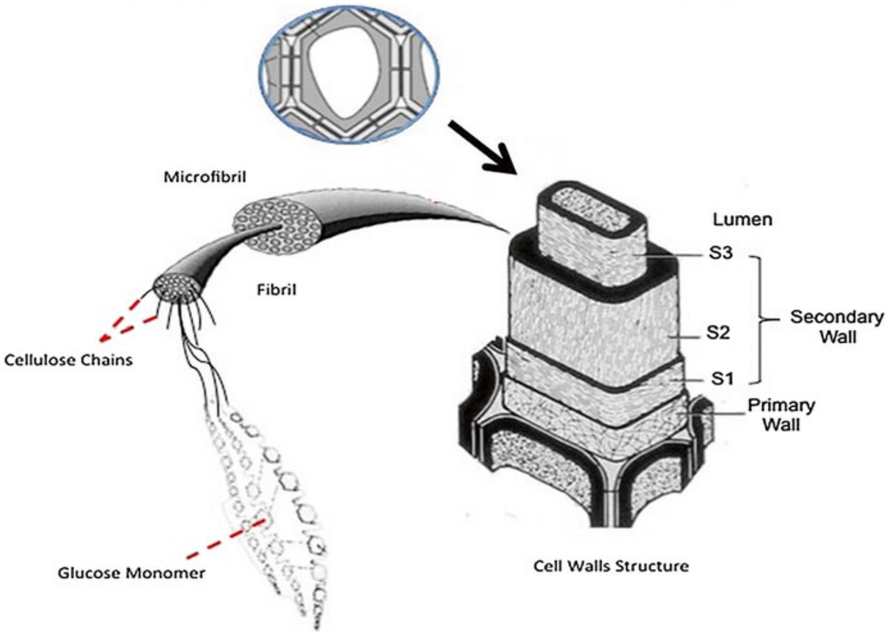

Fig. 5.4 Cell wall structure of agricultural fibre

5.4.2 Biomass Fibre Network

The use of agricultural biomass has been proven in the laboratory scale and has been commercialized as an alternative to wood material. Characteristics, properties and compatibility of the fibres are essential for biomass integration into existing industrial production for various products. Studies conducted on the relationship between structure, network, physical and mechanical properties of biomass fibres shows that they are closely related to each other. These factors have influenced the use and application of biomass fibres, as for example in pulp and paper, textile and biocomposite industry.

5.4.2.1 Biomass in Fibre Industry

Biomass fibres are usually found as short reinforcements which are used to produce mat fabrics. Discontinuous fibres (chopped) are generally used for a randomly oriented reinforcement (mat) when there is not any preferential stress direction and/or there is a low stress/strain level in the composite. The alternative to the use of short fibres is the manufacture of long yarns. Yarn is a long continuous assembly of relatively short interlocked fibres, suitable for use in the production of textile, sewing, crocheting, knitting, weaving, embroidery and rope making that are twisted with an

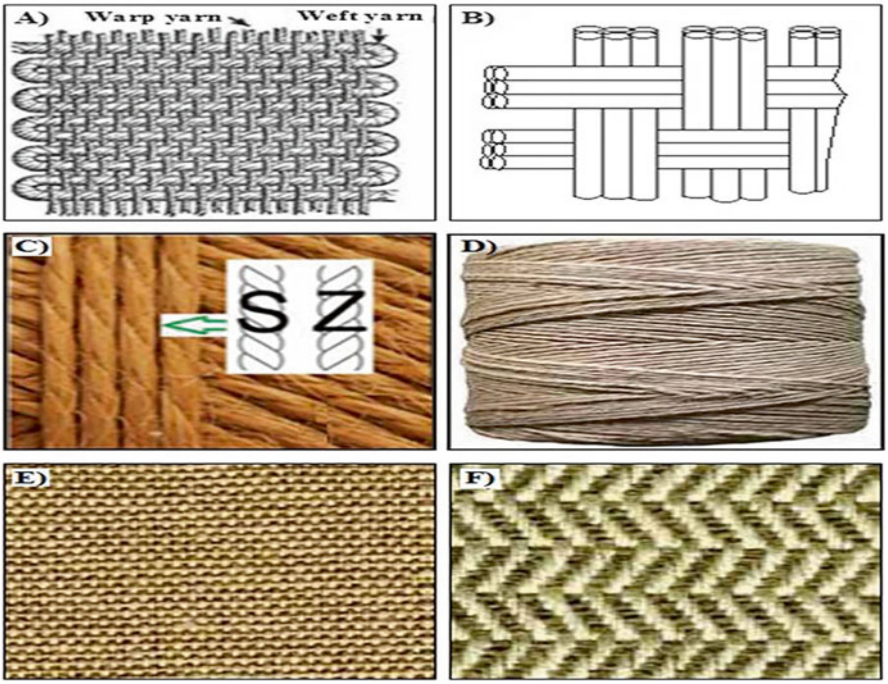

Fig. 5.5 Warp and weft in plain weaving (**a, b**); Plain woven flax yarns (**c, d**)

angle to the yarn axis in order to provide axial strength to the yarn. An important control parameter for such natural yarns is the twist level. Spun yarns are made by twisting or otherwise bonding staple fibres together to make a cohesive thread and may contain a single type of fibre or a blend of various types (Fig. 5.5). Two or more spun yarns twisted together to form a thicker twisted yarn, known as S-twist or Z-twist depending on the direction of the final twist.

The main advantage of using natural yarns is the ability to weave them into 2D and 3D fabrics with tailored yarn orientations. Weaving is a textile production method which involves interlacing a set of longer threads, twisted yarn or roving (warp) with a set of crossing threads (weft). Natural yarns differ from multifilament of synthetic fibres because they are an assembly of short fibre instead of an assembly of aligned continuous fibres. The manner in which the warp and weft threads are interlaced is known as the weave style, which are plain weave, satin weave and twill weave. Plain weave is the most basic type of textile weaves, where the warp and weft are aligned so they form a simple criss-cross pattern. Each weft thread crosses the warp threads by going over one, then under the next and so on. The next weft thread goes under the warp threads that its neighbour went over and vice versa. In balanced plain weaves the warp and weft are made of threads of the same weight (size) and the same number of ends per inch (Cicala et al. 2010).

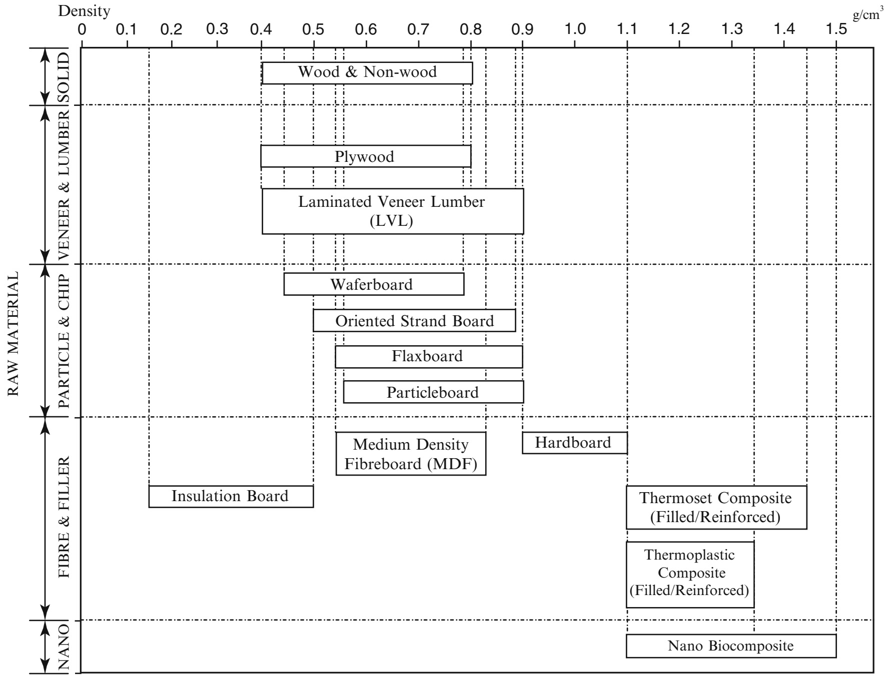

Fig. 5.6 Classification of composite based on raw material, particle size and density

5.4.2.2 Biomass in Biocomposite Industry

The composite-like structure of natural fibres are generally not single filaments as most man-made fibres, where they can have several physical forms, which depend on the degree of fibre isolation to make them competitive in terms of specific and economic properties compared to synthetic fibre. Physical and mechanical properties of biomass fibre depend on the single fibre chemical composition according to grooving, geometry of the elementary cell and extraction/processing method conditions. The earliest review by Maloney (1986) and later Abdul Khalil and Rozman (2004) has outlined a general classification system for various wood-based composites. Conventional wood-based composites (e.g. cellulosic fibreboard, hardboard, particleboard, waferboard, flaxboard, oriented strand board, oriented waferboard) and advanced polymer composites, which frequently termed as biocomposite (e.g. thermoplastic composite, thermoset composite, elastomer composite, hybrid composite, and ceramic composite) are classified by specific gravity, density, raw materials and processing methods (Fig. 5.6). Performance of the composite can be tailored to the end use of the product with each classification category. They are widely used in structural and non-structural applications for both various interior and outdoor structures.

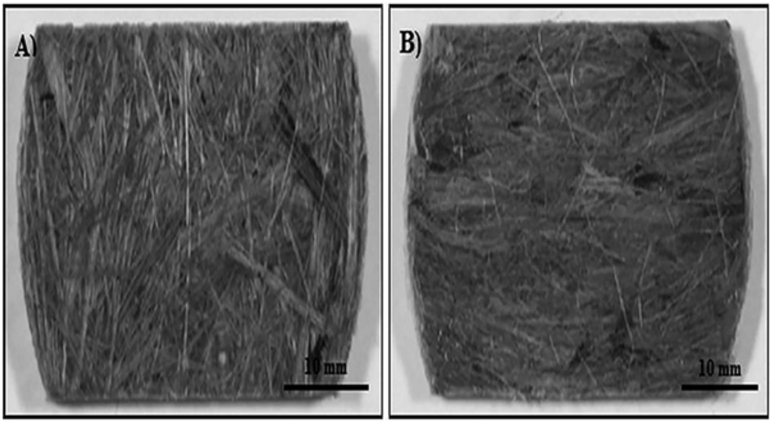

Fig. 5.7 Random kenaf fibre (**a**); Oriented kenaf fibre (**b**) (Shibata et al. 2008)

In composite manufacturing, it is crucial to know the fibre characteristics such as shape and aspect ratio as well as their distribution, orientation, alignment, volume fraction and interfacial adhesion in the polymer matrix. Some experimental studies show that fibre orientation plays a very important role in physical and mechanical properties of fibre reinforced nanocomposites (Smith et al. 2000; Shokuhfar et al. 2008; Wang et al. 2008). Rozman et al. (2013) found good mechanical strength and wettability of non-woven composite from kenaf fibre and PP fibre by using carding process and needle punching process. In other case, Shibata et al. (2008) claimed that fibre oriented kenaf reinforced composites can be produced using additional fabrication steps added into compression moulding process. Example for random and oriented kenaf fibre is shown in Fig. 5.7.

Furthermore, nanotechnology is able to manipulate and control fibre-to-fibre bonding at a microscopic level, which offers an opportunity to control nanofibrillar bonding at the nanoscale. Preparation and application of nanocomposites using nano- and microfibrils of biomass fibres are undergoing rapidly in biocomposite science (Bhat et al. 2011; Henriksson et al. 2008; Moon et al. 2006). The fibrillation of pulp fibre from biomass fibres was done to obtain nano-order unit web-like network structure, called microfibrillated cellulose. It is obtained through a mechanical treatment of pulp fibres, consisting of refining and high pressure homogenizing processes. In the range between 16 and 30 passes through refiner treatments, pulp fibres underwent a degree of fibrillation that resulted in a stepwise increase of mechanical properties, most strikingly in bending strength (Abdul Khalil and Rozman 2004; 2010). The bulk of the fibres went through a complete fibrillation that causes the increase in mechanical properties. For additional high pressure homogenization-treated pulps, composite strength increased linearly against water retention values, which characterize the cellulose's exposed surface area, and reached maximum value at many passes through the homogenizer (Kamel 2007).

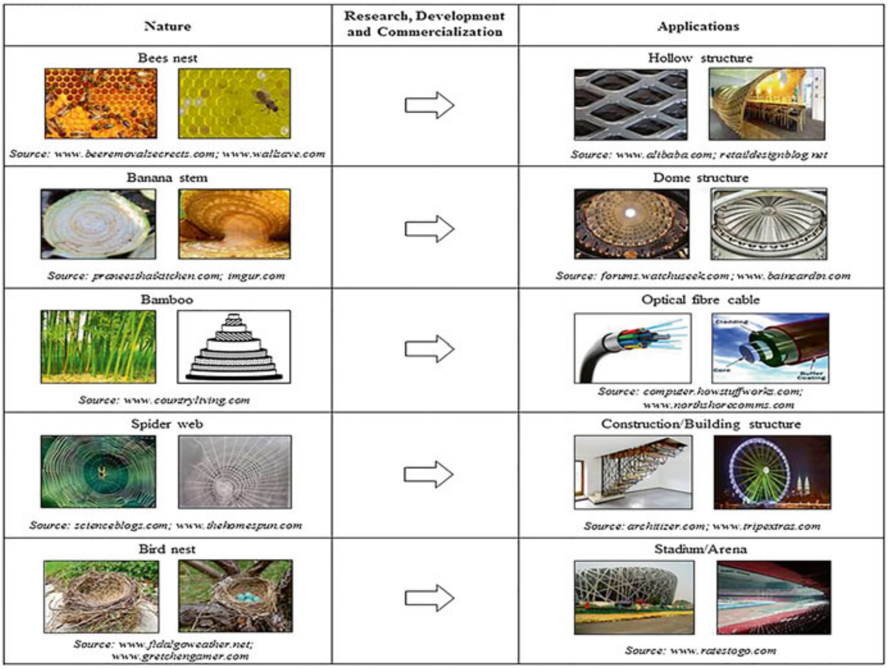

Fig. 5.8 Application of material structure inspired by nature

5.4.2.3 From Nature to Community

Without us realizing it, invention or innovation, particularly in the areas of development and construction in everyday life, is indirectly inspired by natures, which in this context are the network, structure and arrangement of biomass fibres or lignocellulosic raw materials. The architecture and fibre network which in fact may look nothing to normal eyes actually have a huge influence in terms of dimensional stability and strength for various material structures in the real world. Thus, by doing research, development and commercialization, researchers/scientists are inspired to apply the ideas in inventing some kinds of bio-inspired material structures for our daily use. For example, the structure of optical fibre cable is inspired by fibre network in bamboo structure. Other examples are bees nest, banana stem, spider web as well as bird's nest, where their fibre design and network give ideas to scientist for their new inventions (Fig. 5.8) (Amirul Hakim 2014; Baincardin 2014; Cahaya Purnama 2014; Cooper 2014; Pugh 2014a, 2014b).

5.5 Current and Future Applications of Agricultural Biomass

Biodegradable/bio-based polymeric products is based on renewable plant and agricultural biomass as a basis for sustainable portfolio with eco-efficient products that can compete in markets, which currently dominated by petroleum-based products. Through intensive research and development, the large quantities of biomass have now found applications in commercially viable bio-based products. The utilization of lignocellulosic materials from biomass for a number of value-added products is very significant through chemical, physical and biological innovations to invent such innovative and competitive products in various fields, as shown in Fig. 5.9.

5.5.1 Future Potential of Biocomposite Industry

Both upstream and downstream activities are covered in biocomposite industry. Upstream activities involve a systematic and sustainable harvesting of natural forests and plantations, whereas downstream activities include primary, secondary and

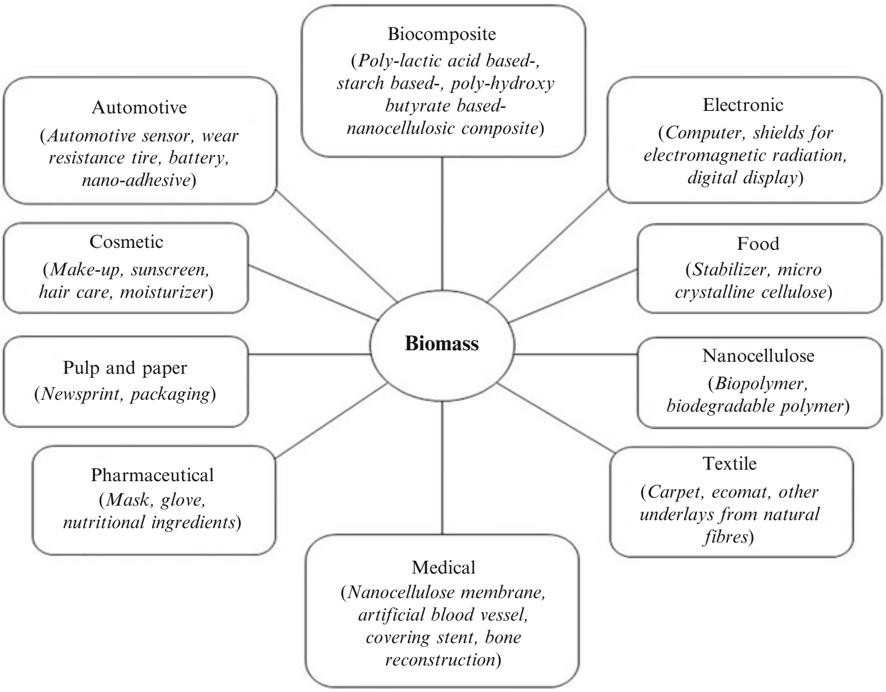

Fig. 5.9 Application and potential of biomass in various fields

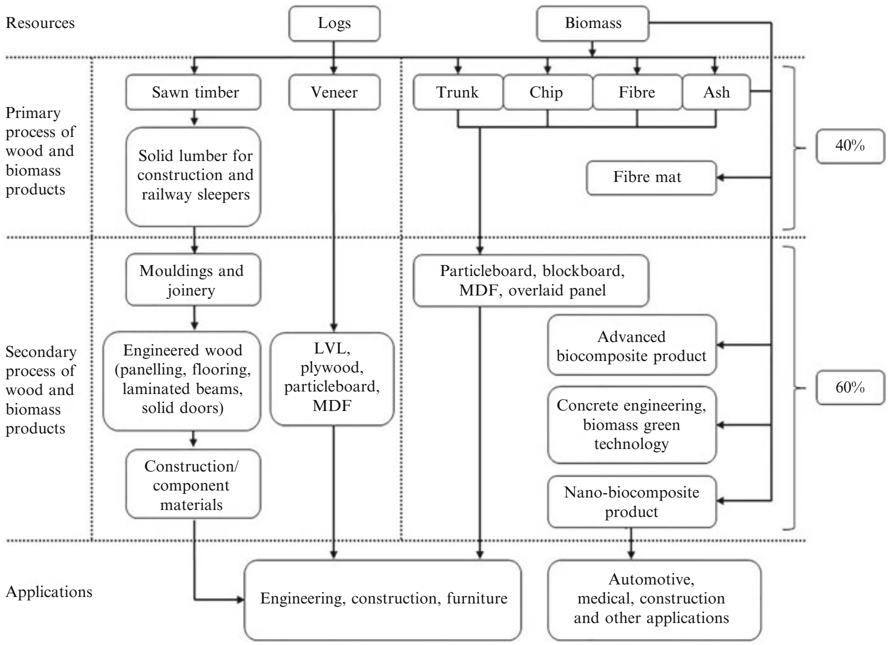

Fig. 5.10 Recommended resources and products for biocomposite (wood and non-wood) industry

tertiary level of operations, ranging from the processing of raw materials to the manufacture of semifinished and finished products. The proposed exports value percentage of the primary processing is shown in Fig. 5.10. Primary, secondary and tertiary processing activities contribute 40 % and 60 %, respectively.

5.5.2 *Value Chain of Biocomposite Industry*

Biocomposite industry is acknowledged as an important contributor to the economic growth of other industries. The biocomposite industry value chain begins from the preparation of agricultural biomass raw materials and resin production to produce consumer products (Fig. 5.11). Reduction in the supply of raw materials has caused concern and, in this context, agricultural biomass raw material is used as an alternative material for the industry to produce value-added biocomposite products. Therefore, research and development sectors are encouraged to explore the potential of natural resources for the production of new value-added products to enhance growth, competitiveness and sustainability of biocomposite industry.

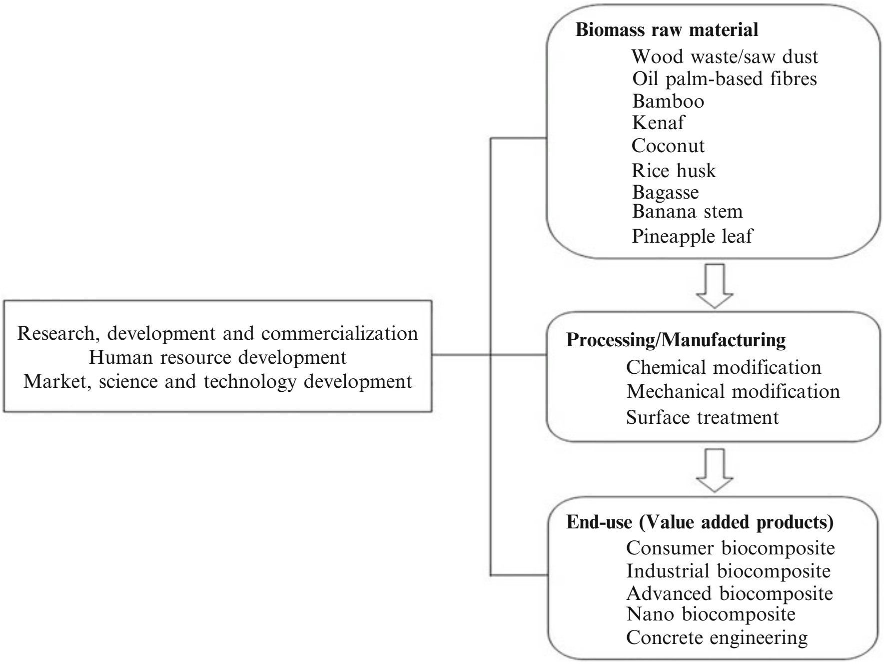

Fig. 5.11 Value chain of the biocomposite industry

5.6 Agricultural Biomass Raw Materials for Sustainable Economical Development

Wise development of agricultural biomass within prudential excellence should have some elements to ensure that the sustainability of the environment with other living thing is not affected in terms of quality and quantity. Elements of ecology, economy and technology as shown in Fig. 5.12 are determined based on the importance and the effectiveness of the product life cycle, processes and properties of raw material from excellent research by scientists.

Environmental issues often become a hot topic of the international community every year since rapid urbanization has resulted in the loss of conventional raw materials due to lack of natural resources. The world is confronted with serious environmental hazard problems such as environmental pollution, global warming, greenhouse gas emissions, ozone depletion, acid rain, extinction of habitat, flora and fauna also cause less health. The main key of all these problems is closely related to the sustainability of the world's ecology which was declining dramatically each year due to the ineffective management system of natural waste material (Kramer 2012). The industrial world has expanded exponentially over the past

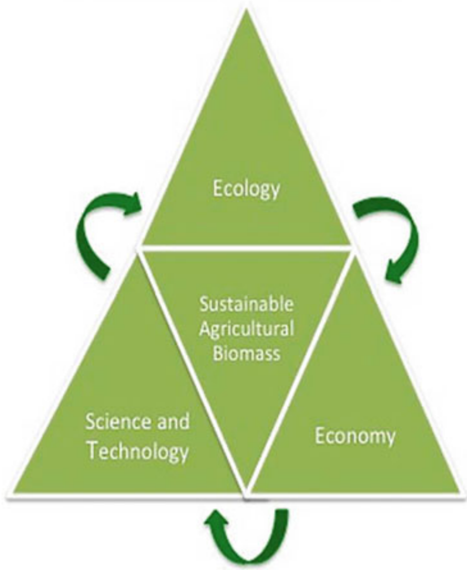

Fig. 5.12 Three elements of agricultural biomass raw materials for sustainable economical development

century involving raw materials usage without emphasizing universal aspects of sustainability, but only profit oriented that may soon become a silent killer to the world ecology cycle.

All levels in the ecology of the world will receive a direct impact on development, agricultural waste resource operation that involved in different stages. This concept can be illustrated based on the increase demand by society for the product, preservation of balance of the forest, the diversity of material resources and benefits (Bovea and Vidal 2004). Previous research demonstrated that the use of composite biomass-based products in the market can sustain the ecology and economy of a country and the effect caused very less damage to ecosystems and natural resources. Society awareness can be achieved by evaluating the advantages of using agricultural biomass materials and its impact on the environment. The perspective of the product life cycle in terms of raw materials manufacturing process, marketing and disposal should also be considered. Transformation of low impact materials such as kenaf, oil palm, coconut fibre, and bagasse is necessary to diversify the market by providing alternative sources of fibre that has many advantages in mechanical properties for advanced applications. This can increase the market potential of the new manufacturing industry in developing sustainable solutions (Kar and Jacobson 2012).

Agriculture is one of the world's largest industry also a lifeblood of the economy of each country as it involves a lot of the manufacturing sector, such as food (e.g. wheat, sugar, oil), construction (e.g. buildings, automotive) and the production of products (e.g. furniture, clothing, tools packaging). Agriculture is one of the world's largest industry also a lifeblood of the economy of each country as it involves a lot of the manufacturing sector, such as food (e.g. wheat, sugar, oil),

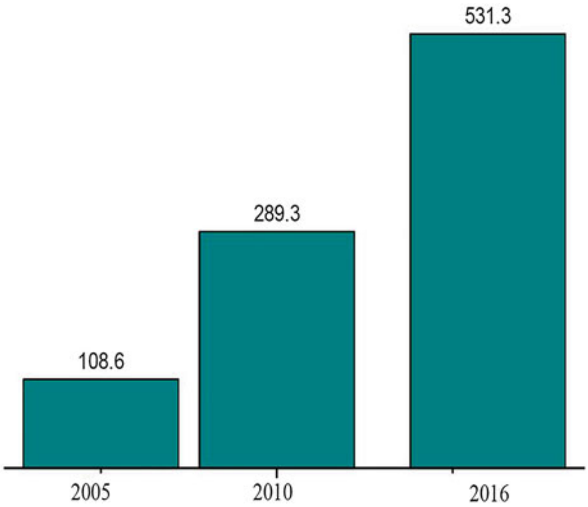

Fig. 5.13 Global growth trend and forecast (million USD) of natural fibres sector from year 2005 to 2016 (Lucintel 2011)

construction (e.g. buildings, automotive) and the production of products (e.g. furniture, clothing, tools packaging). Pawlak (2007) detected the importance of the economic transformation for country depends on how the success of the product. Economics is an important factor related to the development of the country, and the demand of natural fibres using appropriate technology to produce quality fibre reinforced for use in concrete construction is gaining high score. Among the examples of countries Japan and America who excel in a variety of advanced design and high demand in the world market successfully provide economic incentives and strengthen the country's agricultural and industrial sectors. On the other hand, the economy had jumped up along with the effectiveness of economic development based on sustainability, and product can be evaluated based on the production process of a product from base till the end by provided at minimal cost. The "waste to profit" step is very important to exploit biomass raw material in the production of value-added and innovative new products.

As shown in Fig. 5.13, the global exports trend for biomass-based manufacturing sector continues to increase every 5 years from 2005 to 2016 (Lucintel 2011). Electrical and electronic sector, pharmaceutical, textile and other significant contributors in the export value of 90 % compared to wood-based industry sector and only 10 % biocomposites. Continues scenario will be able to bring a stronger economy for the world market. Many factors such as easy planting and care, short-term crops, easy handling and minimal cost might benefit two fold compared with conventional materials (Majeed et al. 2013). For example, an oil palm biomass crop that is widely grown in ASEAN countries such as Malaysia and Indonesia can be used and converted into various products that would create an optimal supply of raw materials cycle continuously through a secure supply of quality and can prevent wastage of raw materials. Raw material costs were seen to be at the highest with carbon fibre at the price of between MYR20,000 and 50,000 per tonne, followed by fibre glass with the price starting from MYR6,000 to 10,000 per tonne, and at the lowest was oil palm fibre with the cost ranging from MYR600 to 1,000 per tonne. Advantages of agricultural waste-based manufacturing industry can have a positive impact on society and the country creates many job opportunities and is able to raise the living standards of the community (Kar and Jacobson 2012). Well-income communities while increasing consumer purchasing power and domestic sources of raw materials might be able to help reduce the loss of imports.

Over recent years, many researchers have focused on research related to agricultural waste to solve the environmental problems due to the disposal of the biomass waste material. Agricultural waste biomass have become an interesting research field and led to the creation of new solutions and materials through research and development in science and technology. The research continued to become important for producing a new generation of processes and innovative composite products with the features of a more sustainable and improved quality (Kramer 2012). Advances in science and technology enable the world's manufacturing industry to manipulate matter at the policy level to improve the overall properties of alternative materials to replace conventional materials. Technology-based research with a focus on biomass species variety with high potentialities can be grown to be applied in various industries for energy, pulp and paper, textiles, composites, cosmetic, construction, nanotechnology and pharmaceutical. This activity can make a huge impact not only on the product and the community, but to the transformation of technology development (Lane and Fagg 2010).

5.7 Conclusions

Agricultural biomass raw materials are highly potential candidates either as replacement or as complement to synthetic fibre in various applications due to their comparable properties. This integrated biomass technology is not only devoted in minimizing the environmental impact but in maximizing the performance and functionality of fibres, sustainability of resources and profitability. The growing enthusiasm to fully exploit agricultural biomass as material for green product also benefiting towards people as its generating many posts and opportunities. Agricultural biomass as a fascinating material brings the possibility to gain plenty of interest application in multidisciplinary fields. Until now, there have been a vast amount of well-established applications of agricultural biomass especially in construction, automotive, etc. However, the potential applicability of this raw material is unlimited and rapidly expanding due to their variety of unique characteristic which offered many properties that meet different requirements.

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