CELL WALL ARCHITECTURE, PROPERTIES AND CHARACTERISTICS OF BAMBOO, KENAF AND RICE STRAW FIBERS

by

IREANA YUSRA BT ABDUL FATAH

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LIST OF ABBREVIATIONS

B	Bamboo
CML	Compound Middle Lamella
DSC	Differential Scanning Calorimetric
Ep	Epidermis
F	Fiber
FDT	Final Decomposition Temperature
FT-IR	Fourier Transform Infrared
H_2SO_4	Sulfuric Acid
IDT	Initial Degradation Temperature
KB	Kenaf Bast
KBr	Kalium Bromide
KC	Kenaf Core
MDF	Medium Density Fiberboard
MFA	Microfibril Angle
ML	Middle Lamella
NaOH	Sodium Hydroxide
P	Primary Wall
Pa	Parenchyma
Ph	Phloem
RS	Rice Straw
S_1, S_2, S_3	Secondary Walls
Sc	Sclerenchyma
TEM	Transmission Electron Microscopy
TGA	Thermogravimetric Analysis
UV	Ultraviolet
V	Vessel
WAXS	Wide Angle X-ray Scattering

STRUKTUR BINA DINDING SEL, SIFAT DAN KARAKTERISTIK BAGI GENTIAN BULUH, KENAF DAN JERAMI PADI

ABSTRAK

Kajian mengenai ultrastruktur dinding sel, anatomi, komposisi kimia, penyebaran lignin dan dimensi gentian bagi gentian lignocellulosic dari buluh (B), kenaf (K) dan jerami padi (RS) telah dijalankan. Ciri-ciri anatomi seperti ultrastruktur dinding sel dan anatomi telah dikenalpasti menggunakan *Transmission Electron Microscopy* (TEM) dan *Light Microscopy* (LM). Sudut mikrofibril diperoleh daripada teknik *Wide Angle X-ray Scattering* (WAXS). Analisis kimia yang telah dijalankan merujuk kepada *TAPPI Test Standard Method*. Kumpulan berfungsi dalam gentian telah dikenalpasti menggunakan *Fourier Transform Infrared* (FT-IR). Sifat termal telah dianalisis menggunakan *Thermogravimetric Analysis* (TGA) and *Differential Scanning Calorimetric* (DSC). Dimensi gentian telah diukur menggunakan *Image Analyzer*. Dalam kajian ini, TEM mikrograf membuktikan bahawa, kenaf dan jerami padi menunjukkan ultrastruktur dinding sel adalah sama dengan kayu yang terdiri daripada lapisan pertama (P) dan kedua (S1, S2 dan S3) kecuali bagi buluh yang berstruktur polilamela. Melalui ciri-ciri anatomi, buluh dan jerami padi adalah monokotiledon dimana terdapat berkas vaskular didalam gentian, yang terdiri daripada tisu asas vascular seperti gentian, floem, vessel dan parenkima. Taburan lignin dalam gentian menggambarkan bahawa lignifikasi terbukti hanya berada pada sebahagian besar gentian, sel salur dan epidermal tetapi tidak pada floem dan sel parenkima. Komposisi kimia telah menunjukkan bahawa buluh mempunyai peratusan kandungan ekstraktif yang tertinggi diikuti oleh, jerami padi, dan kenaf, sementara jumlah holocellulose tertinggi terkandung pada kenaf diikuti oleh

jerami padi dan buluh. Dalam pada itu, buluh telah menunjukkan peratusan tertinggi bagi kandungan selulosa dan lignin berbanding kenaf dan jerami padi. Jerami padi mempunyai peratusan yang paling tinggi, manakala, buluh adalah yang paling rendah, bagi kandungan abu. Kumpulan hidroksil, carbonil dan carboksilik daripada analisis FT-IR telah membuktikan kehadiran selulosa, hemiselulosa dan lignin di dalam gentian. Nilai tertinggi bagi panjang gentian adalah pada kenaf *bast*. Gentian buluh mempunyai dinding sel gentian yang paling tebal dengan diameter gentian tertinggi dan diameter lumen gentian terendah. Bagi sifat termal, TGA telah menunjukkan kenaf mempunyai kestabilan terma dan ketahanan terhadap degradasi terma yang lebih baik kerana kepekatan hemisellulosa dan lignin yang lebih tinggi. Manakala pada DSC, perubahan endoterma kedua berlaku pada suhu 150^{o}C dan 180 ^{o}C bagi kenaf and jerami padi tetapi keadaan ini tidak wujud di dalam buluh. Suhu yang tinggi ini adalah disebabkan kehadiran kombinasi lignin dan polisakarida dalam gentian.

CELL WALL ARCHITECTURE, PROPERTIES AND CHARACTERISTICS OF BAMBOO, KENAF AND RICE STRAW FIBERS

ABSTRACT

A study on cell wall ultrastructure, anatomy, chemical composition, lignin distribution and fiber dimension of cultivated lignocellulosic fibers such as bamboo (B), kenaf (K) and rice straw (RS) were conducted. Anatomical features such as, cell wall ultrastructure and anatomy was viewed using Transmission Electron Microscopy (TEM) and Light Microscopy (LM) respectively. Microfibrill Angle was obtained from Wide Angle X-ray Scattering (WAXS) technique. Chemical analysis was done according to TAPPI Test Standard Method. The functional group in fibers was detected using Fourier Transform Infrared (FT-IR). Thermal properties were analyzed from Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetric (DSC). Fiber dimensions were measured using Image Analyzer. In this study, TEM micrograph confirmed that, kenaf and rice straw showed similar cell wall ultra structure as compared to wood with the presences of primary (P) and secondary (S_1, S_2 and S_3) layers accept for bamboo, polylamellate structure. Anatomical characteristics determined bamboo and rice straw were monocot due to the vascular bundles that appeared in the fiber, which consist of basic vascular tissue such as fiber, phloem, vessel and parenchyma. Lignin distribution in fibers illustrated that most of the fiber; vessel and epidermis exhibited an evidence of lignification except for phloem and parenchyma cell. Chemical composition analysis showed that bamboo had the highest percentage of extractive content followed by rice straw and kenaf while kenaf contained highest amount of holocellulose followed by rice

straw and bamboo. In conjunction, bamboo showed the highest percentage in cellulose and lignin content compared to kenaf and rice straw. Rice straw fiber exhibited the highest while bamboo showed the lowest percentage for the ash content. FT-IR analysis showed that appearance of hydroxyl, carbonyl and carboxylic group proved the existence of cellulose, hemicelluloses and lignin in the fibers. The highest value for fiber length was in kenaf bast fiber. Bamboo fiber had the thickest cell wall fiber with the highest in fiber diameter and the lowest in fiber lumen diameter. For the thermal properties, TGA showed kenaf had a better thermal stability and resistance to thermal degradation due to the higher concentration of hemicelluloses and lignin. While in DSC, second transitional endotherms occured at temperature 150^{o}C and 180 ^{o}C for kenaf and rice straw respectively but not appeared in bamboo. This higher temperature was due to the presence of lignin and polysaccharides combination in the fiber.

CHAPTER 1

INTRODUCTION

1.1 General

Woody and non-woody biomass (agricultural residues, wood fibers, etc) containing cellulose, hemicelluloses and lignin, is an abundant alternative source of renewable polymers that are also highly biodegradable. Recently, scientists and fiber producers are exploring the use of alternative fiber crops (such as kenaf, jute, and hemp), forestry products (such as bamboo) and agricultural by-products (such as rice straw and sugar cane) which are presently underutilized. For an example, in addition to its high strength and porosity, kenaf fiber is biodegradable, environmentally friendly, and able to grow in a wide range of climatic conditions and soil types.

The increase in the production of pulp and paper demand indirectly causes the deforestation. Since deforestation can lead to green house effect, many countries have come to realize the importance of trees to earth well-being, and thus, have taken steps to preserve forest from destruction. The increasing demand for paper worldwide has led researchers to look for alternative sources to produce virgin fiber. According to Sabhrawal *et al.* (1994), in 1900, as much as 12.9 million hectares of forest lands was cleared in order to meet global demand. This figure was expected to increase up to 23 million hectares by the year 2010. To avoid further depletion of forest lands in meeting the need of fiber industry, alternative fiber sources ought to be considered. The continuing dependence of fiber production on natural forest (95.8%) and plantation (4.2%) at the current rate cannot be sustained. Soon, the world will not be able to support per-capita consumption of fiber.

As more and more attention is paid to the protection of our environment and saving of petroleum resources, there is an increased tendency to use biodegradable natural fibers in manufactured products. One important advantage of using natural fibers to reinforce products is the possibility of designing the product by arranging (long) fibers in the direction of the applied forces in order to create lightweight components with anisotropic properties, tailored to specific requirements (Mueller *et al.*, 2002). Xiaoqun Zhang (2004) has stated that, only about 11% of the world's virgin cellulose pulp is made from non-wood sources (mainly straw, bagasse, and bamboo).

A large number of novel end-uses for cellulosic fibers have been identified and demonstrated to be technically feasible. Growing awareness of the ecological aspects of consumption and production of raw materials has been leading towards the trend of sustainable utilization of the natural resources. For an example in automotive industry, the use of cellulosic fibers as renewable raw material is receiving much attention and has shown much promise. Another potential market for lignocellulosic materials is an increased interest for renewable materials in building and construction applications.

Bamboo, kenaf and rice straw fibers are non-wood natural plant fibers which are also known as agricultural byproducts that can be found naturally abundant in Malaysia. Bamboo is one of the oldest organic raw-materials used for a large number of different purposes such as being used as raw materials in industry based production and in daily end uses. Besides its excellent properties for constructional purposes and its manifold uses as commodity, bamboo plays an important role as a basic material for pulp and paper. The increasing demand for paper in Asia is being met to a large extent by the use of bamboo (Grosser and Liese, 1971). With such abundance, relatively cheap capital investment and a weather that is perfect for propagating further bamboo stands, it is a shame that the private sector has not really explored the vast economic potential of bamboo cultivation.

Kenaf may be Malaysia's next industrial crop based on research findings about its technical and commercial potential. It was first introduced in the early 1970's in Malaysia and was highlighted in the late 1990's as an alternative and cheaper source of material for producing panel products such as fiberboard and particleboard, textiles, and fuel. Malaysian kenaf is composed of two distinct fibers, bast and core, with a makeup of about 35% and 65%, respectively. Each fiber has its own usage; thus, separation of the fibers produces higher monetary returns over whole-stalk kenaf. Major factors involved in separation of kenaf into its two fractions include: size and amount of each portion; type and number of separation machinery; processing rate through separation machinery; moisture content of whole-stalk kenaf; and humidity of ambient air.

Rice straw is produced as a byproduct of rice cultivation and is unique relative to other cereal straws for being high in lignin and silica. It is also readily available in large quantities since rice is routinely cultivated by farmers. Of late, rice straw has been subjected to increasing interest, study and utilization for some decades. The increase in environmental concern and the rapid depletion of wood species due to uncontrolled deforestation has made rice straws a potential alternative to replace wood as a source of fiber. The rice straw has almost the same physical and chemical properties as wood. Therefore, it is the good alternative for wood, where its usage can help to reduce the need of wood in the production of fiber. Further, its use will result in cleaner environment since rice straws are no longer left to rot or are burnt away in order to make way for replanting, but are now used as input in fiber production. In summary, the advantages of using rice straws instead of wood in the production of fiber is that it is abundant in supply, inexpensive and can help to minimize the environmental pollution.

At the moment, there is increasing interest in utilizing forest and agricultural residues as raw materials for industries. Therefore, from basic fundamentals to the high value product, the study and research had been done in order to maximum utilized the usage of different types of bamboo species available in Malaysia. Kenaf, a relatively new and potential wood source of fiber are now being planted in some region in the west of the Peninsular Malaysia for a considerable economical and ecological importance. As for the rice straw, generates a large amount of residues, because the straw of plant are cut and left abundant, usually are burnt as firewood. At present, only small amount of the stubble is used for the production of fiberboard, with the remainder being underutilized (Xu *et al.*, 2004). As expected, these residues could be used in a more rational way, such as a source of cellulosic fibers.

1.2 Justification

The lignocellulosic fibers had been used as a structural material. Demand for this material is increased unexpectedly because of issues, such as energy used, environmental problem such as global warming and an initiative to produce a product from the renewable sources (Bledzki *et al*., 2002; Drzal *et al*., 2003; Markus *et al*., 2003; Abdul Khalil and Rozman, 2004). In recent years, natural fibers appear to be the outstanding materials which come as the viable and abundant substitute for the expensive and nonrenewable synthetic fiber. Natural fibers like sisal, banana, jute, oil palm, kenaf and coir has been used as reinforcement in thermoplastic composite for applications in consumer goods, furniture, low cost housing and civil structures (Peters, 2002; Drzal *et al.*, 2003; Angelo *et al.*, 2006; Zampaloni *et al.*, 2007).

Various researchers around the globe have focused on the utilization of bamboo, kenaf stems (woody core and fibrous bark) and rice straw for panel manufacturing, pulp and paper in industries. But there is no substantial study available specifically on the cell wall ultrastructure, anatomy and lignin distribution of Malaysian cultivated fibers. To fill this gap, we have recently started a research program aiming to deepen the knowledge of the cell wall properties, anatomical characteristics and chemical, physical and thermal properties of these non-woody fibers. Such understanding on the basic information is of a great importance relative to its industrial processing and potential utilization in value-added products mitigating the environment concerns. Furthermore, the fibers are being studied to assess the suitability for the purposes mention above.

Taking into consideration the potential use of plant fibers, it is required that there should be more than a sufficient volume of forest and agricultural fiber available globally for new industrial products. The extent to which this potential can be realized will depend upon numerous factors, not least of which will be consumer demand, the availability of suitable processing and product handling equipment, and further development of existing and new technologies. Hence, the knowledge from this basic study can be beneficial to the food technologist, material scientist, and polymer chemist for future applied research studies.

1.3 Objectives

The main objectives were:-

1. To characterize the anatomical features of bamboo, kenaf and rice straw fibers such as cell wall ultrastructure and microfibrill angle.
2. To investigate the chemical composition, lignin distribution and thermal properties of bamboo, kenaf and rice straw fibers.
3. To study the fiber morphology and dimensions of bamboo, kenaf and rice straw fibers.

CHAPTER 2

LITERATURE REVIEW

2.1 Natural Fibers

Fiber is a class of hair-like materials that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread. They can be spun into filaments, thread, or rope. They can be used as a component of composite materials. They can also be matted into sheets to make products such as paper or felt. Fibers are of two types: natural fiber and man made or synthetic fiber. Natural fibers include those made from plant, animal and mineral sources. Natural fibers can be classified according to their origin.

Natural cellulose fibers widely used are seed hair fibers such as cotton fibers, and bast fibers, such as flax, hemp, and kenaf. Natural cellulose fibers are replacing synthetic fibers in many applications due to their biodegradability, improved acoustics of products, higher processing and operational safety, higher strength and stiffness, lower weight, and lower product cost (Mueller *et al.*, 2002).

The cellulose based fibers can be classified to wood fibers and non-wood fibers. In non-wood fibers, they can be further classified into straw, plant (such as bast, leaf and seeds) and grass. Cellulose fibers have comparatively high density and relatively low elasticity vs. synthetic fibers, and are good conductors of heat and electricity. Cellulose fibers have good resistance to bases, but are susceptible to damage by mineral acids (Xiaoqun Zhang, 2004).

2.1.1 Lignocellulosic Fibers

Lignocellulosic fibers are main polymer composite produced by cellulose, hemicelluloses and lignin containing a little of glucose, protein, starch, extractive and non-organic compound. Basically, natural lignocelulosic fibers can be categories into 3 types of fibers, which are wood fiber, non-wood fibers and non-plant fibers. Different from wood, non-wood fibers or argo-based fibers are derived from various monocotyledonous and dicotyledonous plant selected tissue (Han, 1998) and usually is an annual crop and required to harvest it in a particular time.

According to Rowell *et al.* (2000), lignocellulosic fiber have more advantages compared to other compound such as metal, plastic, glass, concrete and others. Lignocellulosic fibers from agriculture waste have high potential for food industry and non-food industry (conventional composite, polymer composite, pulp and paper). Most of these lignocellulosic fibers have been used as source for industrial material (Sreekala *et al*., 1997). The character of this fiber that can be recycle, renewable, easy to process, reactive chemical surface, environmental friendly and low cost make them a best choice as raw material for the industrial.

2.1.2 Bamboo

Bamboo grows wildly in former logging areas in Peninsular Malaysia. The total estimated area of bamboo in forest compartments is 421,722 hectares accounting for 6.9 percent of Malaysia's forested land. Bamboo fibers are classified as non-wood grass fibers. In Asia, most of them are within the Indo-Burmese region, which are also considered to be their area of origin. There are about 300 different species of bamboo were identified by Grosser and Liese (1971).

Bamboo belongs to the grass family, Gramineae, tribe Bambuseae. It is distinguished by the special structure of its stem, or culm, the fact that it reaches full height in a short period, its rapid rate of growth, and its singular flowering habit. Bamboo does not flower annually, but once every 7 to 120 years, depending on the species. At time, the species flower (generally produce seed, depending on the genus) all over the world with variances due to environmental and horticultural influences. The parent plant may then die completely.

Bamboo does best in well-drained, light, sandy soil. Organic supplements (compost, peat, mulch, and manure) are beneficial. It does like a lot of water, but once established in the ground, it is much more drought tolerant than is commonly believed. Adequate water during establishment (approximately twelve months) cannot be over emphasized. Good drainage is also critical.

Bamboo will respond impressively to a heavy fertilization schedule; fast release, slow release, and foliar feeding of major and minor elements are all recommended. As with all plants, newly acquired bamboo will do best in the light situation in which it was grown. The tropical tend to prefer full sun. This means full sun must reach the leaves. The base of the plant may be grown in shade and is often more attractive this way.

Bamboo is an evergreen plant that is it does not lose its leaves in the autumn and grow fresh ones in the spring like other broad-leaved trees. Bamboo leaves stay green throughout an average winter. In early spring the young leaves grow out and the old ones are gradually lost. All bamboo is a very hardy and vigorous plant.

Even when the stems and leaves have been severely damaged the plant will usually recover, although it may take years to regain its previous height. Bamboo is the fastest growing woody plant in the world. Their accelerate growth rate is due to a unique rhizome system and is dependent on local soil and climate conditions.

2.1.2.1 *Bambusa blumeana*

A tall, thorny bamboo originates from India and Indonesia. It is also known as "Thorny Branch Bamboo" because of the thorns around lower branches (Figure 2.1) (http://www.germanlipa.de/garten/pflanzenb.htm). It is a type of clumping with 15 m height and 10 cm in thickness. It is equally effective as a living fence. The culms are strong and straight. Applications are use for fence, furniture, construction, baskets, and edible shoots

Figure 2.1: *Bambusa blumeana* (http://www.germanlipa.de/garten/pflanzenb.htm).

2.1.2.2 Applications of Bamboo

Belonging to the grass family, the bamboo is versatile not only in its fluid movements but also in its utilitarian value. It is this very versatility that makes bamboo a good raw material for numerous applications. Along with palms, bamboos are one of the world's most important building materials, particularly in areas where timber trees are in short supply (Katleen and Ronald, 2009).

Traditionally, bamboo was used to make everything required for a rural house from bamboo stilts to roof rafters, floors to walls and even matted bamboo splits. It is still a popular material for fencing, chicken coops, fish traps, baskets, water conduits and decorative domestic landscaping. But within its versatility lies the potential for so much more. Bamboo can also be made into high-value building products such as floor boards, panels, parquets, laminates and even distinctive designer furniture (Shivaprakash *et al.*, 2008; Wegst, 2008; Mishra, 2009; Ren *et al.*, 2009).

In fact, as a building material bamboo plays an important role in almost every country in which it occurs. In Burma and Bangladesh, about fifty percent of the houses are made almost entirely of bamboo. In Jawa, woven bamboo mats and screens are commonly used in timber house frames. In tropical climates it is used in elements of house construction, construction scaffolding, as a substitute for steel reinforcing rods in concrete construction.

When treated, bamboo forms a very hard wood which is both lightweight and exceptionally durable, with an excellent tensile strength. But there are some bamboo stems which are untreated, have the same tensile strength as certain types of steel and can be used as reinforce concrete (Katleen and Ronald, 2009; Krishnaprasad *et al.*, 2009).

With modern polymer glues and bonding cements, bamboos are made into plywood, mat board and laminated beams. Modern companies are also attempting to popularize bamboo flooring made of bamboo pieces steamed, flattened, glued together, finished, and cut. However, bamboo wood is easily infested by wood-boring insects unless treated with wood preservatives or kept very dry.

Bamboo fiber is also a unique biodegradable textile material. As a natural cellulose fiber it can be 100% biodegraded in soil by microorganisms and sunshine. It is a common fact that bamboo can thrive naturally without using pesticide. Scientists have found that bamboo owns a unique anti-bacterium and bacteriostatic bio-agent. This substance is combined with bamboo cellulose during the process of being manufactured into bamboo fiber resulting in a naturally antibacterial fabric. It is also characterized by its good hygroscopic and excellent permeability.

Another benefit of bamboo fiber is its unusual ability to breathe and ventilate. A cross-section of the bamboo fiber will show that it is filled with various micro-gaps and micro-holes, giving excellent moisture absorption and ventilation. With this unparalleled micro-structure, bamboo fibers fabrics can absorb and evaporate moisture in a split second, making people feel extremely cool and comfortable in the hot summer (Rekha and Sudam, 2009).

2.1.3 Kenaf

Kenaf (*Hibiscus cannabinus* L.) is a traditional, third world crop after wood and bamboo that is poised to be introduced as a new annually renewable source of industrial purpose in the so-called developed economies. Kenaf, a family member of Malvaceae is a warm-season annual fiber crop growing in temperate and tropical climate condition areas. In tropical climatic, it can produce twice crops per year (Figure 2.2 a).

It is related to cotton, okra, and hibiscus due to systematics. It is a fibrous plant, consisting of an inner core fiber (60–75%), which produces low quality pulp, and an outer bast fiber (25–40%), which produces high quality pulp, in the stem (Voulgaridis *et al.*, 2000). Mechanical properties of kenaf fibers are similar to those of jute, but kenaf fibers are stronger, whiter, and more lustrous.

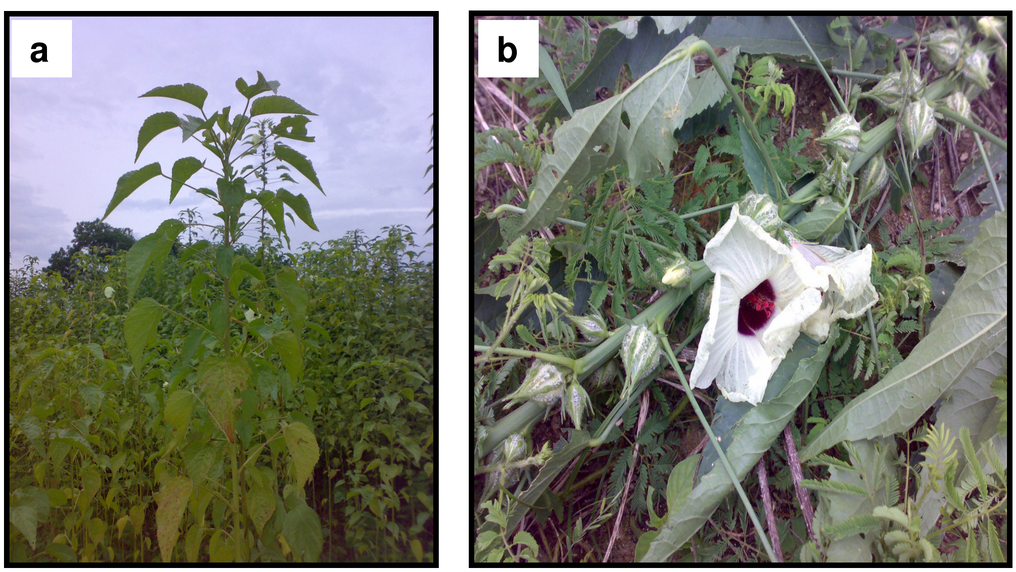

Figure 2.2: (a) Cultivated Malaysian kenaf; (b) The kenaf stem and flower (Abdul Khalil *et al.*, 2009).

Each plant of kenaf has a single, straight stem without a branch. The leaves are individually stalked and lobed to some degree. Flowers are yellow or white with a red centre (Figure 2.2 b) and can be up to 10cm in diameter. Fruits are fleshy; producing seed capsules 1cm long containing many seeds. Seeds are brown and wedge shaped, 5 mm long with a 1000-grain weight of 25g.

Kenaf grows fast and will achieve 5 to 6 m in height and 2.5 to 3.5 cm in diameter within 5 to 6 months (Kaldor *et al.*, 1990; Kaldor, 1992; Sabharwal *et al.*, 1994). Kenaf seeds require two to three months of frost free condition to reach the point of germination (Sullivan, 2003). It's mode of reproduction was through seed and it fibers was pale in color. It is harvested for its stalks, from which the fiber is extracted.

Table 2.1 showed the chemical composition and climatic requirement of kenaf. As an annual crops plant, it capable to produce annually yields approximately 6 – 10 tons of dry fibers per acre (Clamari *et al*, 1997).

Table 2.1: Chemical composition and climatic requirement of kenaf (Roswell, 1998).

	Chemical Composition		**Climatic requirement**		
	Cellulose (%)	Lignin (%)	Minimum moisture (mm)	Optimum soil (pH)	Growth cycle
Kenaf	44 – 57	15 – 19	120	6.0 – 6.8	150 – 180

Kenaf requires less than six months for attaining a size suitable for practical application. Due to the fast growth and good fiber quality, since the 1960's, there has been increasing interest in kenaf, primarily for its potential use as a commercial fiber crop for the manufacture of newsprint and other pulp and paper products, leading to collaborations between research and development, economist, and market research.

In addition, kenaf stem are environment-friendly. It has a substantially higher ability to absorb carbon dioxide compared to other plants. Due to its ability to absorb and retain a large amount of carbon dioxide, it is known as a plant that can contribute to global warming prevention.

With a decrease in wood resources, interest has grown in using kenaf as an alternative raw material for pulp because it has the excellent advantages of being renewable, inexpensive, and easily grown even under severe conditions such as low water supply and little fertilizer. Kenaf production yields are favorable when compared to softwood and the hardwood. Recognizing its immense potential and interest generated by its fiber potential for the wood-based sector, the Malaysian government has pursued various measures to promote downstream value-added processing of kenaf as well as its cultivation among smallholders and estate owners.

2.1.3.1 Types of Kenaf Fiber

The stalk of the kenaf plant consists of two distinct fiber types. The outer fiber is called "bast" and comprises roughly 40% of the stalk's dry weight. While the whiter, inner fiber is called "core", and comprises 60% of the stalk's dry weight. These refined fibers measure 0.6 mm and are comparable to hardwood tree fibers, which are used in a widening range of paper products. Kenaf fibers can be use either in whole stalk or in separated forms.

Bast are the strong fibers in the phloem of a number of dicotyledonous plants, in particular jute, hemp, flax, ramie, kenaf, roselle hemp, etc. They support the conductive cells of the phloem and provide strength to the stem. Bast fibers are often called skin fibers, since the fiber is extracted from the "skin" of the plant. Kenaf bast fibers consist around 35 – 40 % by weight and 3 – 4 mm long of fibers length (Kaldor *et al*., 1990).

The physical paper properties such as opacity, porosity and surface roughness which are produce from these kenaf bast fibers are quite similar to wood pulp (Kaldor *et al*., 1990). Therefore, these types of fibers are suitable to replace the used of wood pulps. The bast of some plants is commercially important fiber crops. Bast fibers are use in industrial non-woven products because the fibers are low density, local raw material at a good price, good mechanical properties, good workability and good recycling properties.

While, the core fibers; consist of 60 – 65 % by weight with the fibers length 0.5 – 0.7 mm. It has high tensile strength and burst strength, beside it also has low tearing strength (Kaldor *et al*., 1990).

The decision to separate the bast fiber from the core was based on value-added products that can be made from the two different fibers. While whole stalk kenaf that be used to produce the end product must made using high purity core and bast fibers.

Other markets for high purity fibers include plastic and non-woven applications. Thus, bast/core separation is important to insure possibilities that the two fibers can be used for the highest value product.

Industry derives two distinct fibers from kenaf stalks: long-fibered, bast fiber from the bark, and short-fibered, wood-like fiber from the stem core. The end-products depend on the fiber portion used. The different usage or applications are shown in Table 2.2.

Table 2.2: The applications of kenaf core and bast (Xiaoqun, 2004)

Core	Bast
The core fiber was processed and being used in products such as: - packing material, oil-absorbent mats, burned for fuel, sorbents, poultry house and laboratory animal bedding, chicken and cat litter, paper, particle boards, engineered lumber,	The bast fiber was used in making products such as: - carpet padding, cordage, inexpensive paper, fine writing paper, cigarette paper and tea bags, yarns, ropes, handicraft, geotextile (netting or matting), traditional carpets, hessian or burlap, sacks, non-woven mats and carpets, composite boards as furniture materials, automobile door panels and headliners.

2.1.3.2 Applications of Kenaf

Kenaf's major use for several decades was in the pulp and paper industry as a substitution of wood due to world wide decrease of forest resources. Before kenaf used as a potential alternate source for pulp and paper production, it was used as a coarse textile and cordage.

In the early of 1960s, researchers began to study kenaf as a source of virgin fiber. Researchers have been successfully made newsprint paper by blending kenaf chemithermomechanical pulp with kraft pulp in a fixed ratio (Horn *et al*., 1992). Newspaper made from kenaf pulp is whiter, stronger, and smoother, has better ink retention, and does not yellow with age as readily as wood pulp based newsprint (Kaldor *et al*., 1990).

Kenaf by itself or together with other annual bast plants like flax, hemp and jute could also be used in the making of lignocellulosic boards, such as particleboards or fiber boards, which are the most popular building materials in the furniture and interior decoration industry. For example, Kozlowski *et al.* (1999) found that bast plants such as kenaf could be used as one of the main components to build a special three layer structure flame-resistant lignocellulosic particleboard. While Sellers *et al.* (1993) found that the woody core of kenaf has potential application as raw material for low density panels used as thermal resistance or sound absorption building materials.

Another potential use for kenaf is hardboard or medium-density fiberboard. Very little research has looked into this possibility, particularly in using the whole stalk.

Besides fiberboard for housing construction, kenaf can also be used to make car seats, padding and trimmings, and various grades of paper from newsprint to bond paper. As automakers paid more attention to the recyclability of newly produced vehicles, researchers found that kenaf is ideal for making automotive non-woven composites because of its high strength and porosity structure. Incorporating kenaf fibers in the manufacture of automotive non-woven, not only increased the biodegradability of the non-woven, but also reduced their weight and enhanced their noise absorbent ability.

Kenaf fibers were also found their utilization in the manufacturing of fabrics. Kenaf's strength and resistance to rot and mildew make the fabrics containing kenaf fibers attractive in diverse applications. Fashion designers are always looking for novel textiles, and the characteristics of the retted kenaf fiber made it possible to be applied in the apparel industry. After retting, kenaf fibers are still too stiff to spin. They need to be chemical softened to go through yarn and fabric process (Xiaoqun Zhang, 2004).

2.1.4 Rice Straw

Straw is an agricultural by-product waste, the dry stalk of a cereal plant, after the nutrient grain and seed has been removed. Straw makes up about half of the yield of a cereal crop such as barley, oats, rice, rye or wheat. In rice-producing countries, rice straw constitutes an important source of roughage for ruminant. The estimated annual amount of rice straw in Asia was 541 million tones, representing 53% of the total cereal straw production in Asia and 90% of rice straw in the world (Haifeng *et al.*, 2006).

Rice is a keystone of the grass family that produces a vast number of grains consumed by humans and is an annual crop that needs to be harvest each year. One-third of the population of whole world depends on rice for vital nutrition and has been under intensive cultivation originating in Asia for over 4,000 years and has since spread across the world. Rice is grown in partially submerged fields, also called paddies, and when mature, the plant reaches a height of approximately three feet (one meter).

Rice is in the genus *Oryza*, which is separate from that of wheat and similar grass crops, although it resembles them in structure. It also has a small cluster of kernels at the top of a long stalk. Rice is harvested when it turns golden, and the resulting crop is threshed to remove the hulls. Many developing nations use the chaff of rice as fuel for electricity generation.

Rice straw is an abundant by-product waste of rice production (Figure 2.3) (Ireana Yusra and Abdul Khalil, 2009). Recently, there has been increasing interest in exploiting low quality straws for ruminant feeding in many Asian countries, because the cost of good quality forages is often high and forage availability is limited. However, the nutritive value of rice straw for ruminants is relatively low due to its high lignocellulosic content, low crude protein content, poor palatability, and low organic matter digestibility. In addition to its high cell wall content, the ruminant degradability of rice straw is limited by its epidermal surface which contains a high concentration of silica compare to most other grass plant, which acts as a physical barrier preventing bacterial attachment (Widyastuti *et al*., 1987).

Figure 2.3: Rice straw (Ireana Yusra and Abdul Khalil, 2009).

Rice straw also has a high content of cellulose and hemicellulose (about 70%) with energetic values similar to those of corn. Unfortunately, these carbohydrates have no values either as animal feeds, since they are hardly digested by ruminants and cannot be digested by single gutted animals and humans or as feedstock for sugars production because of a very low conversion if they are not chemically and physically pretreated.

On the other hand, about 188 million tones of rice straw are produced in China annually, but only limited amount of it is used for animal feeding. In some areas of China, straws are burned after cropping in the field by farmers, causing serious pollution problems (Haifeng *et al.*, 2006). However, several concerns about this practice have arisen in terms of air pollution, and therefore, it is necessary to look for other uses for the straw. Several groups are trying to use rice straw as a feedstock for ethanol production (Ye and Jiayang, 2002).

2.1.4.1 Applications of Rice Straw

Rice straw can be modified into quality rice straw paper. The rice straw paper is strong, absorbent, finely made and designed for arts usage. Rice straw paper is widely used in Carlifornia and Philippine. Rice straw is also excellent in strength and thickness of fibers. When the paper is coat with heavy paint, the bottom layer of the paper functioned as a blotting paper, taking up extra moisture from top layer while the full-bodied tonal effect was being perfectly preserved. This rice paper is favored for its stable ink response to the printing blocks in the printmaking.

Rice straw can be use in construction materials. In acoustical basis material produce from rice straw, contain good quantity acoustic. Acoustical sound absorbing panel have been used successfully to control problem with noise and sound in all types of indoor environment. It can reduce tension, make music sound better, allow people to speak and heard better and provide safer work environment.

Other than using as paper making, animal forage and acoustics basis material, rice straw also can be converting into inexpensive new renewable sources of biofuels. There is study discussing on innovative way to boost production of biofuel from rice straw by nearly 65%. Example for type of biofuels is ethanol fuels.

2.2 Cell Wall Ultrastructure

2.2.1 Cell Wall Architecture

Wall architecture varies in different types of cell and in the different layers of the wall (Brett and Waldron, 1996). In addition, all walls known contain a crystalline polysaccharide of specific composition embedded in a matrix consisting usually of the wide variety of polysaccharide and of other compounds (Preston, 1974).

The overall structure of the cell wall is extremely complicated, with a great complexity and variety of the components. A number of investigators have attempted to produce models of the whole cell wall. Therefore it is perhaps best to visualize the cell wall architecture as containing a number of polymer networks which, further to form the whole complex structure. The certain amounts of main polymer networks distribute in the wall are including the cellulose-hemicellulose networks; the pectin networks; the extension networks and the lignin networks (Brett and Waldron, 1996).

2.2.2 Plant Cell Wall Formation

Plant cells formed walls in shapes of few layers. The earliest cell wall layer is formed in the cells divide level. This layer is known as the middle lamella situated in the middle of close two cell wall. It is formed from cell plats that always exist during the cells divide process. After the cells plat becomes matured, the young cell continues to produce the next layer that is known as primary wall. The thicknesses of these walls are maintained between 0.1-1.0 μm where these walls continue to ballooned when the cells continue to form on the surface area (Eames and MacDaniels, 1974).

Most cells only consist of two layers, but there are some cells that continued to produce one more layer that are known as secondary walls. These layers are thicker than the primary wall. All cell wall layers consist of two phase that is microfibril and matrix. Microfibril phase are differentiated from matrix phase in terms of high degree of crystallizations. Microfibril phase consists from long and thin structure known as microfibril. Table 2.3 shows the main component in matrix that exists in plant cell walls (Mauseth, 1988; Brett and Waldron, 1996).

Table 2.3: Cell wall components (Brett and Waldron, 1996).

Phase	Components	
Microfibril	Cellulose (β 1, 4-glukan)	
Matrix *	Pectin	Ramnogalaktoronan I Arabinan Galaktan Arabinogalaktan l Homogalakturonan Ramnogalakturonan ll
	Hemicellulose	Xylan Glucomanan Manan Galactomanan Glucuronomanan Xyloglucan Kalos (β 1,3-glucan) β 1,3-, β 1,4-glucan Arabinogalactan ll
	Protein	Ekstensin Arabinogalactan-protein Others including enzyme
	Phenolic	Lignin Ferulic acid Others like coumaric acid, truccilic acid

* Not all of these matrix components are in all cell walls

2.2.3 Plant Cell Wall Ultrastructure

The main components wood cell wall consists of cellulose, hemicellulose, and lignin and pectin substance. Each has been studied for a few years but knowledge about biosynthesis, structure and the elements plus three dimension chemical components collection in the cell wall still not fully understood. Research in this field is found rather difficult because of the cell wall ultrastructure varies among species, tissue, cells among tissue and also in morphology which are different in each cell wall (Grunwald *et al*., 2002).

According to Smook (1992), wood fiber cell wall consists of a few layers (Figure 2.4). The middle lamella has high lignin level separating two fibers close by. Every fiber has a primary wall and three layers of secondary walls (S_1, S_2 and S_3) with certain microfibril order.

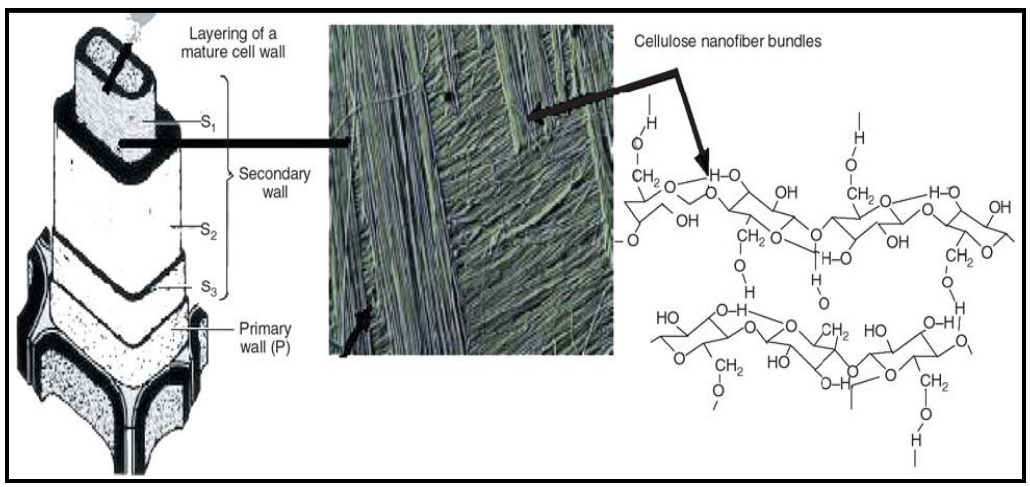

Figure 2.4: Microstructure of wood fiber cell wall: P, primary wall; S1, S2, and S3 are the inner, middle and outer layers of the secondary wall, respectively (Kamel, 2007).
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In all plant fiber, these cell wall layers consist of cellulose, hemicellulose and lignin in various quantities. Cellulose reach the highest percentage in S_2 layer (about 50%) and lignin have the highest percentage in middle lamella (about 90%) where principally it is free of cellulose. S_2 layer till now is the thickest layer and dominates fiber element. In S_2 layer, microfibril is in almost parallel position with axis fiber.