RETTING PROCESS OF SOME BAST PLANT FIBRES AND ITS EFFECT ON FIBRE QUALITY: A REVIEW

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Retting is the main challenge faced during the processing of bast plants for the production of long fibre. The traditional methods for separating the long bast fibres are by dew and water retting. Both methods require 14 to 28 days to degrade the pectic materials, hemicellulose, and lignin. Even though the fibres produced from water retting can be of high quality, the long duration and polluted water have made this method less attractive. A number of other alternative methods such as mechanical decortication, chemical, heat, and enzymatic treatments have been reported for this purpose with mixed findings. This paper reviews different types of retting processes used for bast plants such as hemp, jute, flax, and kenaf, with an emphasis on kenaf. Amongst the bast fibre crops, kenaf apparently has some advantages such as lower cost of production, higher fibre yields, and greater flexibility as an agricultural resource, over the other bast fibres. The fibres produced from kenaf using chemical retting processes are much cleaner but low in tensile strength. Enzymatic retting has apparent advantages over other retting processes by having significantly shorter retting time and acceptable quality fibres, but it is quite expensive.

Keywords: Kenaf; Bast long fibres; Retting; Fibre characteristics; Pectic materials; Enzyme

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INTRODUCTION

Plant fibres such as sisal, ramie, bamboo, kapok, pineapple, coir, hemp, jute, flax, and kenaf are generally classified by the part of the plant from which they are obtained such as leaf, seed, fruit, stem, and bast. As its name implies, bast fibres are obtained from the outer layer, i.e. the inner bark or phloem, of bast surrounding the plant stem. The fibres are usually very long (as long as the stem) and are relatively strong. For this reason, the bast fibre is considered to be the most important fraction of any bast plant. Since all plant fibers are made up of mainly cellulose, they are categorised as “natural cellulosic fibers”, which may consist of one plant cell or an aggregate of cells cemented together by non-cellulose materials. Thus, a cellulosic fiber can be either unicellular like wood and cotton, or multicellular like jute, hemp, flax, and kenaf (Sur 2005). Jute, for example, has 5 to 15 cells, i.e. the ultimate cell, which may be reduced upon storing or processing. Because of this characteristic, fibers that are separated from bast plants are often referred to as “crude fiber” (aggregates of single fibers bound together), which are usually much coarser and much longer, whilst those reported in many studies are defined based on scanning electron micrographs of microfibrils or single-strand fiber. Hence the reported average fiber lengths and widths reported are much smaller, e.g., respectively 2.5 mm and 18 µm for jute (Sur 2008), versus 2.3 mm and 16.1 µm for kenaf (Paridah et al. 2009). The terminology is sometimes interchangeable, thus readers may have to make their own inferences based on the context of the discussion.

Bast fibres are produced and used to manufacture a wide range of traditional and novel products; these include textiles, ropes and nets, carpets and mats, brushes, and mattresses, in addition to paper and board materials. They can be used in many ways, for instance, in the form of fine powder as in sawdust, short fibres as in random and non-woven mat, or even long fibres as in woven mat, for making various kinds of biocomposite products. Some composites made from natural fibres have useable structural properties at relatively low cost (Mohanty et al. 2001). Advantages of bast fibres over the traditional reinforcing fibres such as glass and carbon include low cost, low density, high toughness, acceptable specific strength properties, improved energy recovery, carbon dioxide sequestration, and biodegradability. With the increasing consciousness of preserving the environment and the need to recycle, there has been renewed interest in composite sectors using natural fibres as partial replacement for synthetic carbon, glass, or aramid fibres. Long fibres offer greater flexibility for enhancement processes, particularly in the woven and pultrusion composite industries (Paridah and Khalina 2009). The long fibres are transformed into threads or yarns that are used to join, connect, or attach to each other. According to Sur (2005) any textile fibre should be made up of long-chain molecules so as to ensure continuity and strength along the length of the fibre axis. The homogeneity of this long fibre depends very much on the technique of producing the fibre bundles, which is known as the retting or degumming process.

COMMON BAST FIBRES

Hemp (*Cannabis sativa* L.) is the earliest developed source of plant bast fibre, and it has gained considerable interest, since it produces a strong and durable fibre (Kymalainen 2004). Hemp prefers a mild climate, humid atmosphere, and a rainfall of at least 625 to 750 mm (25 to 30 inches) per year. Hemp requires a good soil moisture for seed germination, and for young plants to grow until about a month old. The world hemp fibre market is dominated by low cost producers such as China, South Korea, and the former Soviet Union, which together produce about 70% of the worlds supply. It was restricted as a narcotic drug in the US in 1948; thus the cultivation of this plant has since been limited. Nevertheless, many traditional growing countries still continue to produce textile grade fibre from hemp. Studies to develop composite materials from hemp fibres for building industry are also being carried out (Thygesen 2005).

Jute (*Corchorus capsularis* and *Corchorus olitorius*) is the most important bast fibre in Bangladesh and India. In hot and humid climate jute plants can be harvested within 4 to 6 months. Jute is traditionally used as textile fibres for fabrics, particularly for making jeans and other heavy-duty types of fabrics. As a textile fibre, jute produces poorer quality fabrics compared to cotton and silk. To improve the quality, many jute yarn producers blend their products with either cotton or silk for making apparels. However, the major breakthrough came when the automobile, pulp and paper, and furniture industries started to use jute for the production of non-woven and woven composite materials. Nowadays, more jute manufacturers are shifting their interests towards biocomposites and pulp and paper products. Amongst the bast fibre plants, jute has become the most produced and traded in the world markets.

Flax (*Linum usitatissimum*) production goes back to ancient history. It can be grown and harvested within three months under reasonable moisture and relatively cool temperatures (Oplinger et al. 1989). Flax has also been considered as a source of linen, providing high-quality fibres for textiles for thousands of years (Lamb and Denning 2004). Longer fibers are used for spinning into yarn and making textiles, a fabric type that is also known as linen. Shorter flax fibers are either spun into yarns, often mixed with cotton, or used in many other novel applications including packaging materials, reinforcements for plastics and concrete, asbestos replacement, panel boards, lining materials for vehicles, and alternatives for fiberglass as an insulation material. One advantage of flax fiber is it's ability to absorb up to 12% of its own weight in water, and its strength increases by 20% when wet. It also dries quickly, and it is anti-static. For some applications it is a suitable substitute for man-made synthetic fibers such as heavier fiberglass. The fibers are twice as strong as those of cotton and five times as strong as those of wool (Garstang et al. 2005).

Another equally popular plant fibre is kenaf (*Hibiscus cannabinus* L.), which sometimes is used interchangeably as mesta (*Hibiscus sabdarifa)*. Both types grow well in tropical and sub-tropical areas. The characteristics of kenaf fibres (both bast and core) are similar to those of wood, while hemp, flax, and jute fibres are substantially different. According to research results (Wood 2000; Rymsza 2000; Kozlowski 2000), kenaf yields are greater than those of hemp, flax, and jute, thus providing a more cost-effective raw material. The dry fibre yield was reported to be between 5 and 6% of the fresh stems, and this equals 18 to 22% of the dry plant. In the U.S., dry yields of 1 to 2 ton/ha have been reported, but yields of 3 to 4 ton/ha can be reached under ideal conditions (Dempsey 1975). Paridah and Khalina (2009) reported that under a Malaysian climate, yields of kenaf vary from 2 ton/ha to 25 ton/ha, depending on among others, soil type, month planted, variety, and planting density.

Kenaf has a long history of cultivation for its fibre in the U.S.A, Bangladesh, India, Thailand, Australia, Indonesia, and to a small extent in Southeast Europe, parts of Africa, and Brazil, where it is cultivated throughout the year. Similarly with other bast fibres, kenaf comprises two distinct fibres: the bast (30% of the total dry weight of the stalk) and the core (70%) fibres (Sanadi et al. 1997). In addition, the whole parts of kenaf stem can be used to make composites or other products. The core part resembles low-density wood, having light straw colour and density of about 0.1 g/cm^3.

Kenaf and jute are among the least expensive, most versatile textile fibres and provide reliable employment in many rural areas (Rome 1998). In many developing countries such as India, Thailand, and Indonesia the development of kenaf industry may be the key to future advancement of rural areas, provided that kenaf can be tailor-made for specific higher value products such as technical textile, security paper, winery notes, etc. Such applications rely very much on the retting method, a process of separating the bast fibres from the core and converting these fibres into individual fibres. Retting degrades the pectin-rich bast and lignin in the middle lamella that is connected to the adjacent fibre cells, releasing individual bast fibres (Sur 2005; Zhang et al. 2005). The long period of natural degradation, which normally ranges from 14 to 28 days, can be considered as the dominant problem in the production of long fibre. Water retting, the conventional method for long fibre production, was reported to generate much water pollution (Lu et al. 1999). In rural areas of China, Bangladesh, and India, a paddy field method of retting has been practiced in a fixed and small area, but the resulting fibre is very much degraded (He and Zhao 1990). Other types of retting have been extensively studied, such as low cost pond (Anon 2009), mechanical decortication, and water and chemical retting (Paridah and Khalina 2009; Kawahara et al. 2005; Goodman et al. 2002).

Kenaf cultivation has declined significantly since 1990 (FAO 2008) due to land inavailability, competition with other food crops and slow technological advancement in mechanization. Nevertheless from the reports of Food and Agriculture Organization (FAO) (Anon 2008) and the International Jute Study Group (IJSG) (Anon 2009) the demand for kenaf has never been diminishing, and in fact it is still growing. Such increment is due to the global awareness and trend of using green material, and kenaf offers many advantages over other bast plants, particularly for the Asian region.

This paper reviews the production, anatomy, retting processes, and the effects of retting method on fibre qualities of four major bast fibre crops, namely hemp, jute, flax, and kenaf. Since kenaf has been recently declared as Malaysia's seventh commodity, this review mainly focuses on the use of kenaf fibres as compared to hemp, jute, and flax.

Annual Production of Bast Plant Fibres

Detailed global supply/demand and price analyses for hemp, jute, flax, and kenaf are not available widely. The following statistics were taken from various sources, hence may have some discrepancies in the basis of calculations. Nevertheless, for comparison purposes the values are quoted as they appeared in the respective sources. Tables 1, 2, and 3 show the current world leading producers of jute, hemp and flax, and kenaf, respectively. Jute continues to dominate the natural fiber market with a continuous stable supply at 3,225,000 tonne, whilst hemp and flax together are close to 300,000 tonne, and kenaf is at an average of 400,000 tonne annually.

Table 1. Top World Jute Producers in 2008 by Country

Country	Production (x 10^3 tonnes)
India	2,1401
Bangladesh	8001
People's Republic of China	992
Côte d'Ivoire	401
Thailand	311
Myanmar	301
Brazil	26.712
Uzbekistan	201
Nepal	16.782
Vietnam	111
World	3,225.49

Source: Food And Agricultural Organization of United Nations: Economic and Social Department: The Statistical Division, 2008

Table 2. Top World Flax and Hemp Producers in 2005

Country	Production (x 10^3tonnes)			
	Flax			Hemp
	Long Flax fiber [tonnes]	Short Flax fiber [tonnes]	Total	
Belgium	19 .03	11.89	30.92	-
Czech Rep	2 .93	3.55	6.48	. -
Germany	0.11	0.12	0.23	2.36
Spain	-	-	-	1.7
France	105	75	180	14
Italy	-	0.13	0.13	0.42
Lithuania	0.32	0.75	1.07	-
Latvia	2.54	3.80	6.34	-
Hungary	-	-	-	0.94
The Netherlands	4.52	3.33	7.85	0.08
Austria	82	0.13	82.13	0.44
Poland	0.15	0.12	0.27	0.14
Finland	-	0.10	0.10	0.008
UK	-	0.12	0.12	1.58
People's Republic of China	25	-	25	43
Total			340.64	64.67

Source: Food And Agricultural Organization of United Nations: Economic And Social Department: The Statistical Division, 2008. Note: Values were rounded to two decimals.

Table 3. Top World Kenaf Producers

Country	Production (x 10^3 tonnes)				
	2004	2005	2006	2007	2008
India	198.00	203.20	202.14	198.70	156.40
People's Republic of China	125.90	136.00	155.00	165.00	86.92
Thailand	29.60	29.50	41.00	57.00	35.66
Vietnam	11.30	14.60	20.50	21.00	14.20
Brazil	7.30	7.20	10.20	10.90	12.65
Cuba	10.00	10.00	10.00	10.00	10.00
Indonesia	7.00	7.00	6.82	7.00	7.00
Myanmar	1.63	3.73	9.45	11.27	5.26
Cambodia	0.20	0.20	0.50	0.50	0.65
World	390.93	411.43	481.37	481.07	328.74

Source: Food And Agricultural Organization of United Nations: Economic And Social Department: The Statistical Division, 2008. Note: Values were rounded to two decimals.

Table 4 shows the world annual production and prices for hemp, jute, flax, and kenaf. Both hemp and flax have been dominated by the European countries, whilst jute and kenaf by the Asian. The prices of bast fibres from these stems range from USD$ 0.60 to 0.90 per kilogram, with jute maintaining reasonably high prices. These are the prices officially quoted by various reports up to the preparation of this manuscript. As indicated in Table 4, among the four bast fibres, kenaf seems to be more economically favorable, producing reasonably high yield with a good selling price. Kenaf prices have escalated between five to eight times as a result of new demands by composite industries that include building, automotive, defense, and aerospace in their efforts to combat the current environmental issues, and in meeting the government policy. This trend can be seen in the Malaysian kenaf market, as shown in Table 5. The Malaysia climate with its abundant sunshine, together with availability of rainfall throughout the year offers a suitable environment for kenaf. In such a climate, kenaf is able to grow all year round and can be harvested twice a year. Other Asian countries that fall under the same category are Thailand, Indonesia, Myanmar, and Vietnam. Between 1990 and 2002 Thailand used to be the major producer and consumer of kenaf (Anon 2003); however this scenario has changed due to competition with other crops as well as environmental issues due to water retting.

Table 4. Annual Production and Prices of Hemp, Jute, Flax and Kenaf

Fibre type	Botanical name	Family	Main sources	Stem production (10^3 Tonnes) per hectare	Prices ($/kg) of dry bast fiber	Refer-ences
Hemp	*Cannabis sativa* L.	Cannabaceae	Germany, UK, France and possibly Romania	214	0.7-0.8	1,2,5,6
Jute	*Corchorus capsularis*, *Corchorus olitorius*	Tiliaceae	Bangaladesh, India	2850	0.8-0.9	5,6,7
Flax	*Linum usitatis-simum*	Linaceae	France, Spain, Belgium, Lithuania,UK	830	0.6-0.8	1,2,3, 4,5,6
Kenaf	*Hibiscus cannabinus*	Malvaceae	Bangaladesh, China	970	0.7-0.8	1,2,5,6

1 Rebson et al. 1993; 2 Rwell and Han 2000; 3 Semder and Liljedahl 1996; 4 Karus and Kaup 2002; [5] Mwaikambo et al. 1999; 6 llison and McNaught 2000, 7 Riccio and Orchard 1999.

Table 5. Selling Price[1] of Kenaf Stem, Short Fiber and Core in Malaysia

Raw material	USD/tonne			
	2007	2008	2009	2010
Stem	91	91	152	152
Short fiber (70mm-150mm)	n/a	525	525	525
Core	n/a	46	91	91

[1] One US Dollar is equivalent to RM3.06 (as of October 2010)
Source: Kenaf Fibre Industries, 2010

Anatomical Structures of Bast Fibres

Generally, bast fibre bundles are composed of elongated thick-walled ultimate cells that are joined together both end-to-end and side-by-side, forming aggregates of fibre bundles along the height of the plant stem. During the growing period of the stem, a circumferential layer of primary fibres are developed from the protophloem, but, as vertical growth ceases in the lower parts, the secondary phloem fibres (where the bast fibres can be obtained) are developed as a result of cambial activity. Figure 1 shows stem and cell structure of hemp, jute, flax and kenaf. Unlike cotton which is unicellular,

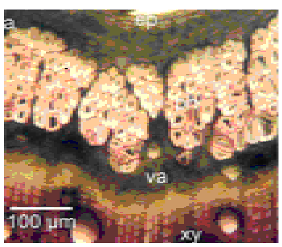
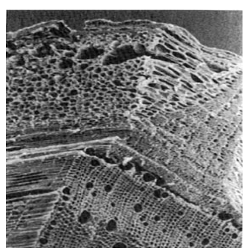
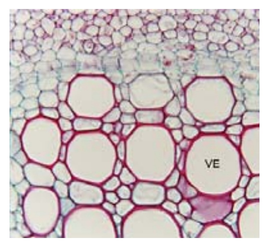
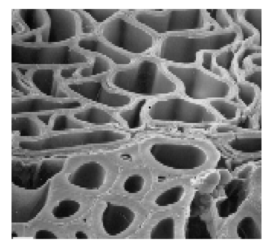
	Type of plant			
	Hemp	**Jute**	**Flax**	**Kenaf**
Stem				
cells	 Cross-section of hemp bast fibers. (6)	 Jute stem (combined transverse section and longitudinal section).(5)	 Flax stem in transverse section. (4)	 Bark (lower part) and core (upper part) in transverse section. (3)

Fig. 1. Stems and cell structure in, hemp, jute, flax, and kenaf fiber

[1](Goodman et al. 2002), [2](Voulgaridis, et al. 2000), [3](Oliver and Joynt 1999), [4]www.sbs.utexas.edu/, mausethweblab/, webchap5scler/ 5.1-4.htm, [5]Rowell and Stout 1998), [6](Tavisto et al. 2002).

these fibres have multicellular type cells. The cross section of jute cell is polygonal with slightly rounded corners and a medium-sized lumen. Retted jute fibres normally contain 15 to 30 fibre cells (Sur 2005) whilst the number of fibre bundles in the stem of flax ranges from 15 to 40. Each bundle contains between 12 and 40 ultimate fibres. The ultimate fibres consist of pointed cells with very thick walls and very small lumens. Goodman et al. (2002) investigated each flax fibre bundle using light microscopy and revealed that flax fibres originate from primary phloem tissues which are located between the outer cortical tissue and the secondary phloem tissues. Each fibre contains 30 to 40 ultimate fibres. In another study, Oliver and Joynt (1999) clearly observed the cross-section of hemp stem and found that it's bast fibres are composed of 'primary bast fibres', which are long and low in lignin, and 'secondary bast fibres', which are intermediate in length and higher in lignin.

Depending on the location in the stem, kenaf contains three types of fibre: bast, core, and pith. The fibres from bast are long and have thick cell walls, whilst those of core fibre are thinner with much shorter fibre length (Paridah et al. 2008). The core fibres appear as wedge-shaped bundles of cells intermingled with parenchyma cells and other soft tissue. The pith consists exclusively of parenchymatous cells, which are not typically prismatic but polygonal in shape. In mature plants, kenaf can reach a height of 2.5 to 3.5 m (Rowell and Stout 1998). Zhang 2003 reported that the kenaf fibers are shorter at the bottom of the stalk and longer at the top. The increase in length from the bottom to the top was found not to be gradual, but S-shaped (Rowell and Han 1999). It was reported that the fibre length increases during the early part of plant growth, and decreases again as the plants mature (Chen et al. 1995). Kenaf single fibers are only about 1 to 7 mm long and about 10 to 30 microns wide, thus too short for textile processing (Calamari 1997). Compared with cotton fiber, these fibres are coarse, brittle, and not uniform, which makes them difficult to be processed using conventional textile or nonwoven fabric equipment. Table 6 compares the morphology of natural cellulosic fibres against other types of bast plants.

Table 6. Morphology of Natural Cellulosic Fibres

Type of fibre	Cell type	Cross-sectional shape of ultimate cell
Jute Mesta Kenaf	Multicellular	Polygonal with slightly rounded corners and medium-sized lumen
Ramie	Multicellular	Elongated ellipse with collapsed elongated lumen
Flax	Multicellular	Appreciable roundness in the corners and medium size lumen
Hemp Pineapple	Multicellular	Oval cross-section with collapsed small size lumen
Sisal	Multicellular	Polygonal with sharp corners and medium to large size lumen
Coir	Multicellular	Polygonal with rounded corners and large size lumen
Cotton	Unicellular	Peanut-shaped cross-section of each fibre with elongated collapsed lumen

Source: Sur (2005)

RETTING OF PLANT FIBRES

Most bast fibres are cemented to the adjacent cells inside the stem with pectin (a form of carbohydrate), which can be extracted by retting processes. Retting is sometimes termed degumming. It is a chemical process for removing non-cellulosic material attached to fibres to release individual fibres. After harvesting, the stems are usually kept either in the field or under water for 2 to 3 weeks, during which the pectinous substances that bind the fibre with other plant tissues are softened and degraded by micro-organisms. A quality of fibre is largely determined by the retting condition and duration. Table 7 compares five types of retting processes, namely, dew, water, enzymatic, mechanical, and chemical retting, which are normally applied to hemp, jute, flax, and kenaf. Apparently, there is no single method that can give optimum results in terms of retting period, fibre strength, environmental pollution, and cost. Dew retting largely relies on indigenous soil fungi to colonise the stem/bast and to degrade pectin and hemicellulose (particularly the arabinose) by releasing polygalacturunase (PGase) and xylanase (Brown et al. 1986). The resulting fibres are often coarse and of variable quality. Conversely, water retting is performed in an aqueous environment, and anaerobic, pectinolytic bacteria are responsible for the decomposition of pectic substances and the subsequent release of fibre (Akin et al. 2002). This process consistently yields high quality fibres (Van Sumere 1992). Chemical and enzyme retting offer substantially more control compared with dew and water retting. Paridah et al. (2009) used 5% sodium hydroxide and 5% sodium benzoate during retting of kenaf bast fibre and found that both methods produced fibres of relatively lower tensile strength than those obtained with water alone. The colours of chemically-treated bast fibre were also darker (Fig. 3). Song and Obendorf (2006) found that enzymatic retting was the most suitable method to reduce the amount of lignin in kenaf bast fibres. Yu and Yu (2007) removed 91.3% of pectin from kenaf bast fibre by subjecting the bast fibres with enzyme from fungal strain isolated from the river where the kenaf was retted. The optimal retting conditions used were: culture temperature 32ºC, initial pH 6.0 of the culture medium, cultivation time 24 h, retting time 21 h, and inoculation size 25%. Evans et al. (2002) studied an enzymatic retting of flax bast fibres using several fungi and found that *Aspergillius niger* PGase resulted in 62% increase in fine fibre yield without significantly affecting the strength as compared with that of untreated and other fungal sources. Van Sumere (1992) reported that the bacterial method is relatively better than chemical, because it gives better fibre quality and lower pollution, whilst chemical retting requires high energy and generates costly wastes.

Enzymatic Retting

Microbial retting is not a new process. This traditional method is mainly achieved by the pectic enzymes produced by bacteria. During retting, the bacteria multiply and produce extracellular pectinases, which release the bast fibre from the surrounding cortex by dissolving the pectin. Nowadays, with the advancement of biotechnology tools, such enzymes can be commercially produced, thus making enzymatic retting a more popular choice for the production of long fibres.

Table 7. Various Types of Retting Processes Used for the Production of Long Bast Fbers

Retting types	Description	Advantages	Disadvantages	Duration of retting	Types of bast fiber	Referen-ces
Dew retting	Plant stems are cut or pulled out and left in the field to rot	Pectin material could easily be removed by bacteria.	Reduced strength, low and inconsistent quality; restriction to certain climatic change and product contaminated with soil.	2-3 weeks	Flax, jute	1, 2
Water retting	Plant stems are immersed in water (rivers, ponds, or tanks) and monitored frequently (microbial retting)	Produces fiber of greater uniformity and higher quality	Extensive stench and pollution arising from anaerobic bacterial fermentation of the plant, high cost and putrid odor, environmental problems and low-grade fiber. Requires high water treatment maintenance.	7-14 days	Flax, Hemp, kenaf, jute	1, 3, 4, 5, 6, 7
Enzymatic retting	Enzymes such as pectinase, xylanases etc. are used to attack the gum and pectin material in the bast. The process is carried out under controlled conditions based on the type of enzyme.	Easier refining particularly for pulping purposes that degrades and provides selective properties for different applications. The enzymatic reactions cause a partial degradation of the components separating the cellulosic fiber from non-fiber tissues. The process is faster and cleaner.	Lower fiber strength	12-24 hours	flax	1,8

Table 1. Continued

Chemical retting	Boiling and applying chemicals normally sodium hydroxide, sodium benzoate, hydrogen peroxide.	It is more efficient and can produce clean and consistent long and smooth surface bast fiber within a short time.	The fiber retted in more than 1% NaOH the tensile strength decreases. Unfavorable color and high processing cost.	75 minutes-1 hour	Kenaf, jute, flax	9, 10
Mechanical retting	Hammering or fibers are separated by hammermill or decorticator.	Produces massive quantities of short fiber in short time	High cost and lower fiber quality.		Kenaf	11

[1]Van Sharma 1992; [2]Sharma and Faughey 1999; [3] Sharma 1987a; [4] Hongqin and Chongwen 2007; [5] Cochran, et al. 2000; [6] Banik et al. 2003; [7] Rome 1998; [8] Akin et al. 2007; [9] Kawahara et al. 2005; [10] Mooney et al. 2001;[11] Paridah and Khalina 2009.

Due to the long retting period, many efforts have been focused on studying the degradation of pectic substances, lignin, and hemicellulose through enzymatic degradation (Akin et al. 2001; Goodman et al. 2002; Yu and Yu 2007; Lu et al. 1999; Mooney et al. 2001; Sharma 1987). Pectic substances are abundantly present in the plant kingdom, forming the major components of middle lamella, a thin layer of adhesive extracellular material that separate fibres. The enzymes hydrolyzing these pectic substances are broadly known as pectinases, and they can be produced by a wide variety of microbial sources such as bacteria (Dosanjh and Hoondal 1996; Kapoor et al. 2000), yeast (Blanko et al. 1999), fungi (Huang and Mahoney 1999; Stratilova et al. 1999), and actinomycetes (Beg et al. 2000a). Enzymes are extremely efficient and highly specific biocatalysts (Hoondal et al. 2002).

According to Lang and Donenburg (2000), microbial pectolysis is important in the decomposition of plant by breaking down the pectin polymer. During degradation, the plant polysaccharides can be attacked by several enzymes; however this process is being intiated by pectic enzymes, as it is the most readily available. Hence this type of enzyme has been used by many researchers for retting or degumming of plant fibres such kenaf, ramie, flax, and hemp (Hoondal et al. 2002; Kapoor et al. 2000; Hongqin, and Chongwen 2007) without significant damage to the fibres.

PROPERTIES OF BAST FIBRES PREPARED BY RETTING

Table 8 shows the characteristics of long bast fibers produced from hemp, jute, flax, and kenaf obtained using different retting processes. Apparently, cellulose, hemicelluloses, and lignin are the main constituents of bast fibers. In addition, bast fibers also include pectic materials, the main substance that binds the bast fibers together. The total content of both cellulose and hemicelluloses are 98% for hemp, 80% both jute and flax, while kenaf only has 71% of these polysaccharides. Flax and hemp also have the highest values in fibre length and diameter but with least moisture contents compared to kenaf and jute. These characteristics suggest the flax and hemp are good source of fibres for textile applications rather than for composites (Zhang 2003). Conversely, kenaf has the highest tensile strength among the four types of bast fibres. An earlier study carried out in our laboratory using kenaf bast fibre with different retting process (water, sodium hydroxide, and sodium benzoate) revealed that water retting gave the highest tensile strength (Fig. 2).

As shown in Table 8, even though hemp was reported to give relatively higher fibre yields, its quality is categorized as fair. On the other hand, kenaf produces relatively high fibre yield, acceptable fibre morphology, and chemical content, as well as good fibre quality, which make it more favourable to be used in the composite industry. Kenaf apparently has better commercial value than do flax, hemp, and jute.

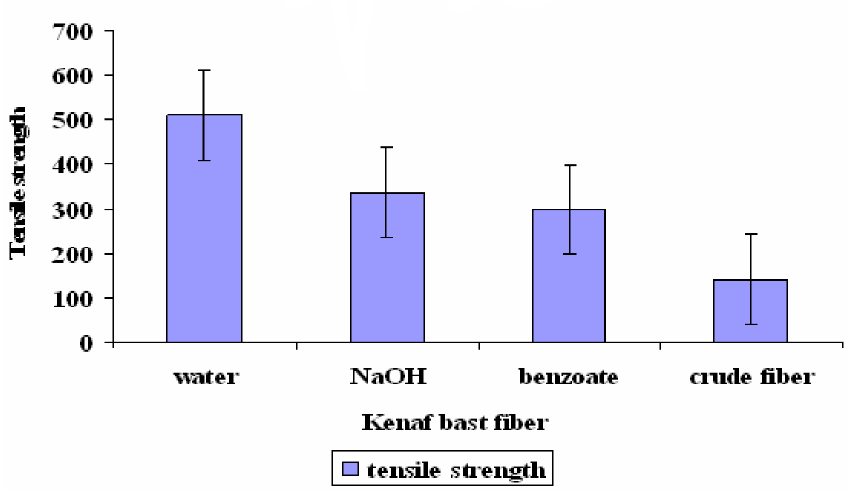


Fig. 2. Effect of pretreatment on the tensile strength of kenaf bast fiber

Kenaf Fibre Quality

To date, standards for fibre quality have been developed only for jute, kenaf, and mesta. Being the most produced and used fibre, jute has its own grading system, which was developed by the Bureau of Indian Standards and Bangladesh National Standards Institution. There have been no official grades published for hemp and flax. Sur (2005) carried out an extensive study on the quality of jute fibre in relation to its suitability for yarn production and its behavior in the manufacturing process. Generally, the assessment of fibre quality is based on their root content, colour, luster, fineness, length, elasticity, strength (flexural and torsional rigidity), and moisture absorption, etc.

Basically, there are two types of kenaf fiber, *kutcha* for the local market and *pucca* for export. Each category can be further classified, into five grades denoted by the letters A to E, with A being the superior grade. Rowell and Stout (2006) recommend the following characteristics as criteria to determine fibre quality:

- Fibre strength
- Cleanness and fineness
- Color and luster
- Length and percentage of cutting

The strength of the fibre is also assessed by snapping a few strands by hand, a qualitative procedure that gives a useful indication to an experienced operator. Cleanliness and freedom from non-fibrous matter is an important feature, and, in this respect, the physical imperfections that may result from improper retting can have a profound effect on the allotted grade. Color is irrelevant, but certain end-users traditionally prefer particular colors of fibre for the sake of appearance. Luster is commonly an indication of strength (Rowell and Stout 2006). All these properties would ultimately determine the success of using these fibres in a fine, woven textile structure (Zhang 2003). In commercial plants, many other factors, such as the following, will influence the fibre quality:

Table 8. Characteristics of Long Bast Fibers Produced from Hemp, Jute, Flax, and Kenaf

Type	Fiber chemical content						Tensile strength (mm)	Moisture content %	Yield (tonne/ hectare)	Retting methods	Quality	references
	Fiber Length (mm)	Fiber diameter microns	Lignin %	Cellulose %	pectin	Hemi cellu-lose %						
Hemp	15-55	17-22.8	5-3	70-92	0.9	18-22	310-750	<15	8-18	Chemical retting	Fair	5,7,10,14,15,16,17,18,19,20,21
Jute	2-5	15.9-20.7	5-13	51-84	0.2	12-20	200-450	23	2-4	Dew retting	Good	5,7,8,9
Flax	9-70	5-38	14-19	60-81	0.9	2.3	345-1100	10-12	1.4-2.5	Enzymatic retting	Fair	2,5,7,9,10,11,12,13
Kenaf	2.6-4	17-21.9	15-19	44-57	2	21	295-1191	10-20	2-4	Water retting	Good	1,2,3,4,5,6

Source: [1] Misra (1987), [2] Mohanty et al. (2001), [3] Rowell and Han (2000),[4] Anon. (2001), [5] Perry (1975), [6] Carr et al. (2005), [7] Skorski (1963), [8] Gassan and Bleddzki (2001), [9] Rowell and Stout (1998), [10] Harders and Steinhauser (1974), [11] Alann André. (200)6, [12] Rowell and Han (2000), [13] Biogiotti and Kenny (2004), [14] Kozlowski (2000), [15] Joseph (2002), [16] Meier and Mediavilla (1998), [17] Mwaikambo and Ansell (2006), [18] Peston (1963), [19] Hughes (2000, 1997), [20] Ronalli (1999), and [21] Mwaikambo (2002)

Variety

Different varieties have different fibre quality. Dempsey (1975) reported that the fibre of kenaf varieties varies from 4 to 5% in the fresh plant. He also stated that the late maturing group cultivars could produce better fibre than early maturing ones.

Environmental conditions

Favorable cultivation conditions could lead to better fibre quality. Kenaf grown on alluvial soil has shown better fibre quality than that of plants grown on sand, which is better than peat soil (Pate et al. 1954). Satisfactory levels of fertility, temperature, plant density, and irrigation could improve the fibre quality (Dempsey 1975).

Harvesting

The highest quality fibre is obtained when kenaf is harvested during the beginning of the flowering period (Duke and Ducellier 1993). Moreau et al. (1995) indicated that fibre quality was obviously reduced after flowering. The period to achieve maturity depends on the climate, for instance in a tropical region within 4 to 5 months, and sub-tropical 5 to 6 months.

Retting process

While water seems to be the most suitable method to produce high quality fibre, other methods such as a combination of chemical and enzymatic retting have been reported to give excellent results. However this method is expensive and complex; thus it cannot be applied in the rural areas. With the advancement of technology, it is hoped that cheaper and more practical methods can be developed to generate better fibre quality with less environmental pollution.

Utilization of Kenaf Fibre

Historically, kenaf fibre was first used as cordage. Industry is now exploring the use of kenaf in papermaking and nonwoven textiles. Pulping kenaf fibres (bast and core) can benefit the environment because generally lower amount of chemicals are required in kenaf pulping than in wood pulping. Subsequently the discharge of spent chemicals is less. Kenaf can be either pulped alone or blended with recycled paper (Liu 2003; Ahmed et al. 2008). When it is used alone, one can produce high quality kenaf fibre suitable for making specialty papers such as security paper, tea-bags, currency notes, etc. Kenaf paper is stronger, whiter, longer lasting, more resistant to yellowing, and has ink adherence better than wood paper (Liu 2003).

Kenaf has attracted attention in recent decades as an abundant natural fibre source in the field of fibre reinforced composites. Many properties of the natural fibre-reinforced composites were found to be comparable or superior to those of the corres-ponding glass fibre-reinforced composites (Wambua et al. 2003). It was found that tensile modulus, impact strength, and the ultimate tensile stress of the kenaf reinforced polypropylene composites increases as the fibre content increases (Wambua et al. 2003).

In another study, liquefied kenaf core (LKC) has been used as a polyol to synthesize polyurethane adhesive (LKCPU). The produced adhesive has shown great potential as a wood laminating adhesive, particularly for edge-gluing (Juhaida et al. 2009).

Kenaf fibres also have a higher reinforcing effect on natural rubber compared with that of synthetic polyester fibres (El-Sabbagh et al. 2001). Kenaf also has excellent properties for reinforcing plastic composites as it has low density, no abrasion during processing, high filling levels, high specific mechanical properties, and biodegradability. On the other hand, polypropylene is a thermoplastic polymer, made by the chemical industry and used in a wide variety of applications, including packaging, textiles (e.g. ropes, thermal underwear, and carpets), stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes (Khalina et al. 2008a).

Kenaf natural fibre/plastic compounds are light and easy to process, and they could replace glass-reinforced plastics in many cases. Kenaf compound panels have the mechanical and strength characteristics of glass-filled plastics and at the same time, they are less expensive and partially recyclable in many instances (Kano 1997). Therefore, they can be used in the automotive (Khalina et al. 2008b), construction, housing, and food package industries (Zhang 2003). Whole stalk kenaf can also be used in corrugated paper medium and also in building materials such as particleboard (Paridah and Juliana 2008; Webber et al. 1999a) and medium density fibreboard.

Zhang (2003) found that blending cotton into pure kenaf yarn can increase the yarn's strength and elongation at break, and make the yarn less stiff. Paridah and Maziah (2010) compared the properties of kenaf with those of similar fibres and concluded that kenaf offers great potential as raw material for technical textile to partially replace the synthetic glass and aramid fibres for making anti-ballistic materials. These applications, however, have to follow strict fibre processing procedures, as well as modification of fibre surface, which are quite complex and costly. Nonetheless, such procedures give added value to the final products, i.e. five to six times higher than the price of an unmodified kenaf stem.

CONCLUSIONS

Based on comparisons in production, anatomical properties, stem processing fibre quality and prices, kenaf apparently has multiple advantages compared to hemp, jute, and flax in tropical countries as a fibre source. Kenaf yields are greater than the others, hence providing a more cost-effective raw material. Kenaf has the lowest aspect ratio, low density, and relatively high tensile strength among other fibres. The retting method is the predominant challenge in the application of bast fibres. The selection of retting method is most important if the fibres are to be used in textiles. Studies have shown that the most efficient method is by combining chemical and enzymatic retting. The future of bast fibre crops relies mainly on the end uses of the fibres. The long bast fibres offer much more domain of usage and hence offer the highest value, whilst short fibers from the same plants can be used in a limited number of applications.

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