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REVIEW ARTICLE

PROCESSING AND APPLICATION OF LIGNO-CELLULOSIC FIBRES

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ABSTRACT

There is an urgent need for increase in land allocation to food crops due to rising population, especially in developing countries and on the other hand, cotton availability and its per capita availability is getting reduced due to which alternative fibre sources need to be identified and appropriate technologies developed for their conversion into useful textile products. Ligno-cellulosic fibres are one such alternative but their extraction is a tedious task which may vary as per the intended use of the fibres extracted. The present paper summarizes the extraction process of ligno-cellulosic fibres according to their end use and also briefs about their possible applications in textiles.

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INTRODUCTION

There is an increase in worldwide demand of man's basic needs for food and fibre according to the growing population. At the same time, communities are striving to achieve sustainable management of natural resources. Agriculturists need to strike a balance between the demand for increased output of agricultural products and sustainability. To make this possible, it is mandatory for farming industries to measure and understand their current sustainability trends and adapt practices as required for the same (www.cottoncrc.org.au). Keeping in pace with these growing demands and giving consumers access to their fibres of choice, the textile industry will have to take an initiative to develop a new, sustainable path for clothing the world and ending the cycle of environmental harm. The major aim should be production of fibre from wood or non-wood based biomass to replace both cotton and polyester production, which burdens the environment, and consumes oil resulting in depletion of natural resources. It requires a fundamental change in attitude for developing a sustainable global economy, which permits improved purchasing power and living standards without exhaustion of natural resources for future generations. The products that are based on photosynthetic carbon dioxide (CO_2) fixation should be preferred due to ecological grounds. The benefit of such sustainable resources is that they can be re-grown within the foreseeable future, without having any negative side-effects on global bio-diversity in the long term (Van, 2008). Natural plant fibres are the renewable fibres taken from different parts of the plant like bast, leaf, seed, fruit and husk. Geometrical dimensions of plant fibres, especially the length is dependent mainly on location of fibres in the plant. For example, fibres from fruits and seeds are few centimetres long while those from stems or leaves are much longer (Smole, Hribernik, Kleinschek & Kreze, 2013). Common bast fibres include flax, jute, hemp, ramie and kenaf; leaf fibres are obtained from banana, pineapple and sisal etc. whereas cotton is the most important fibre obtained from seed and coir is extracted from fruit husk i.e. coconut. Bast fibres form an important category as most of the cellulosic fibres other than cotton belong to this group. Flax fibres hold the distinction of being used in first place by human beings for clothing. *Table 1 gives a view of the chemical composition of various ligno-cellulosic fibres.* The structure, micro fibrillar angle, cell dimensions, defects, and the chemical composition of fibres are the most important variables that determine the overall properties of the fibres. Generally, tensile strength and Young's modulus of fibres increase with increasing cellulose content. The micro fibrillar angle determines the stiffness of the fibres. Plant fibres are more ductile if the micro fibrils have

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a spiral orientation to the fibre axis. If the micro fibrils are oriented parallel to the fibre axis, the fibres will be rigid, inflexible, and have high tensile strength (John & Anandjiwala, 2008). It is this lignin/hemicelluloses matrix which provides nature's protection against microbial invasion. It also renders the material water resistant and inaccessible to chemical reagents (www.patentstorm.us).

natural decomposition or fermentation (Cook, 1993). It uses the action of bacteria and moisture on plants to dissolve or decompose most of the cellular tissues and gummy substances which surround bast-fibre bundles, resulting in separation of the fibres from the stem. These strands are often used commercially without separating the individual fibres one from another. The fibres are extracted from the stalks by retting in

Table 1. Chemical composition of ligno-cellulosic fibres

Fibre	Constituent (%)					
	Cellulose	Hemicelluloses	Lignin	Pectin	Wax	Moisture Content
Jute[1]	64.4	12.0	11.8	0.2	0.5	10
Flax[1]	64.1	16.7	2.0	1.8	1.5	10
Hemp[1]	67.0	16.1	3.3	0.8	0.7	10
Ramie[1]	68.6	13.1	0.6	1.9	0.3	10
Kenaf[2]	63.5±0.5	17.6±1.4	12.7±1.5	-		
Sisal[1]	65.8	12.0	9.9	0.8	0.3	10
Nettle[3]	54	10	9.4	4.1	4.2	
Banana[4]	61.5	20.3	15			
PALF[5]	69.5	17.8	4.4	1.1	3.3	
Coir[6]	45.84	0.25	43.44	3.3	-	
Natural Bamboo[7]	73.83	12.49	10.15	0.37		

1. Lewin, 1985; 2. Jonoobi *et al*, 2009; 3.Franck, 2005; 4.Marella *et al*; 5.Banik *et al*, 2011; 6. Paul *et al*, 2011; 7. Yu *et al*., 2010

Processing of Ligno-cellulosic Fibres

One of the major limitations in using bast fibres is the process of separating fibres from the outer stems. In order to use the bast fibres in textile applications, the fibres need to be separated from rest of the stalk using a microbial process, retting, which leads to breakage of the chemical bonds between the bast fibres and the woody core (Stanhope, 2012). Harvesting and fibre processing differ depending on the intended end use of the crop (Figure 1).

Harvesting

The crop is harvested according to the use for which it is grown. When crop is grown for fibre it needs to be harvested at a time when the fibre is of high quality. After harvesting,fibres are extracted from the crop which involves a series of processes like retting, decortication, scutching and cleaning/washing; varying from fibre to fibre.

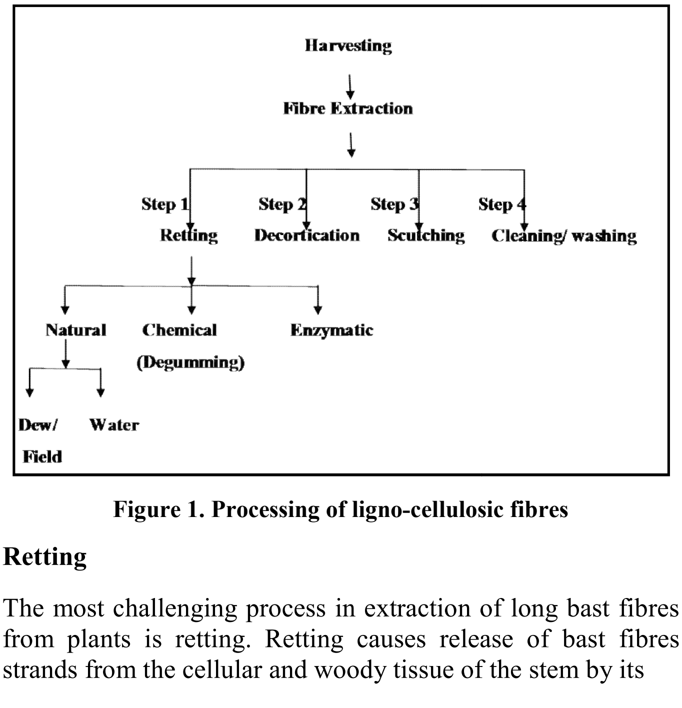

Figure 1. Processing of ligno-cellulosic fibres

Retting

The most challenging process in extraction of long bast fibres from plants is retting. Retting causes release of bast fibres strands from the cellular and woody tissue of the stem by its anyone of the two ways; either (i) biological/natural retting, in which bacteria (water retting) or fungi (dew retting) are acting on the substrate; or (ii) chemical retting or degumming, in which dilute acids or bases are the acting ingredients. Natural retting is a biological phenomenon in which pectin substances in the soft cells are dissolved by means of microorganisms, which make the fibre bundles free and cause separation of the fibre bundles from woody core. Lignin present in the fibre bundles resists the action of microorganisms. During retting the microorganisms feed on pectin substances, proteins, sugars, starch, fats and waxes, tannin and minerals substances like calcium, magnesium etc (Lewin, 1985).

Dew/field retting

Dew retting is carried out in the spring, under conditions of moderate humidity, warmth and freedom from wind (Lewin, 1985). The crop is either pulled up or cut by specialized equipment that lays the plants in rows and then leaves them in the field to rot. Farmers need to monitor this type of retting process so that the fibres separate without getting damaged due to over-retting (www.globalhemp.com). The process takes approximately 3-7 weeks, depending upon the fungi and bacteria present in the soil and on weather conditions (Lewin, 1985). Dew-retting can cause lots of variation in the mechanical properties of the fibres. This happens because biological bacteriological changes of the material are difficult to be kept under constant control. Although weather conditions affect the quality of the fibre obtained (moisture is needed for rotting, but dryness is a must for baling of the stalks), this process is used most abundantly because of its low cost and low requirement of water (Stanhope, 2012).

Water retting

Water retting produces more uniform and higher quality fibre, but the process is not environmentally friendly and requires more time and labour than dew retting. This process involves submerging the crop into water and regularly monitoring the separation process. Large volumes of clean water are required for water retting, which should be treated before discharging in lakes, streams, and ground water because it causes pollution due to anaerobic decomposition. Another limitation is the high cost of drying the rotten stems. Water retting has been mostly discontinued because of environmental regulations in many countries and high investment needed for the process (Stanhope, 2012). Early methods involved placing of the stalk bundles into the nearby water bodies, or into the vats or ditches dug for the purpose and pressing them down beneath the surface of water with stones. Later methods started using tanks which may be open, closed or in cascade arrangement (three or four interconnected tanks). In cascade arrangement the water flows continuously at a constant rate like one change every 2 days. Warm water retting is considered more efficient and commercially viable than previous methods as it requires 3-4 days as compared to 8-14 days taken in normal water retting (Lewin, 1985). The water retting process is currently employed in countries with no environmental regulations, like China and Hungary, but its popularity is decreasing with the increased usage of microorganisms or direct use of enzymes to separate the bast fibres from the woody core (USDA, 2000).

Chemical retting (Degumming)

This process substitutes the action of chemicals in place of bacteria and fungi as in natural retting (Lewin, 1985) and the degumming is carried out by treating the stalks using chemical solutions like caustic soda, sodium carbonate, soaps and dilute mineral acids. Ramaswamy, Boyd, Bel-Burger, & Kimmel (1995) evaluated the effects of surfactants, bleaching enhancers and hydrogen peroxide on the physical, chemical and aesthetic properties of kenaf fibres and concluded that hydrogen peroxide is an effective bleaching agent when applied with sodium pyrophosphate and a phosphate ester and the optimum treatment caused significant reduction in the lignin content of kenaf fibres from 16.05 to 7.15 mg/g of fibres. In another study, Zhang (2003) found that chemical treatment caused improvement in the fibre fineness, softness and elongation at break, but the fibre bundle strength and length were decreased. Moreover, increasing the concentration of sodium hydroxide weakened the fibre strength significantly. But major drawback of this method is that it is costlier than dew or water retting and the fibre produced is not better. The effluents released from chemical treatment also pose a big problem. Hence, this method did not become popular but some fibres like ramie essentially require chemical treatment for their separation (Cook, 1993).

Enzymatic retting

It is also referred to as bio-retting. Microbial retting is not a new process. This traditional method mainly employs the pectin enzymes produced by the bacteria. Bacteria multiply and produce extracellular pectinases, which help in releasing the bast fibres from surrounding cortex by dissolving the pectin (Paridah, Basher, Saifulazry, & Ahmed, 2011). Now a days instead of relying on natural bacteria, inoculums of selected pectinolytic bacteria is added to water to help in retting process, thus making enzymatic retting more popular (Stanhope, 2012). Kimmel, Boylston, Goynes, Akin, Henriksson, & Eriksson (2001) developed an improved retting method called as spray enzyme retting (SER) for flax stems using pectinase-rich mixtures and evaluated on a variety of fibre and seed flax samples. Their method involved crimping of stems to enhance penetration of enzyme formulations into the stems tissues, adding chelators with enzymes in water at pH 5.0 to improve enzyme effectiveness, spraying the formulation on crimped stems and incubating at high humidity for several hours. Chelators added to pectinase-rich enzyme mixtures increased the efficiency of enzyme retting of flax. Of several chelators tested by them, ethylene diamine tetra acetic acid (EDTA) was found to be most effective in sequestering calcium from solution, with substantial activity even at pH 4 or 5 (Adamsen *et al*., 2002). They further tested purified endopolygalacturonase (EPG) from Rhizopusoryzae for its ability to ret flax alone or in combination with other polysaccharides and noticed that EPG alone (without additional enzymes) in combination with chelator gave retting efficiencies similar to enzyme mixtures which led to a conclusion that role of EPG is very important during retting (Akin *et al*., 2002). Song and Obendorf (2006) conducted a study to analyze the impact of biological, chemical and enzymatic retting on the physical and chemical characteristics of kenaf fibres and found that chemical retting was more effective in removing hemicelluloses while enzymatic retting was more effective for removing lignin. Research is continuously being carried out worldwide to improve systems to separate and process bast fibres in a way that impact on environment gets minimized while the quality of fibre remains high for textile production. But the major problem in using enzymes is the maintenance of specific temperature and pH conditions and requirement of a highly skilled manpower, which is difficult to achieve at a commercial scale. This might be a possible reason for enzymatic retting not becoming popular and not progressing forward from laboratories to commercial plants in spite of its numerous advantages. After the completion of retting process, a machine is used to gather and tie the stems into bundles for pickup and delivery into the mill. The machines are designed to maintain parallel alignment throughout harvesting and processing so that longest and highest quality textile fibres are recovered (USDA, 2000). Once the fibres are retted, dried and baled, they are ready to be processed further. This process involves a decorticator to separate hurds (short pieces of the woody core), tow (broken or short fibres), and the longer remaining bast. In the natural state, the fibres within the stalk are cemented by an inter-cellular substance, which consists of lignin and pectin. This cementing material is dissolved during the decortication process in order to separate the bundles of fibres (Stanhope, 2012).

Breaking and Scutching

After retting, fibre is cleaned and dried. Decomposed woody tissue is crushed by iron rollers to convert stalks into small pieces of bark called shives. It involves removing of broken shives by machines or by hand to separate fibre from the stalk completely.

Hackling/Combing

This is a process for separating long fibres (line) from short fibres (tow). To get fine quality fibres, hand combing is preferred over faster and efficient machine combing. Now the fibres are ready for spinning into yarn.

Spinning

It can be done in two ways- dry and wet spinning. Dry spinning is used to produce coarse, heavy and inexpensive linen fabrics, while wet spinning (passing the roving through hot water) produces fine yarn of high count. There has been a

Table 2. Physical properties of ligno-cellulosic fibres

Fibre	Physical Parameters			
	Fibre Denier	Tenacity(g/d)	Breaking Elongation (%)	Moisture Regain (%)
Jute	5-25[2]	2.0-6.3[1]	1.0-2.0[1]	10.08[5]
Flax	12-30[2]	2.6-8.0[1]	1.5-5[1]	8.205[7]
Hemp	16-50[2]	3.0-7.0[1]	1.5-5[1]	8.0[4]
Ramie	16-125[2]	4.5-8.8[1]	1.5-5[1]	6.60[5]
Kenaf	14-33[2]	2.4-3.33[8]	1.6[12]	10-20[5]
Sisal	100-400[2]	6.46[5]	3.02[5]	10.57[2]
Nettle	20-80[2]	5.65[2]	1.2[2]	5-8[10]
Banana[7]	17	29.98	6.54	13
PALF	22-50[2]	3.41-4.53[2]	2.4-3.4[2]	11[9]
Coir[3]	Diameter,16 microns	1.1	30	10.5
Natural Bamboo[6]	23.22	5.43	3.59	10.14

1. Lewin, 1985; 2. Franck, 2005; 3.Geethamma *et al*, 2011; 4.Summerscales *et al*, 2010; 5.Yu *et al*, 2010; 6.Yueping *et al*, 2009; 7.www.webistem.com; 8.Ramarad, 2008; 9. Liu, 2005; 10. www.vasantkothari.com.

Table 3. End uses of various natural plant fibres

Group	Uses	Fibres
Fibres used for the manufacturing of yarns and fabrics	Fibres of sufficient fineness are manufactured into higher quality fabrics: luxury clothing, laces, domestic and commercial fabrics, decorations, tents, sails, etc.	Principally cotton while jute, flax, hemp and ramie in lesser quantities
	Fibres for coarser fabrics: sacks, bagging, floor covering, carpet backs, etc.	Principally jute and lesser quantities of flax, hemp, cotton and sisal
Cordage fibres	Tying twines	Jute, cotton and hemp
	Rope and binder twine	Sisal, coir and jute
Brush and plaiting fibres	Soft and hard brushes	Sisal and coir
	Braided articles: hats, mats, baskets, rugs, etc	Sisal and coir
Filling fibres	Stuffing material: upholstery, mattresses, etc	Cotton, sisal and jute
	Packing material: seams in vessels, barrels, piping, etc.	Hemp and jute
	Reinforcing materials: plastics, wallboards, etc.	Sisal, hemp, kenaf and jute
Fibres for papermaking	All kinds of paper	All natural fibres, often combined with wood pulp

(Source: Food and Agriculture Organization (FAO))

lot of research going on in Europe since many years to investigate methods of bast fibre separation which could replace traditional retting and scutching. One of the old methods of fibre separation, steam explosion is under further exploration in Germany to process hemp fibres. Steam explosion is a process that comprises of impregnating the raw material (usually decorticated fibre) with alkali or detergent solutions and subjecting it to steam pressure for a period of time (1-30 minutes). As soon as the pressure is released, the fibres get blown apart. Fibres are finally washed, rinsed, dried, and carded before spinning. The energy of ultrasonic waves has also been used in a fibre separation method to obtain individual bast fibres in Germany. This technique involves breaking of green (unretted) or partially retted straw mechanically between rollers. The stalks are then washed to remove dust and soluble components, and subjected to ultrasonic treatment in water. Fibres get separated due to very high local pressures created by collapse of gas bubbles which are formed in the liquid by ultrasonic waves. The fibres are then washed, dried, and carded to remove the remaining impurities. Both the methods (steam explosion and ultrasonic waves) seem feasible to be followed at industrial level and minimize weather and material handling problems associated with retting. But the limitation with both the processes is that they produce only short length fibre. There has to be a precise control on all the parameters involved in these processes to get consistent results and avoid fibre damage. None of these technologies has yet advanced beyond laboratory or pilot scale trials, and the costs and output of commercial machinery is also not known (Ehrensing, 1998).

Applications of Ligno-cellulosic Fibres

Due to the increasing concerns regarding sustainability of natural resources, textile industry is banking upon the use of natural plant fibres for various applications. Natural plant fibres have been successful due to their positive impact on our ecological balance. Various plant fibres can be used for a number of textile and technical applications, e.g. bast or stem fibres, leaf fibres and fibres of seeds and fruits. Flax, hemp, jute, ramie, sisal and coir are mainly used for technical purposes.

Physical properties of some major ligno-cellulosic fibres are given in Table No.2. The physical properties of the fibres are the key factor in deciding the end use to which fibres could be put and utilized exploiting their potential to maximum. Table No.3 gives an overview of the various plant natural fibres in textiles according to their end usage.

Conclusion

It is very much apparent that retting is the most challenging task in the application of ligno-cellulosic fibres. The selection of method of retting is most important if the fibres are to be used in textiles. None of the retting methods used alone could give fibres applicable in high end textile applications. Various studies have been conducted which show that the most efficient method is the combination of enzyme and chemical retting though it would cause strength loss. Addition of chelators like EDTA also supports enzyme activity. The future of ligno-cellulosic fibres relies mainly on the end uses of the fibres. The long fibres offer much more domain of usage and hence offer the highest value, while short fibres from the same plant can be used for few applications. Optimization of the retting methods for different ligno-cellulosic fibres needs to be continued and extensive research is still required to make enzymatic and chemical retting, commercially successful.

REFERENCES

Adamsen, A.S., Akin, D.E., Rigsby, L.L. 2002. Chelating agents and enzyme retting of flax. *Textile Research Journal*, 72(4), 296-302.

Akin, D. E., Slomczynski, D., Rigsby, L. L. and Eriksson, K. L. 2002 January. Retting Flax with Endopolygalacturonase from Rhizopusoryzae. *Textile Research Journal*, 72 (1), 27-34.

Banik, S., Nag, D. and Debnath, S. 2011. Utilization of pineapple leaf agro-waste for extraction of fibre and the residual biomass for vermicomposting. *Indian Journal of Fibre and Textile Research*, 36(2), 172.

Cook, J.G. 1960. *Handbook of Textile Fibers*, Merrow Publishing, Watford, UK, 20.

Danny E Akin, Jonn A Foulk, Roy B Dodd, David D McAlister III, Enzyme-retting of flax and characterization of processed fibers, *Journal of Biotechnology*, 89, 2–3, 23 August 2001, 193–203.

Ehrensing, D.T. 1998. Feasibility of industrial hemp production in the United States Pacific Northwest. Department of Crop and Soil Science, Oregon State Univ. Expt. Sta. Bul. 681. Oregon State University, Corvallis. Retrieved from www.css.orst.edu/Hemp/body.

Franck, R.R. 2005. *Bast and Other Plant Fibres*, Cambridge England: WoodheadPublishing in textiles, 331-339, 322-327, 228-242.

Geethamma, V. G., Pothen, L. A., Rhao, B., Neelakantan, N. R. & Thomas, S. 2004. Tensile stress relaxation of short-coir-fiber-reinforced natural rubber composites. *Journal of Applied Polymer Science*, *94*(1), 96-104.

John, M. J. & Anandjiwala, R. D. 2008. Recent developments in chemical modification and characterization of natural fiber-reinforced composites. *Polymer Composites*, *29*(2), 187.

Jonoobi, M., Niska, K. O., Harun, J. & Misra, M. 2009. Chemical composition, crystallinity, and thermal degradation of bleached and unbleached kenafbast (Hibiscus cannabinus) pulp and nanofibers. *BioResources*, 4(2), 626-639.

Kimmel, L. B., Boylston, E. K., Goynes, W. R., Akin, D. E., Henriksson, G. & Eriksson, K. E. L. 2001. Non-traditionally retted flax for dry cotton blend spinning. *Textile Research Journal*, *71*(5), 375-380.

Kivaisi, A., Assefa, B., Hashim, S. & Mshandete, A. 2010. Sustainable utilization of agro-industrial wastes through integration of bio-energy and mushroom production. Retrieved September, 14, 2015 from https://cgspace.cgiar.org/bitstream/handle/10568/10816/project4_biogas.pdf?sequence=6

Lewin, M. & Pearce, E. M. 1985. *Handbook of fiber science and technology*: volume 4-fiber chemistry.

Liu, W., Misra, M., Askeland, P., Drzal, L. T. & Mohanty, A. K. 2005. 'Green'composites from soy based plastic and pineapple leaf fiber: Fabrication and properties evaluation. *Polymer*, 46(8), 2710-2721.

Marella, J. B. R., Madireddy, S. & Maripi, A. N. Production of Pulp from Banana Pseudo stem for Grease Proof Paper. *Table of Content Topics*, 61.

Paridah, M. T., Basher, A. B., SaifulAzry, S. & Ahmed, Z. 2011. Retting process of some bast plant fibres and its effect on fibre quality: A review. *Bio Resources*, *6*(4), 5260-5281.

Ramarad, S. 2008. Preparation and properties of kenafbastfiber filled (plasticized) poly (lactic acid) composites.

Ramaswamy, G.N., Boyd, C.R., Bel-Burger, P. and Kimmel, L. 1995. 'Kenaf/Cotton Blend for Textiles', *Family and Consumer Sciences Research Journal*, 24 (2), 180- 190.

Smole, M. S., Hribernik, S., Kleinschek, K. S., &Kreže, T. (2013). Plant fibres for textile and technical applications. *Advances in Agrophysical Research*, *10*, 52372.

Song, K. H. & Obendorf, S. K. 2006. Chemical and biological retting of kenaffibers. *Textile Research Journal*, *76*(10), 751-756.

Stanhope, C. M. 2012. 'Acceptance of BastFiber Textiles for Sustainable Product Development', Graduate Faculty of North Carolina State University, Raleigh, North Carolina [USDA, 2000].

Summerscales, J., Dissanayake, N. P., Virk, A. S. & Hall, W. 2010. A review of bast fibres and their composites. Part 1– Fibres as reinforcements. *Composites Part A: Applied Science and Manufacturing*, *41*(10), 1329-1335.

Van Dam, J. E. G. October, 2008. *Natural fibres and the environment: environmental benefits of natural fibre production and use.* Paper presented atthe Symposium on Natural Fibres: Common Fund for Commodities, Rome, Italy

Yu, T., Ren, J., Li, S., Yuan, H. and Li, Y. 2010. Effect of fiber surface-treatments on the properties of poly (lactic acid)/ramie composites. *Composites Part A: Applied Science and Manufacturing*, 41(4), 499-505.

Yueping, W., Ge, W., Haitao, C., Genlin, T., Zheng, L., QunFeng, X. & Xushan, G. 2009. Structures of natural bamboo fiber for textiles. *Textile research journal*.

Zhang, T. 2003, 'Improvement of Kenaf yarn for apparel applications', Graduate Faculty of theLouisiana State University, Baton Rouge, LA.

Websites visited

www.vasantkothari.com (*Last accessed on 11.02.2014*)
www.globalhemp.com *(Last accessed on 05.03.2014)*
www.cottoncrc.org.au *(Last accessed on 22.01.2015)*
www.patentstorm.us *(Last accessed on 08.03.2015)*
www.webistem.com *(Last accessed on 26.08.2015)*
www.fao.org (*Last accessed on 11.09.2015*)
www.usda.gov (*Last accessed on 11.09.2015*)

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