



A Review on Preparatory Processes of Bamboo Fibres for Textile Applications

Varinder Kaur^{1*}, Chattopadhyay DP², Satindar Kaur³, Sachin Kumar Godara¹, Sanyog Sharma¹, Simran Kaur¹, Amanjit kaur¹ and Saurabh Garg⁴

¹Department of Chemistry, Guru Nanak Dev University, Amritsar, India

²Department of Textile Chemistry, MS University of Baroda, India

³Department of Chemistry, Sri Guru Granth Sahib World University, Fatehgarh Sahib, India

⁴Department of Textile Design, National Institute of Fashion Technology, Kangra, India

Abstract

This review addresses the potential wet processing techniques for textile fibre extraction, mainly centering on bamboo, one of the most important and newly developed textile natural fibres. The literature survey revealed that although some reports are available on the use of these extracts on different textile substrates viz. cotton, wool, nylon, silk, polyester etc., but yet reports concerning the use on Bamboo fibre/fabric is scanty. Natural bamboo fibers have excellent properties suggesting that there is a good potential for them to be used in textiles; however, they have not received the attention that they deserve owing to their coarse and stiff quality. The high lignin content of the fibre is the major cause of its stiffness.

Keywords: Bamboo; Lignin; Cellulose; Hemi-cellulose; Bleaching; Delignification

Introduction

Ecological or environmental problems have become global in character and there is an urgent need worldwide to tackle these problems. The most famous environmental impacts related to energy and toxic chemical use, as well as ecological or social impacts comprising of low wages and poor working conditions are the major environmental problems needing urgent attention. These detrimental impacts demand sustainable changes not only in each phase of the textile life cycle, but also on a holistic systems-level. Environmental protection and production of quality textiles of international standards are two serious challenges before textile processors. In textiles, market of natural bamboo fibre that is extracted directly from bamboo by degumming process (retting), has risen due to its excellent properties like biodegradability, antibacterial functions and anti-odour. In this review a possible processing system for bamboo fibre bundles has been suggested and properties of treated bamboo fibres have also been discussed.

Use of Bamboo in Textiles

Bamboo has antibacterial properties which bamboo fabric is apparently able to retain, even through multiple washings. This helps to reduce bacteria that thrive on clothing and cause unpleasant odours. It can also kill odour causing bacteria that live on human skin, making the wearer and his or her clothing smell better [1]. In addition, bamboo fabric has insulating properties and will keep the wearer cooler in summer and warmer in winter. The versatility of bamboo fabric makes it an excellent choice for clothing designers exploring alternative textiles, and in addition, it can be dyed by many dyes with bright colors as it is made of cellulose and there are many dyes available to dye cellulose. Natural bamboo fibers have excellent properties suggesting that there is a good potential for them to be used in textiles; however, they have not received the attention that they deserve owing to their coarse and stiff quality. The high lignin content of the fibre is the major cause of its stiffness [2,3].

There are two ways to process bamboo to make the plant into a fabric: mechanically or chemically [4]. The mechanical way is by crushing the woody parts of the bamboo plant and then use natural enzymes like ligninase and salinase to break the bamboo walls into a mushy mass so that the natural fibres can be mechanically combed out, spun into yarn and then into fabric. Bamboo fabric made from this

process is sometimes called bamboo linen. Chemically manufactured bamboo fibre is a regenerated cellulose fibre similar to rayon or modal. The bamboo fibre which is the current fashion range is chemically manufactured by “cooking” the bamboo leaves and woody shoots in strong chemical solvents such as sodium hydroxide and carbon disulfide in a process known as hydrolysis alkalization combined with multi-phase bleaching [5].

The invention of bamboo fibre is the biggest contribution of mankind to protect naturally rare minerals/resources and ultimately the environment as a whole. The property that bamboo is highly renewable grass has resulted in its being classified as eco-friendly, which in turn has resulted in its use in textile industry [5]. Repeated tests have proved that the bamboo fibre has a strong durability, stability as well as tenacity. The thinness and whiteness degree of chemically manufactured fibre obtained from bamboo has been found to be similar to that of viscose staple fibre. Moreover, this fibre being natural cellulosic fibre can achieve natural degradation in soil and can be blended with other materials such as cotton, hemp, lyocell, modal fibre and so on.

The bamboo has been used in agriculture, handicraft, paper making, furniture and architecture for thousands of years; however, it is only recently that efforts have been made to produce textile fibres from bamboo [6]. The worldwide research has been carried out on bamboo to study the structure, properties of bamboo fibre as well as extraction methods of bamboo fibre [7]. The quantitative analysis in chemical component of bamboo fibre resulted that after degumming through a chemical treatment, the cellulose content in bamboo fibre had reached more than 70%, which is the basic requirement of any fibre for its textile application [7]. The presence of lignin and hemicellulose in natural bamboo fibres, on the other hand somehow reduces its applicability

***Corresponding author:** Varinder Kaur, Assistant Professor, Department of Chemistry, Guru Nanak Dev University, Amritsar, Punjab, India, Tel: +91-9888504121; E-mail: varinder_gndu@yahoo.com

Received March 26, 2019; Accepted May 03, 2019; Published May 10, 2019

Citation: Kaur V, Chattopadhyay DP, Kaur S, Godara SK, Sharma S, et al. (2019) A Review on Preparatory Processes of Bamboo Fibres for Textile Applications. J Textile Sci Eng 9: 398.

Copyright: © 2019 Kaur V, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

in textiles. However, some study has also been carried out to reduce lignin and hemicellulose from bamboo fibre to enhance its textile applicability [8].

Few investigations deal with the evaluation of lignification's and lignin heterogeneity for various age classes of bamboo stems were conducted by Lin et al. Zhao standardized the method of production of bamboo fibre following the steps including pre-treatment of raw material from bamboo (material organization, Bamboo stripping, Bamboo soaking), Bamboo fibre decomposition (boiling, rinsing, decomposing), Bamboo fibre formation (fibre softening, dehydration, restoration and boiling) and finally by bamboo fibre post treatment (inspecting, sifting, sorting and drying) [4,9].

Traditionally, bamboo has been used for the manufacturing of houses. Bamboos are used for many different purposes. Often only some species are suitable or preferred for certain uses. A huge percentage of bamboo has been used for foot mats, carpet backing, bed clothes, T-shirts, socks, bathrobes and towel besides its traditional uses, bamboo has gained popularity for its use in non-traditional purposes which are given in Table 1 [10]:

The non-traditional uses of bamboo are presented in the form of a chart in Figure 1. Natural bamboo fibres are also ideal for skin that is sensitive to allergies. Garments manufactured by using bamboo fibre are also claimed to give a score of 50 on the UV protection scale, which is almost equal to a fall of 98% in UV energy. Many manufacturers claimed that even after 50 washes bamboo fibres maintain their natural bacteriostatic and anti-bacterial qualities because of the presence of 'bamboo-kum'. This agent provides the fibres protection

from pests during their growth in fields, thus avoiding the need for pesticides [11-13].

Bamboo is a lignocelluloses fibre i.e. its main components are cellulose (61%) and lignin (32%) [13]. Bamboo fibre in comparison to other natural fibres has fibre bundles which are more brittle due to their thicker diameter. These composition and physical parameters play an important role to finalize single fibre strength, fibre bundle strength and mixing of fibre bundle. In addition to this, moisture regain, fibre swelling and fibre rigidity are also affected by these compositions [14].

Non-cellulosic substances like lignin and gummy materials are found in high quantity in fibres obtained from mechanical treatment. This kind of fibre is having limited areas of application such as handicraft and household articles as well as being reinforcement for composite materials. On the other hand, cellulosic fibres in bamboo are leaning along the bamboo culm and are fixed in a ligneous mold. The standard alkaline process of delignification is the most reliable standard procedure for lignin removal in which the lignin can be dissolved in sodium hydroxide solution and on the subsequent step, the appropriate amount of cellulosic fibres can be extracted [15]. Bamboo fibre is extracted from the long stem of the plant by retting process which results in the removal of water soluble gums and non-fibrous materials and finally the fibres are extracted from the best of the parent plant in the form of fibre bundles [16]. The extraction of bamboo fibres by using mechanical extracting, steam-explosion, alkaline treatment and bio-enzymatic degumming methods were studied by Deng et al., [17]. Fu, et al., studied the bamboo retting system based upon microorganism's isolation [18]. This retting is one of the most important sequences in the extraction of bamboo fibre and the qualities of fibre depend on the type of retting [18,19]. Bamboo is biodegradable, recyclable raw material in line with environmental requirements and sustainable growth. Depending upon the various conditions such as soil, season, year of growth, environmental conditions and the position of bamboo culm within the bamboo, is subjected to greater unpredictability. Some important research is also available on mechanical properties of regenerated and natural bamboo fibres [20,21]. Yarn made from cotton and bamboo fibre has excellent strength, elongation and initial hairiness [22].

S. No.	Name of Industry	Uses
1	Local industries	Furniture A variety of utensils Houses
2	Wood and paper industries	Laminated Paper and rayon
3	Chemical industries	Biochemical products Pharmaceutical industry
4	Energy source	Charcoal

Table 1: Uses of Bamboo for non-traditional purposes.

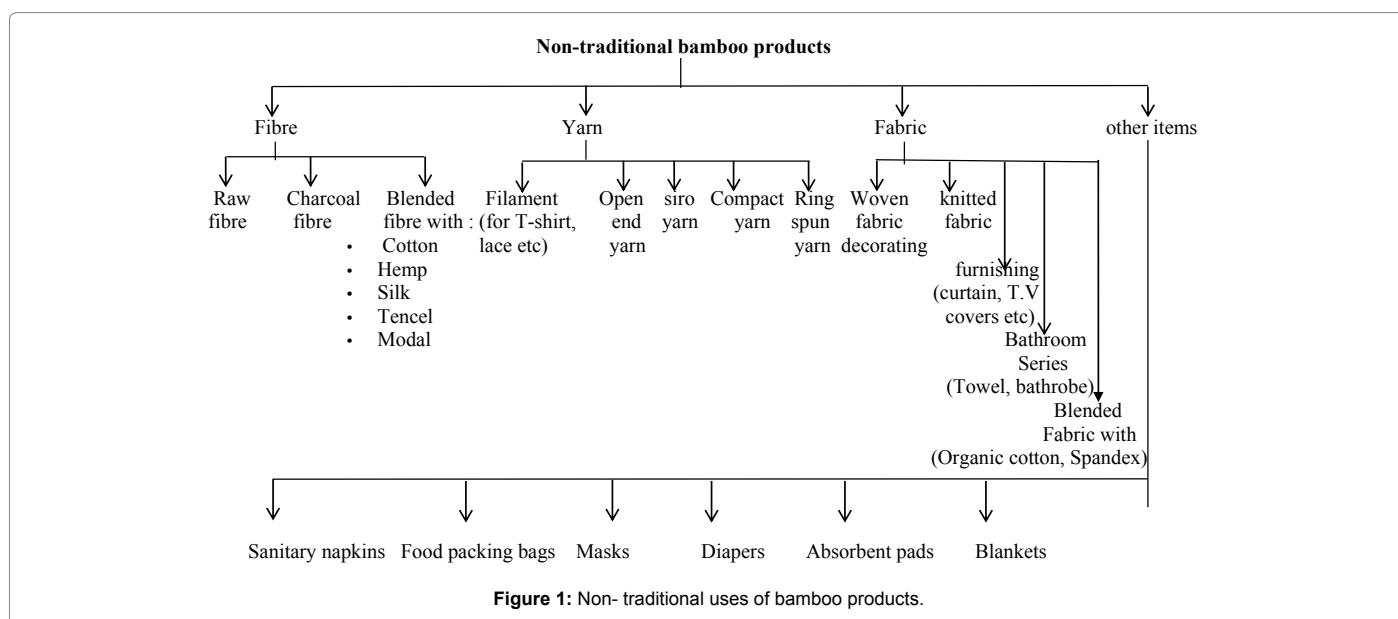


Figure 1: Non-traditional uses of bamboo products.

Chemical Composition of Bamboo

Bamboo fibre is composed of α -cellulose, hemi-cellulose and lignin along with some minor constituents. The average chemical composition of bamboo is presented in Figure 2. In general, the chemical composition of viscose bamboo and natural bamboo is shown in Tables 2 and 3 respectively.

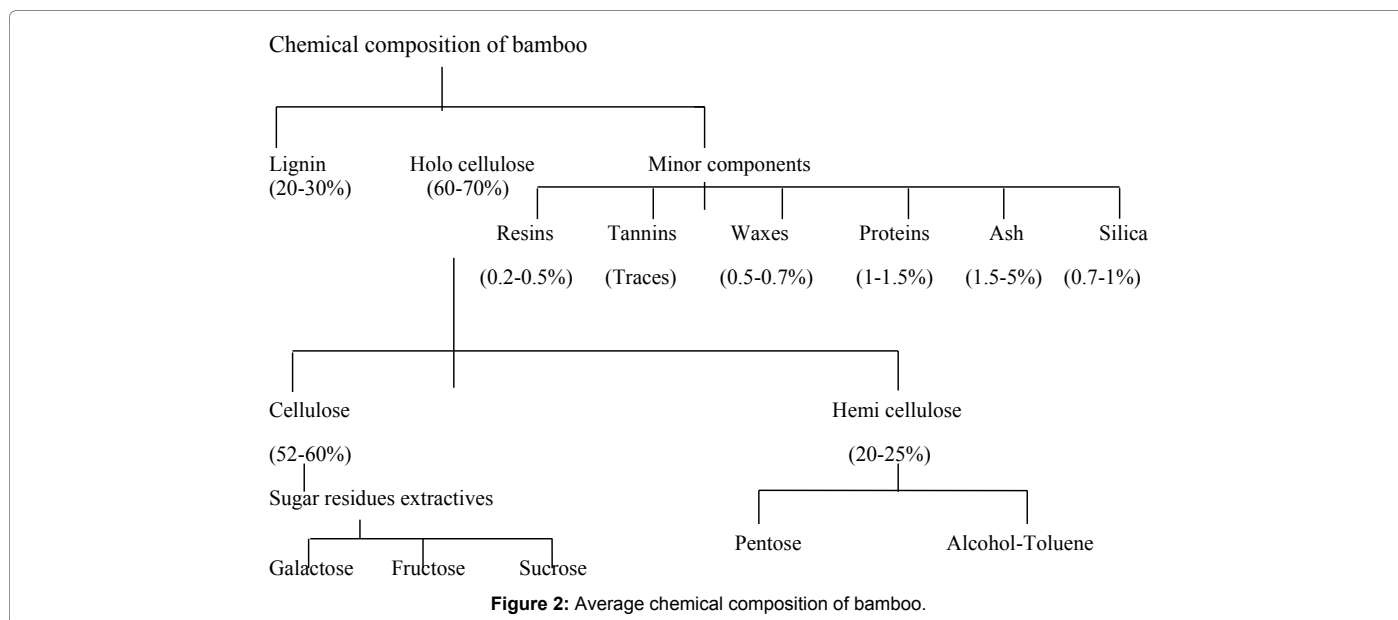
Cellulose

It contains both amorphous and crystalline structure. The degree of crystallinity of the cellulose varies from species to species. It is formed by polymerization of D-anhydro glucopyranose units through 1, 4 β -glycosidic linkage and provides the stiffness to the plant due to its high degree of polymerization and linear orientation. The structural formula of cellulose is shown in Figure 3.

Bamboo is famous for its natural and abundant cellulose having excellent toughness, high crystallinity and hygroscopicity [23,24]. In fact, cellobiose is the building blocks for cellulose. The cellulose is a long chain molecule built up with a large number of glucose residues linked with one another involving glycoside linkage on the pattern shown in the Figure 3. In general α -cellulose content in bamboo is near about 40-50% and this amount is comparable with other best fibres (43-57%), grass fibres (33-38%, softwoods (40-52%) and hardwood (38-56%) [25]. The degree of polymerization (DP) is defined as the number of glucose units in a cellulose molecules and cellulose possess good degree of crystallinity. The degree of polymerization in plant/cane fibres like bamboo & bagasse is reported to be lowest (50-600) among the plant fibres depending upon the determination method used and according to one source it is 1050 of bleached bamboo [26]. Cellulose

molecules have a great tendency to form inter crystalline regions and are generally randomly oriented. Cellulose derived from plants is highly crystalline and generally contains near about 80% crystalline region and remaining portion is referred to as amorphous cellulose. Cellulose present in bamboo provides the stiffness to the plant fibre. It is also very difficult to isolate in pure form because it is closely associated with the hemicellulose and lignin [27].

It is seen that the functional group in cellulose are all alcoholic hydroxyl groups. Each of the two ends contains four hydroxyl groups while all others of the main body of the chain are associated with three hydroxyl groups. Each unit of the main body contains one primary alcoholic group (C6- having CH_2OH group), the remaining hydroxyl groups are secondary alcoholic groups. The secondary hydroxyl group, of one of the end units, attached to C1 is potentially aldehydic in nature, while that attached to C4 of the other end unit is alcoholic. Hydrolytic breakdown of cellulose takes place in the presence of acid. The hydrolysis of cellulosic chain in to smaller fragments leads to the production of new reducing and non-reducing hydroxyl groups. The reaction actually starts on the surface layer of the fiber breaking down the molecule while at the same time the deeper layers may be affected to the lesser extent. Consequently, after a certain time of hydrolysis, product with wide range of degree of polymerization may be obtained. Progressive attack by acids causes cellulose to lose strength. The product found by the acid treatment of cellulose that has been partially hydrolyzed and has not lost its fiber structure. It is, in fact, a complex mixture of unchanged cellulose and shorter chain molecules, some of which may be soluble in dilute alkali or even in water. The hydrocellulose will invariably contain a higher proportion of aldehyde groups. Hydrocellulose is



Components	Average %
Alpha cellulose	80%
Hemicellulose	15%
Pentosans	3.5%
Other components include resin, soaps, sulphur, ash & lignins like substances.	2-3%

Table 2: Chemical composition of bamboo viscose fiber.

Components	Average %
Cellulose, hemicelluloses, lignin	90%
Other components are protein, fats, pectin, tannis, pigments, ash	10%

Table 3: Chemical composition of the natural bamboo fiber.

more sensitive to heat than cellulose and it will start to scorch at 110°C as against 170°C at which unmodified cellulose scorches. The treatment of cellulose fiber with oxidizing agents in acidic, neutral or alkaline mediums leads to oxidation of cellulose almost invariably with loss in tensile strength. Products of oxidation of cellulose almost are normally referred to as oxy-cellulose which are heterogeneous in nature with widely different in properties. The oxidation of cellulose represents a rather complex phenomenon. Most oxidizing agents attack the fiber progressively from layer after layer and oxidation may continue slowly until the entire cellulose is oxidized [28].

At the earlier stages not only the available hydroxyl groups of the surface layer of cellulose will be oxidized but also the glucosidic linkage may breakdown, resulting in the formation of substances of lower molecular weight. All the alcohol groups in the cellulose molecule will be oxidized by the action of most of the oxidizing agents. In general there are six points of oxidative attacks:-

- Attack at the C2 or C3 or both oxidizing these two secondary alcohol groups to ketones without breaking the ring.
- Oxidation of the both C2 and C3 to form aldehyde with a simultaneous rupture of the ring.
- Oxidation of the primary alcohol group at C6 to aldehyde.
- Any of these three oxidations will yield an oxycellulose of the reducing type, with almost no carboxyl group in it.
- Further oxidation of the aldehyde groups at C2 and C3 to carboxyl groups.
- Oxidation of the primary alcoholic group (C6) to carboxyl group. These two types of oxidations will yield a carboxyl type of oxy-cellulose.
- The oxidation may result in the conversion of one of the alcohol groups at C2 and C3 positions into carboxyl groups, while the other one may be oxidized to CHO group.

Such an oxy-cellulose will have a high -COOH content and also a high reducing property [29].

Hemicellulose

It is a polymer like cellulose but having shorter chain length (DP>150). It is composed of mainly pentosan and a little hexosan [30]. It is soluble in cold 18% caustic soda. The predominant polysaccharide in jute is composed of a backbone of β-D - xylopyranose unit carrying a terminal 4-O-methyl -α-D- gulcouronic acid residue linked through position two. When pentosan that is a polymer of pentose sugar such as xylan, araban etc. is heated with strong hydrochloric acid (13.15%), the pentose is first hydrolyzed to pentose sugars and the sugars are then dehydrated to furfural (Figure 4).

When hemicellulose containing uronic furfural acid such as glucouronic, galactouronic etc. is heated with strong hydrochloric acid solution (13.15%) uronic acid solution hydrochloric acid solution. A relatively high concentration of reducing aldehyde group present in hemicellulose contributes to its relatively strong reducing action compared to native cellulose. The hemicellulose present in bamboo constitutes mainly the amorphous portion of the fibre and is responsible for acidic nature and high moisture regain of the fibre remain linked with lignin as an ester. It is in the main chain linear, but appears to be different from the xylan found in the woods of gymnosperms with regard to the degree of branching and molecular properties. In addition, the bamboo xylan contains 6-7% of native acetyl groups, which is a characteristic possessed by hardwoods.

Due to the presence of arabinose it is closer to softwoods (Figure 5). Thus, the bamboo xylan is in-between between hardwood and softwood xylans [31].

Lignin

Subsequent to cellulose, lignin represents the second richest ingredient in the bamboo and processors have been focused on its chemical nature and structure. Bamboo lignin is a typical grass lignin, which is built up from the three phenylpropane units p-coumaryl, coniferyl, and sinapyl alcohols unified through biosynthetic patterns (Figure 6). The lignin is derived from the Latin word 'lignum' meaning

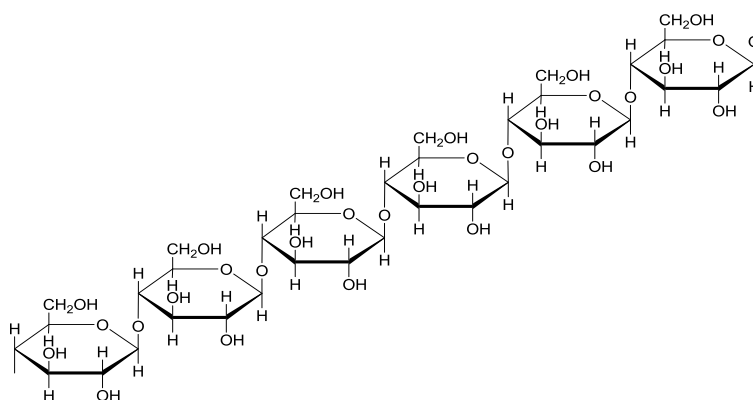


Figure 3: Structure of cellulose.

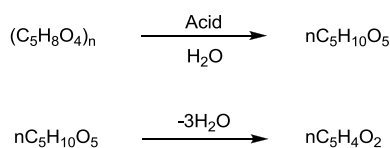


Figure 4: Hydrolysis and dehydration of pentose. sugar

wood and indeed lignin form an essential component of woody stems as well as cell wall constituents of many plants. It imparts rigidity to the cell wall and woody parts (Figure 6).

The growing bamboo shows a variety of lignification stages from the bottom to the top portions of the same culm. The lignification's within every internode proceeds downward from top to bottom, while crosswise from inside to outside. During the height growth lignification of epidermal cells and fibres precedes that of ground tissue parenchyma. Higuchi et al., reported that full lignification of bamboo culm is completed within one growing season, showing no additional ageing effects. It has also been detected that there is no difference in lignin composition between vascular bundles and parenchyma tissue [32].

The rigidity in bamboo is basically due to its lignin content and acts as a permanent bonding agent between cells generating a composite structure outstanding by resistance towards impact, compression and bending. Lignin is a highly branched three dimensional polymer and is not swelled by the usual swelling agents. A possible structure of lignin is shown in Figure 7. Structural units of lignin are aromatic alcohols with a phenyl propane backbone, such as p-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol. The molecular weight of solubilised lignin varies from 300 to 1, 40,000 depending on the source and the method of estimation. The main functional groups present in lignin are alcoholic & phenolic hydroxyl group, methoxy, dioxymethylene etc. Lignin is believed to be formed by oxidative polymerisation of the phenyl propane units to give large cross-linked molecules containing carbon-carbon and ether linkages. It is non-crystalline and low DP material. Lignins as they occur in plants are known as native lignins or photo lignins. Lignins are sometimes designated with the source from which they are isolated such as soft wood lignin, spruce lignin, bast fibre lignin etc. isolated Lignins are normally named by the process or chemicals used for isolation or by the name of the scientists associated with a particular process of isolation such as: alkali lignin, methanol lignin, dioxane lignin, cuprammonium lignin, Braun's lignin etc. The combined yields of the three aldehydes may account 65% of some Lignins [32-34].

Chemical Treatment of Bamboo

Effect of alkali on bamboo

Reports from literature prove that bamboo is having extremely tight structure when it is compared with other types of best substances/materials [35,36]. To open the culms, mechanical beetling (treatment) action is required so that the penetration of chemicals can take place easily when it is exposed to the wet processing for the extraction of fibres. The individual cells of bamboo are cemented with lignin and hemicelluloses. A severe alkaline treatment is generally recommended to remove non-cellulosic substances i.e., lignin and gummy substances. This treatment with alkali is one of the standard methods in the paper and pulp industries [37]. In this way lignin can be removed/ dissolved in sodium hydroxide solution followed by subsequent washing and neutralization. Due to this, alkali treatment lignin gets broken up but it cannot break itself into smaller segments. Few investigations have been reported that sodium salts of these smaller segments are easily soluble in the subsequent washing using a particular medium. Apart from the solution of sodium hydroxide (NaOH), there are number of aqueous alkaline solutions such as sodium carbonate (Na_2CO_3), potassium hydroxide (KOH) and lithium hydroxide (LiOH) [37,38]. Among of the above mentioned aqueous solutions, sodium hydroxide (NaOH) is in maximum use due to its availability in abundant form and cheaper than other alkalis. It acts as a swelling agent enhances the dissolution and removal of lignin along with other non-cellulosic materials. Alkali treatment with dilute caustic soda solution cleans the surface of fibre bundles without any severe damaging. It enhances the regularity of fibres in the bundles and thus increasing the fibre productivity. The most important changes in the properties of bamboo fibre are brought about when it is treated with NaOH solution at ambient temperature. At lower temperature, the composite acquires excellent extraction of fibres having remarkable mechanical properties [39-41].

With the gradual increase in concentration of caustic soda solution, physical and chemical changes occur and at the concentration of 16%, soft appearance is observed due to the generation of high degree of twist and shrinkage –this phenomenon is termed as mercerization of bamboo [42]. During this treatment twisting and shrinkage effects take place due to longitudinal shrinkage of fibres, along with some partial

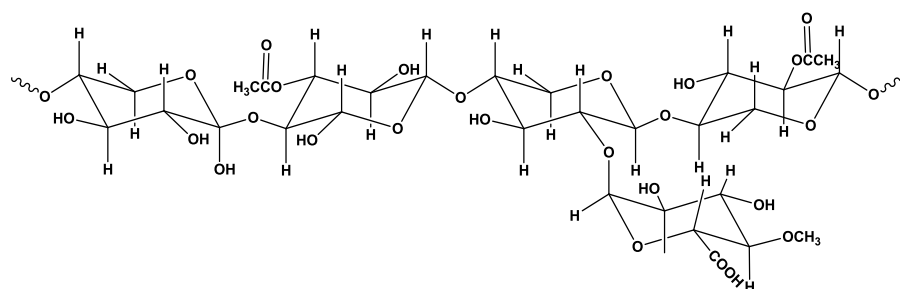


Figure 5: Partial structure of glucuronoxylan, a hardwood. Hemicellulose.

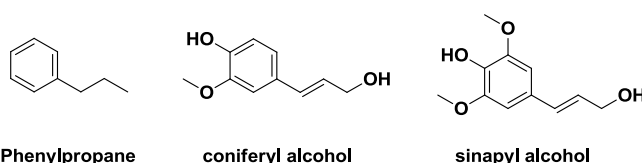


Figure 6: Building blocks of lignin

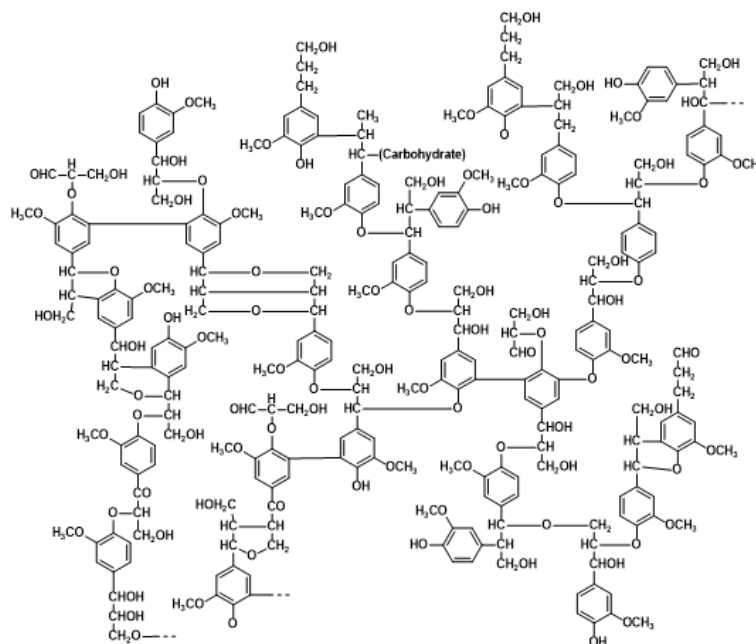


Figure 7: Partial structure of one type of lignin.

conversion of native cellulose-I to cellulose-II, as a consequence of partial loss of crystallinity due to the lateral swelling effect [43,44]. The efficiency of this treatment depends on the de-crystallisation and the degree of lattice conversion [45]. The strength and weight loss in bamboo due to treatment with caustic soda solution increases with the increase in the concentration of alkali. These losses are mainly due to removal of fibrous material consisting of mainly hemicellulose during the treatment. The aim of this process of mercerization of bamboo is entirely different from well-established mercerization of cotton.

Following are the effects of various parameters on treatment with alkali:-

Concentration of alkali: Below 15% concentration of caustic soda, less softness is achieved at any temperature. Thermal stability, weight loss and softening increase with increase in concentration of caustic soda solution up to 17.5-20% after which the cuts take up a stable configuration [45].

Reaction time: The reaction of bamboo materials with alkali is usually accomplished within short time. But an immersion time 20-30 minutes is generally recommended for effective de-crystallisation [46].

Temperature: It has been reported that at 20°C without tension applied to the fibres, great crystal lattice conversion and de-crystallisation with good softness produced with 16% alkali. However the mercerization of bamboo is normally done at the ambient temperature [47].

Important tips on mercerization of bamboo:-

- The handle and appearance of bamboo are improved by mercerization which can be further enhanced by subsequent bleaching and dyeing processes.
- The mercerized bamboo can be blended to other natural fibres to improve their utility according to their end usages.

- The cost of mercerization treated is a bit high, since to recover caustic soda, from water of mercerization bath is difficult due to high percentage of non-fibrous impurities e.g. the remains of node and stem fragments.

It is reported that the benzylated bamboo shows damaging in the crystalline structure of the native ball-milled bamboo. This is because of low crystallinity as well as large non-polar groups obtained during this treatment [48].

Bleaching of bamboo

As for linen bamboo or regenerate bamboo viscose, a common practice is to omit scouring before bleaching of bamboo due to its chemical composition and alkali sensitivity and it is directly taken for bleaching.

Bleaching is an important operation in the processing of bamboo and its blends to produce white shade. Like other lignocelluloses fibres, bleached bamboo material turns to brownish yellow color when it is exposed to sunlight. This pale brown color of bamboo is due to residual lignin in the fibre because of its high molecular weight and hydrophobic nature [48]. To produce different degrees of whiteness ranging from light yellow to milky white, bamboo material is bleached by controlled treatment with selected oxidizing agents like sodium hypochlorite, hydrogen peroxide in an alkaline pH, potassium permanganate, and sodium chlorite under neutral or slightly acidic pH in aqueous medium. Oxidizing bleaching agent breaks up the lignin molecule which ultimately introduces solubilising groups into its fragments and disrupts lignin-carbohydrate bonds. It causes dissolution of fragments in the subsequent after wash process. Oxidizing bleaching agents can be classified as chlorine containing agents and non-chlorine containing agents as follows Table 4.

Reducing bleaching agents viz. sodium hydrosulphite, sodium sulphite, sulphur dioxide, sodium bisulphate etc. are also used for bamboo bleaching. But they are not much in use due to drawbacks of non-permanency of whiteness.

The criteria to select the right bleaching agent for bamboo fibres is dependent on some important characteristics viz. equivalent weight, efficiency, reactivity, selectivity and environmental implications. In case of oxidative bleaching agents, one equivalent weight of that chemical required to do a specific amount of oxidation. Equivalent weight is, therefore, an inverse measure of oxidative power. Equivalent chlorine is another way of expressing the oxidizing power of a bleaching chemical. It is defined as the number of pounds (or kg) of chlorine that has the same oxidizing power as one pound (kg) of the bleaching agent. Equivalent chlorine is, therefore, a direct measure of oxidizing power. Efficiency of bleaching agent used for bamboo is a measure of the degree to which a bleaching agent's oxidizing power is used in desirable lignin-degrading reactions. Reactivity can be defined in terms of the fraction of the residual lignin that the bleaching agent is practically capable of removing it. Selectivity is the degree to which the bleaching agent can remove lignin without dissolving or damaging the other components of fibre like cellulose and hemicellulose [49]. Efficiency, reactivity and selectivity according to equivalent weight and equivalent chlorine are discussed in Table 5.

For good lignin removal, chemical reaction with lignin must be slow enough to allow time for diffusion of chemical into interstices of fibres. Different bleaching agents engender different levels of concern for environment [50,51].

Bleaching with sodium hypochlorite

The detailed methodology of bleaching with sodium hypochlorite is given by some authors [49,50]. Sodium hypochlorite can be used to obtain bleached bamboo fibres, white in colour. De-lignified bamboo fibres strands can be bleached with sodium hypochlorite having 5-8 g/l available chlorine at room temperature for 1-2 hours. Sodium carbonate can be used to maintain alkaline pH in the range 10-10.5. It is then thoroughly washed with water and antichlored with 0.2% sodium sulphate for 15 minutes at 60°C. The fibres are then finally washed and dried. The problem of this bleaching method is that pH around 7 is dangerous for cellulosic plant substrates. Therefore, the parameters viz. pH, time and temperature have to be chosen to optimize bleaching action. So, precaution must be taken and checked them from time to time. The bleaching bath temperature should be maintained regularly to avoid the increase in temperature; otherwise, this fluctuation may enhance the speed of the reaction and may cause degradation. For this purpose, it should be assured that there is no leakage in steam

S. No.	Chlorine containing Compounds	Non-chlorine containing compounds
1	Bleaching Powder	Hydrogen peroxide
2	Sodium hypochlorite	Potassium dichromate
3	Sodium Chlorate	Potassium permanganate
4	-	Peracetic Acid

Table 4: Classification of oxidizing bleaching compounds.

Sr. No.	Chemical Class	Eq. Wt.	Eq. Chlorine	Efficiency	Reactivity	Selectivity	Lignin Removal	Env. Implication
1	Cl ₂	35.5	1.00	E	E	E	E	E
2	ClO ₂	13.5	2.63	E	A	E	E	A
3	O ₂	8	4.44	P	P	A	A	P
4	H ₂ O ₂	17	2.09	P	P	E	P	P
5	NaOCl	37.2	0.93	A	A	E	E	E
6	O ₃	8	4.44	E	E	A	P	P

Note: E: Excellent, A: Average, P: Poor, Eq.: Equivalent, Wt. Weight.

Table 5: Equivalent and efficiency of various bleaching agents.

valve in the processing machine. Hypochlorite bleaching is generally not considered an eco-friendly due to the presence of chlorine in hypochlorite.

Bleaching with sodium chlorite

Bamboo can be successfully bleached with sodium chlorite solution [52,53]. Its strands can be bleached using 4% (mass/volume) sodium chlorite at boil, pH 3-4.5 for 90 minutes using M:L :: 1:20. Formic acid can be used to maintain an acidic pH of the bleaching bath. It is then thoroughly washed and finally dried.

Sodium chlorite acts as a bleaching and delignification agent for lignocellulose materials like jute, hemp, ramie, bamboo etc. By using sodium chlorite treatment, lignin portion dissolves while carbohydrates portions remain almost unaffected.

The problem of this method is that acidified sodium chloride solution is very reactive and causes evaluation of large amount of chlorine gas which creates environmental pollution.

Bleaching with hydrogen peroxide

Hydrogen peroxide has been most widely used as an universal bleaching agent for high-yield bleaching processes for textiles [54,55]. It is having a number of following reasons for obtaining high-yield bleached bamboo fibres:-

- It damages only chromophoric groups in the lignin rather than delignification [56]. Therefore, under optimum conditions of bleaching, cellulose and lignin are not degradable.
- It is known as an environmentally responsible bleaching agent because reaction products are non-ionic. It decomposes to oxygen and water therefore reduces the effluent problem of bleaching agent.

Some disadvantages are also associated with hydrogen peroxide bleaching process [57]:-

- Due to its instability and due to the catalytic actions from the presence of some metallic ions like iron, copper etc., hydrogen peroxide can be decomposed easily during the bleaching process. Automatically it increases the running cost of process.
- High temperature and pH are required for bleaching which most of the time causes tendering in terms of significant fibre strength loss.

A general recipe for bleaching of bamboo is given in Table 6 and it may vary from textile industry to industry [58,59].

Sodium silicate is a mixture of Na₂O & SiO₂ and acts as a stabilizer in peroxide bleaching bath. In the absence of adequate alkalinity, insoluble SiO₂ will precipitate and may deposit on fabric and machinery used for bleaching. That is why to maintain the Na₂O: SiO₂ ratio of 1:1 in the bleaching bath. It can be maintained by a small quantity of sodium hydroxide. There should be a regular check on pH of bath for

S. No.	Chemicals and conditions recommended	
1	Hydrogen Peroxide (50%)	3-8% (owf)
2	Sodium silicate	6-8% (owf)
3	Caustic soda	0.5-0.7% (owf)
4	Non-ionic detergent	0.2-0.5% (owf)
5	Temperature	85-90 °C
6	pH	10.5- 11
7	Time	1.5-2 hour

Table 6: General recipe for bleaching of bamboo using Hydrogen Peroxide.

good efficiency of bleaching process. However, there is no need of the addition of caustic soda, if sodium metasilicate is used where $\text{Na}_2\text{O}:\text{SiO}_2$ is in balanced stage. The use of sodium metasilicate may advantageous instead of use of sodium silicate. It may also be recommended 1.5-2% trisodium phosphate in the place of sodium hydroxide.

The use of non-ionic detergent enables easy wetting of bamboo and helps in thorough penetration of the bleach liquor in to the interstices of material. Moreover, the added and natural impurities removed during bleaching process are also held in the solution and detergent prevents their re-deposition on the material. It is then washed to remove impurities and residual traces of chemicals which should be followed by cold wash. It is finally treated with 2-3 g/L acetic acid to neutralize the residual alkalinity.

Literature reveals different views and opinions from different researchers regarding peroxide bleaching of bamboo. It has been reported that the treatment of bamboo with hydrogen peroxide in the presence of tetra acetyl ethylene diamine (TAED) which acts as an activation in hydrogen peroxide bleaching improves bleaching efficiency [60]. The satisfactory results has been observed using 25-35 g/L hydrogen peroxide at 30-40°C for 45-60 minutes at alkaline pH on pre-treated bamboo fibre with 0.6 g/L NaOH at 100°C for 60 minutes using 1:20 bath ratio. The process of bamboo pretreatment was given as: Chip → roll → high pressure steaming → roll → immersion → sorption → alkali leaching treatment → scouring → rolling combing → washing → drying → crude fibre → bleaching. Experts say that the pretreatment can improve biological degumming efficiency of bamboo lignin by using less treatment time and reduce the production cost. Much improved brightness and satisfactory bleaching was noticed by Changhai X et al., by using a novel bleach activator, N-[4-(triethylammonium-ethyl) benzoyl] butyrolactam chloride (TBBC) in hydrogen peroxide bleaching using equimolar amounts of TBBC and hydrogen peroxide at pH 7 at 50°C [57]. They found better whiteness and less fibre damage, when it was compared with conventional peroxide bleaching. The brightness of lignocelluloses material was found to be increased by about 2-3% when pretreated with xylanase enzymes. Best results are found for pretreated lignocelluloses and xylanase at 45°C using pH 4.5-5 for 6-7 hours treatment.

A study on comparison of peracetic acid and bleaching with hydrogen peroxide showed that peracetic acid bleaching was more effective to reducing the eight and tensile strength [61]. A two stage method is generally practiced to bleach bamboo sequentially, first with hypochlorite and subsequently with hydrogen peroxide. The process gives acceptable whiteness with moderate loss in tensile strength. In a study, Hu J et al., suggested a replacement of conventional sequential bleaching, employing 5g/L peracetic acid at 60°C for 60 minutes using pH 5 in the presence of ammonium sulphate and urea as stabilizer [62]. The suggested process claimed to produce better whiteness with less damage in strength, weight and abrasion resistance.

Delignification of bamboo

Significant delignification of bamboo is conservatively based on techniques similar to those generally applied to wood pulping [63]. On the other hand, hemicellulose and lignin can be regenerated to fabricate preparatory materials for phenolic resin, epoxy, and furan resin production. A serious drawback in utilizing Lignocellulosic biomass for biofuel manufacture has been the restraint in its pretreatment process due to the presence of covalent cross-linkages between lignin and carbohydrates in the plant cell wall and the crystallinity of the cellulose [64]. Further processing on the Lignocellulosic biomass may overcome this problem to some extent, a number of methods have been used but each has its own negative aspect. Chemical treatments using acid or alkali are expensive and not eco-friendly [65]. Physiochemical treatments viz., steam explosion require high temperatures, pressures and make use of boosters, although, are measured as very capable methods [65]. On the other hand, natural methods require long treatment time while mechanical methods viz., milling, involve considerable energy and high capital deal. The effectiveness of the mechanical methods is also doubtful for complete removal of lignin. Removal of lignin during treatment with reducing agent after hydrogen peroxide bleaching of lignocelluloses material pre-bleached with sodium hypochlorite was found to be dependent on the nature of reducing agents used [65].

Conclusion

From the detailed literature review, the following conclusions were drawn:

Natural bamboo fibers have excellent properties suggesting that there is a good potential for them to be used in textiles; however, they have not received the attention that they deserve owing to their coarse and stiff quality. The high lignin content of the fibre is the major cause of its stiffness. The invention of bamboo fibre is the biggest contribution of mankind to protect naturally rare minerals/resources and ultimately the environment as a whole. The property that bamboo is highly renewable grass has resulted in its being classified as eco-friendly, which in turn has resulted in its wide use in textile industry. Repeated tests have proved that the bamboo fibre has a strong durability, stability as well as tenacity. The thinness and whiteness degree of fibre obtained from bamboo has been found to be similar to that of viscose staple fibre. Moreover, this fibre being natural cellulosic fibre can achieve natural degradation in soil and can be blended with other materials such as cotton, hemp, Lyocell, modal fibre and so on. Thus, keeping in view of these observations, wet processing of extracted bamboo fibres from raw culm can be designed for textile industries.

References

- Afrin T, Tsuzuki T, Kanwar RK, Wang X (2012) The origin of the antibacterial property of bamboo. *J Text Inst* 103: 844-849.
- Fu J, Li X, Gao W, Wang H, Cavaco-Paulo A, Silva C (2012) Bio-processing of bamboo fibres for textile applications: A mini review. *Biocat Biotransfor* 30: 141-153.
- Li LJ, Wang YP, Wang G, Cheng HT, Han XJ (2010) Evaluation of properties of natural bamboo for application in summer textiles. *J Fib Bioeng Informa* 3: 94-99.
- Zhan Z (2007) Bamboo fibre and its manufacture. US Patent Application No. 20070267159A1.
- Processing of Bamboo fibre in textile industries, *Colourage LIV* 4: 72-74.
- Nayak L, Mishra S P (2016) Prospect of bamboo as a renewable textile fiber, historical overview, labeling, controversies and regulation. *Fashion Text* 3: 1-25.
- Jain S, Kumar R, Jindal UC (1992) Mechanical behaviour of bamboo and bamboo composite. *J Mat Sci* 27: 4598-4604.

8. Yueping W, Ge W, Haitao C, Genlin T, Zheng L, et al. (2010) Structure of bamboo fibre for textiles. Text Res J 80: 334-343.
9. Sirghie C, Dochia M, Istoc I V, Chambre D, Copolovici L (2015) A comparison of a new method mediated by molybdenum complex with an enzymatic method for bleaching flax fibres. J Nat Fib 12: 378-387.
10. Lin J, He X, Hu Y, Kuang T, Ceulemans R (2002) Lignification and lignin heterogeneity for various age classes of bamboo (*Phyllostachys pubescens*) stems. Physiologia Plantarum 114: 296-302.
11. Casin RF, Mosterio AD (1970) Utilization and prevention of bamboos. Wood Preser Report 5: 86-92.
12. Parameswaran N, Liese W (1977) Occurrence of warts in bamboo species. Wood Sci Technol 11: 313-318.
13. Parameswaran N, Liese W (1980) Ultrastructural aspects of bamboo cells. Cell Chem Technol 14: 587-609.
14. Jiang ZH, Yu WJ, Yu YL (2006) Analysis of chemical components of bamboo wood and characteristic of surface performance. J Northeast Fores Univer 34: 1-6.
15. Deshpande AP, Rao MB, Rao CL (2000) Extraction of bamboo fibres and their use as reinforcement in polymeric composites. J Appl Poly Sci 76: 83-92.
16. Phong NT, Fujii T, Chuong B, Okubo KJ (2012) Study how to effectively extract bamboo fibres from raw bamboo and waste water treatment. J Mat Sci Res 1: 144-155.
17. Alves C, Ferrao PMC, Silva AJ, Reis LG, Freitas M, et al. (2010) Eco design of automotive components making use of natural jute fibre composites. J Clean Prod 18: 313-327.
18. Fu J, Zhang X, Yu C, Guebitz GM, Cavaco-Paulo A (2012) Bioprocessing of Bamboo Materials. Fibres Text. East Eur 20: 13.
19. Akin DE, Foulk DA, Dodd RB, McAlister DD (2001) Enzyme-retting of flax and characterization of processed fibres. J Biotechnol 89: 193-203.
20. Liu L, Cheng L, Huang L, Jianyong Y (2012) Enzymatic treatment of mechanochemical modified natural bamboo fibers. Fib Poly 13: 600-605.
21. Fu J, Li X, Gao X, Wang H, Cavaco-Paulo A, Silva C (2012) Bio-processing of bamboo fibres for textile applications: a mini review. Biocatal Biotransform 30: 141-153.
22. Tyagi GK, Bhattacharya S, Kherdekar G (2011) Comfort behaviour of woven bamboo-cotton ring and MJS yarn fabrics. Ind J Fib Text Res 36: 47-52.
23. Majumdar A, Makhopadhyay S, Yadav R, Mondal AK (2011) Properties of ring-spun yarns made from cotton and regenerated bamboo fibres. Ind J fib Text Res 36: 18-23.
24. Latif MA, Ashaari A, Jamaludin K, Zin JM (1993) Effects of anatomical characteristics on the physical and mechanical properties of Bambusa blumeana. J Tropic Forest Sci 6: 159-170.
25. Stamm AJ (1964) Wood and cellulose Sciences, The Ronald Press Corporation, New York, USA.
26. Fengal D, Wegener G (1984) Wood Chemistry, Ultra structure, Reactions. J Poly Sci 23: 613.
27. Dence CW (1992) The determination of Lignin. In: Lin SY and Dence CW (Eds.), Methods in Lignin chemistry, Springer, Berlin Heidelberg New York 3.
28. Netravali AN (2005) Biodegradable natural fiber composites, In Blackburn R S(Ed.), Biodegradable and sustainable Fibre (Woodhead Publishing, Cambridge, England), p: 271.
29. Williams GI, Wool RP (2000) Composites from natural fibers and soy oil resins, In Wallenberger F T and Weston N (Eds.), Applied Composite Materials (Springer, Netherlands), p: 421.
30. Dorée C (1947) The Methods of Cellulose Chemistry including methods for the investigation of substances associated with cellulose in plant tissues, Chapman and Hall, London, UK.
31. Saheb DN, Jog JP (1999) Natural fibre polymer composites: A review. Adv Poly Technol 18: 351-363.
32. Chen ZH, Li ZQ, Lin S (1993) Distribution and Characterization of bamboo (*Sinocalamus affinis*). Cellulo Chem Technol 27: 519-524.
33. Higuchi T, Kimura N, Kawamura I (1966) Differences of chemical properties of lignins of Vascular Bundles and of Parenchyma Cells of Bamboos. Mokuzaki Gakkaishi 12: 173-177.
34. Higuchi T (1969) Bamboo Lignin and Its Biosynthesis. Wood Res 48: 1-14.
35. Muhammad N, Bustam MA, Mutalib MIA, Cecilia D (2011) Dissolution and Delignification of Bamboo Biomass Using Amino Acid-Based Ionic Liquid. Appl Biochem Biotechnol 165: 998-1009.
36. Callum AS, Hill HPS, Khalil A, Hale MD (1998) A study of the potential of acetylation to improve the properties of plant fibres. Indust Crops Prod 8: 53-63.
37. Grosser D, Liese W (1971) On the anatomy of Asian bamboos, with special reference to their vascular bundles. Wood Sci Technol 5: 290-312.
38. Farrelly D (1984) The book of bamboo, Sierra Club Books, San Francisco, California.
39. Peng WX, Xue Q, Ohkoshi M (2014) Immune effects of extractives on bamboo biomass self-plasticization. Pak J Pharm Sci 27: 991-999.
40. Cai J, Zhang L (2005) Rapid dissolution of cellulose in LiOH/urea and NaOH/urea aqueous solutions. Macromolecul Biosci 5: 539-548.
41. Khuhwaha P, Kumar P (2009) Enhanced Mechanical Strength of BFRP Composite Using Modified Bamboos. J Reinfor Plast Compos 28: 2851-2859.
42. Das M, Chatraborty D (2006) Influence of alkali treatment on the fine structure and morphology of bamboo fibers. J Appl Poly Sci 102: 5050-5056.
43. Liu Y, Hu H (2008) X-ray diffraction study of bamboo fibres treated with NaOH. Fibre and Polymers 9: 735-739.
44. Stout HP (1985) Fibre chemistry, Hand book of Fibre science and Technology, Vol: 4, Marcel Dekker, New York.
45. Jones FR (1994) Hand book of Polymer-Fibre composites, Longman Scientific & Technical, New York.
46. Das M, Chakrobert D (2008) Thermogravimetric analysis and weathering study by water immersion of alkali treated bamboo fibres. BioRes 3: 1051-1062.
47. Yueping W, Ge W, Haitao C, Xiaojun T, Xushan G (2010) Structure of bamboo fiber for textiles. Text Res J 80: 334-343.
48. Trotman ER (2008) Dyeing and Chemical technology of Textile Fibres,(4th edn.) Textile scouring and bleaching, Hodder Arnold, England.
49. Ullmann's Encyclopedia of Industrial Chemistry 1997: Ethanolamines and Propanolamines to Fibres, Synthetic Organic. VCH Verlagsgesellschaft, Weinheim- Basel- Cambridge, New York, Vol. A10.
50. Kushwaha PK, Kumar R (2011) Influence of chemical treatments on the mechanical and water absorption properties of bamboo fibre composites. J Reinfor Plast Compos 30: 73-85.
51. Rao KMM (2007) Extraction and tensile properties of natural fibers: Vakka, date and bamboo. Compos Struct 77: 288-295.
52. Subramanian K, Kumar SP, Jeyal P, Venkatesh N (2005) Characterization of lingo-cellulosic seed fibre from *Wrightia Tinctoria* plant for textile applications-an exploratory investigation. Europ Poly J 41: 853-861.
53. Sengupta AB, Radhakrishnan T (1972) The Diversification of Jute Decorative Fabrics in New Ways to Produce Textile. Text Inst Manche Pp: 112-114.
54. Biagiotti J, Puglia D, Torre L, Kenny J (2004) A systematic investigation on the influence of the chemical treatment of natural fibers on the properties of their polymer matrix composites. Poly Compos 25: 470-479.
55. Changhai X, Shamey R, Hinks D (2010) Activated peroxide bleaching of regenerated bamboo fiber using a butyrolactam-based cationic bleach activator. Cellulose 17: 339-347.
56. Andrews DH, Singh RP (1979) Peroxide Bleaching, in: R. P. Singh (Eds.), The Bleaching of Pulp (Tappi Press, Georgai USA) 2: 211-253.
57. Erdumlu N, Ozipek B (2008) Investigation of Regenerated Bamboo Fibre and Yarn Characteristics. Fib Text East Eur 16: 43-47.
58. Standard Test Method for Active Oxygen in Bleaching Compounds (2003) American Society For Testing And Materials International, ASTM D2180, West Conshohocken.
59. Majumdar P, Sanyal S, Dasgupta B, Shaw SC, Roy TKG (1994) Bleaching of jute with peracetic acid. Ind J Fib Text Res 19: 286-294.

60. Zakzeski J, Bruijninx PCA, Jongerijs AL, Weckhuysen BM (2010) The Catalytic Valorization of Lignin for the Production of Renewable Chemicals. *Chem Rev* 110: 3552-3592.
61. Gomez LD, Steele-King CG, McQueen-Mason SJ (2008) Sustainable liquid biofuels from biomass: the writing's on the walls. *New Phytologist* 178: 473-485.
62. Wyman CE, Dale BE, Elander RT, Holtzapple M, Ladisch MR, et al. (2005) Coordinated development of leading biomass pretreatment technologies. *Biores Technol* 96: 673-686.
63. Chandra RP, Bura R, Mabee WE, Berlin A, Pan X, et al. (2007) Substrate pretreatment: the key to effective enzymatic hydrolysis of lignocellulosics?. *Adv biochem Eng biotechnol* 108: 67-93.
64. Galbe M, Zacchi G (2007) Pretreatment of Lignocellulosic Materials for Efficient Bioethanol production. *Adv Biochem Eng Biotechnol* 108: 41-65.
65. James AP, MacKirdy IS (1990) The chemistry of peroxygen bleaching. *Chem Ind* 15: 641-645.