We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

5,200
Open access books available

129,000
International authors and editors

150M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us? Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Surface Modification of Bast-Based Natural Fibers through Environment Friendly Methods

Tayyaba Fatma

Abstract

Nowadays, natural products are extremely preferred among the people. These natural products are produced by environment friendly sources. In case of textiles, bast fibers play significant role in producing natural products that are extracted from the stem of various plant and environment friendly in nature. The bast fibers can also improve the livelihood of the poor farmers who are involved in the cultivation of the plants and extraction and processing of the fibers. Therefore, surface modification of established natural fibers (such as hemp, flax, jute, kenaf, urena, nettle, and ramie) and explored natural fibers are momentous area for doing research. And, these modifications can be done through environment friendly methods such as plasma treatment, and utilization of enzymes, bacteria, and fungi.

Keywords: natural fibers, surface modification, environment friendly methods, physical and mechanical properties of fibers

1. Introduction

At global level, 58% of synthetic fibers is used in clothing in which 77% polyester, 9% nylon, 6% acrylic, and 7% cellulosic fibers take place. Hence, the utilization of synthetic fibers is higher as compared to natural fibers. The synthetic fibers are generally made from polymers that have been synthetically produced from chemical compounds, which create lot of air, land, and water pollutions. These synthetic fibers are more harmful for health of the human being as well as environment because these cannot easily degrade after its use.

To overcome health-related problems and also for environmental safety, people are gradually attracted toward more and more use of natural products in both developed and developing countries. Thus, increasing concerns toward natural products have led to the search for ecological safe, biodegradable, and recyclable characters in their production. Though in case of textiles, production of natural products from natural fibers play a significant role. Natural fibers obtained from natural resources are one of the proficient fibers that replace the synthetic fibers. Numerous natural fibers such as cotton, wool, silk, and jute are used at commercial level and established as the conventional fibers. Apart from these fibers, some other plant-based natural fibers are also used that are introduced as bio-fibers or vegetable fibers.

The utility of vegetable fibers for preparation of textiles started prior to recorded history. Since the dawn of history to present day, the world is being endowed with

IntechOpen

an abundant availability of vegetable fibers such as flax, jute, hemp, ramie, kenaf, urena, nettle, coir, sisal, pineapple, bamboo, and banana.

Globally, cotton is the leading natural fiber which is produced 25 million tons. It is an estimated average production of cotton. Wool and silk fibers are produced around 2.20 and 0.10 million tons per year, respectively. Other vegetable fibers including jute, flax, kenaf, coir, sisal, ramie, hemp, abaca, kapok, and henequen are produced in considerably 4.61 million tons [1, 2]. On the basis of morphological classification, vegetable fibers are categorized into several sub-categories such as bast fibers, leaf fibers, and seed fibers.

2. Bast fibers introduced as a natural fiber

The bast fibers are usually very long and relatively strong. For this reason, the bast fiber is considered to be the most important fraction of any plant [3].

The bast fibers are referred to as "soft" fibers, which are obtained from the stems of plants. Generally, the stem of fiber-yielding plant consists of bark layer, bast layer, and stem core. The bark layer is the outermost thin skin, that is, cuticle of stem that holds the bast fibers and protects the whole stem. The bast layer occurs between the bark layer and stem core, which is introduced as a fibrous layer of plant. The stem core has two parts, that is, woody tissue (xylem) and pith (**Figure 1**).

The fibrous layers are introduced as forms of primary and secondary fiber layers, which run parallel to the stem of dicotyledonous plants between the nodes. These fiber layers are referred to as bast or phloem or soft fibers, and their bundles vary from stem to stem and in different parts of the stem. There may be as few as 15 bundles to 35 or greater than 35. Each fiber bundle contains 10–40 individual fiber cells that are pointed. The number of cells in the bundle depends on the position of bundle in the stem, which means the largest number being found at the middle of the stem. The size of ultimate fiber cells also varies according to their position in the stem, which means the cells at the bottom of the stem being about three times as thick and longer as those at the top of the stem.

The molecular structure of bast fibers is formed by chains of cellulose molecules and an amorphous matrix of hemicellulose, lignin, pectin, and other substances in a single fiber unit. Therefore, all bast fibers are cellulosic in nature [4, 5]. The large

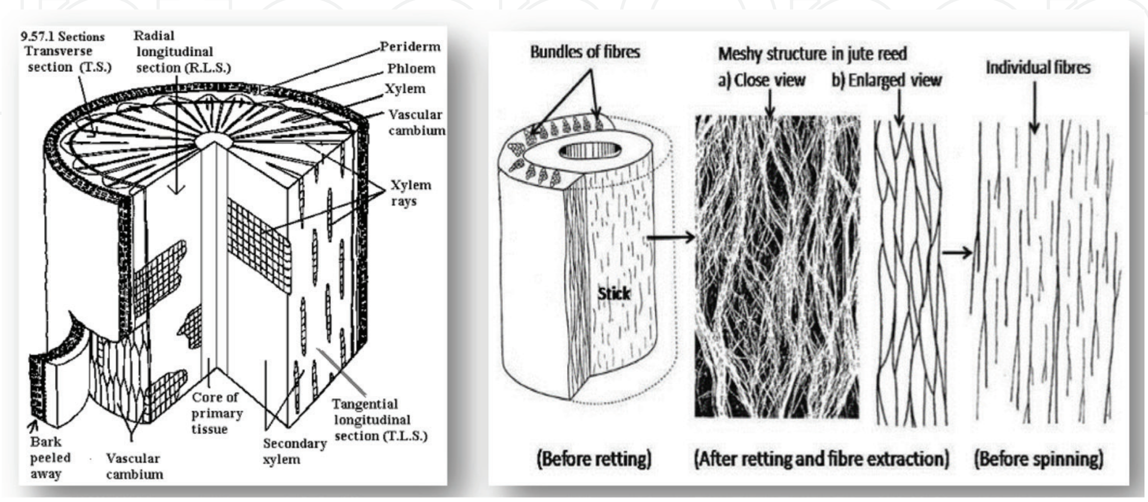

Figure 1.
Microscopic view (cross sectional and longitudinal) of bast fibers. Source: https://textilestudycenter.com/jute-fibre-properties-and-end-uses/ [Accessed: 09-02-2019].

DOI: http://dx.doi.org/10.5772/intechopen.85693

S. no.	Order	Family	Botanical name (genus and species)
1	Asterales	Compositae	*Eupatorium cannabinum*
2	Gentianales	Apocynaceae	*Apocynum cannabinum, A. venetum, Chonemorpha macrophylla*
3		Asclepiadaceae	*Asclepias syriaca, A. fruticosa* and *A. incarnate* *Calotropis gigantea* *Cryptostegia grandiflora* *Marsdenia tenacissima*
4	Geraniales	Euphorbiaceae	*Euphorbia gregaria and E. gummifera*
		Linaceae	*Linum angustifolium and L. usitatissimum*
5	Laminales	Labiatae	*Phlomis lychnitis*
6	Loasales	Datiscaceae	*Datisca cannabina*
7	Malvales	Malvaceae	*Abutilon angulatum, A. indicum, A. bedfordianum, A. incanum, A. graveolens* *Adansonia digitata* *Hibiscus abelmoschus, H. cannabinus*, and *H. furcatus* *Lavatera arborea* and *L. maritime* *Malachra capitata* and *M. radiate* *Pavonia velutina* and *P. schimperiana* *Paritium elatus* *Plagianthus betulinus* and *P. pulchellus* *Pseudabutilon spicatum* *Sida acuta* and *S. cordifolia* *Sphaeralcea umbellata* *Thespesia macrophylla* and *T. populnea* *Urena lobata* and *U. sinuate*
		Moraceae	*Artocarpus elastic* *Broussonetia papyrifera* *Cannabis sativa* *Ficus benghalensis* and *F. nekbudu*
		Sterculiaceae	*Abroma augusta* *Commersonia fraseri* and *C. echinata* *Dombeya buettneri* and *D. cannabina* *California fremontia* *Helicteres isora* and *H. viscid* *Sterculia acerifolia, S. diversifolia, S. lurida* and *S. villosa*
		Tiliaceae	*Cephalonema polyandrum* *Corchorus acutangulus (syn. fuscus), C. aestuans, C. capsularis, C. hirsutus, C. olitorius,* and *C. siliquosus* *Grewia occidentalis* and *G. oppositifolia* *Honckenya ficifolia* *Sparmannia africana* *Tilia americana, T. europaea* and *T. japonica* *Triumfetta cordifolia, T. pentandra (syn neglecta), T. semitriloba, T. bartramia* and *T. rhomboidea*
		Urticaceae	*Boehmeria cylindrical, B. nivea*, and *B. tenacissima* *Debregeasia hypoleuca* *Girardinia palmata* *Laportea gigas* *Maoutia puya* *Pouzolzia hypoleuca* and *P. viminea* *Sarcochlamys pulcherrima* *Touchardia latifolia* *Urtica dioica, U. urens* and *U. pilulifera* *Villebrunea integrifolia* and *V. rubescens*

S. no.	Order	Family	Botanical name (genus and species)
8	Myrtales	Onagraceae	*Epilobium angustifolium* and *E. hirsutum*
		Lecythidaceae	*Couratari tauari*
9	Polygalales	Polygalaceae	*Securidaca longipedunculata*
10	Rosales	Leguminosae	*Acacia leucophloea* *Bauhinia racemosa* and *B. vahli* *Brachystegia spicaeformis* and *B. tamarindoides* *Crotalaria juncea (syn. tenuifolia)* *Cytisus scoparius* *Pueraria thunbergiana* and *P. phaseoloides* *Sesbania exaltata* *Lonchocarpus sericeus* *Spartium junceum* *Vigna sinensis* *Wisteria floribunda*
11	Sapindales	Anacardiaceae	*Rhus typhina*
12	Thymelaeales	Thymelaeaceae	*Aquilaria agallocha* and *A. malaccensis* *Daphnopsis guacacoa* and *D. occidentalis* *Dirca palustris* *Lagetta lintearia*

Sources: Mauersberger, Herbert R. Mathew's Textile Fibers: Their Physical, Microscopic and Chemical Properties. 6th ed. New York: John Wiley & Sons, Inc. and Landon, Chapman and Hall Limited; 1954.

Table 1.
List of potential plant sources of bast fibers.

number of plants included in the bast fiber group, which represents in relation to the number that are cultivated and processed on a commercial scale. This group is a very rich potential supply in the field of textiles fibers (**Table 1**).

3. Background information

The history of bast fibers is not clearly defined. But the several evidences indicate that the bast fibers were used by prehistoric people. The ancient people started their nomadic life by using plant materials for covering and protecting their body, thatched leaf for shelter, and mats for household and other day to day activities. So, the bast fibers were specially cultivated by people to fulfill their needs.

Fragments of linen fabric have been found in excavations at the prehistoric lake regions of Switzerland, which date back to about 10,000 B.C. [6]. The actual samples of woven linen fabric have been recovered from Egyptian tombs dating from 4000 B.C. [7]. The early cultivation of kenaf fiber goes back to 4000 B.C. in West Africa [8]. Ramie has been cultivated for hundreds of years in China, Taiwan and to some extent in Egypt [6]. Hemp is the oldest fiber giving plant, which originated in Southeast Asia and spread to China. The cultivation date of hemp reports back to about 4500 B.C. In 3400 B.C., the skill of spinning and weaving of linen fabric was also well developed in Egypt that indicates the flax was cultivated sometime before that date. According to historical interest, the best known bast fibers include hemp, flax, jute, and ramie and minor fibers are kenaf, urena, and nettle [7].

4. Physico-chemical properties of bast fibers

To evaluate the quality of natural fibers, the fiber length and fineness are two important dimensions which are considered. The length of fiber must be several hundred times to the width, which enables fibers to be twisted together to form a yarn or thread. The length of fiber can be infinitely long but it should not be shorter than 6–12 mm (¼–½ inch) because it may not hold together for spinning. The width of the fiber can vary between considerable limits. The natural fibers vary in fineness from place to place on an individual fiber.

In addition, the fiber must be strong and flexible. Strength is needed to enable the spinning and weaving processes and to provide strength in the final cloth. Flexibility gives draping to a textile due to its unique characteristics. Many experts consider a single fiber strength of 5.0 g/D to be necessary for a fiber suitable in most textile applications, although certain fibers with strengths as low as 1.0 g/D have been found suitable for few applications. The elasticity is an important because the individual fibers in textiles are often subjected to sudden stresses, and the textile must be able to give and recover without significant overall deformation of the textile.

The density of a fiber is related to its inherent chemical structure and the packing of the molecular chains within its structure. The density of a fiber will have a noticeable effect on its esthetic appeal and its usefulness in given applications. Fiber density may be used as an aid in fiber identification [9–12].

The cross-sectional shape is important in luster, bulk, body, texture, and hand or feel of a fabric. The cross-sectional shape may be round, dog-bone, triangular, lobal, bean-shaped, flat, or straw like. The natural fibers derive their shape from the way by which the cellulose is built up during plant growth [13].

The estimation of chemical composition is needed for better understanding regarding the nature of fiber and for making different value-added products. The main constituent of the vegetable fiber cell is cellulose and represented by the general formula $C_6H_{10}O_5$. Apart from cellulose, vegetable fibers also contain significant amounts of other chemicals such as hemicellulose, lignin, pectin, resin, mineral matter, fats, and waxes [14, 15].

Traditionally, bast fibers were used for making carpets, hessian or burlap, sacks, brooms, and wrapping purposes.

Now-a-days, representative of various industries and research institutes are producing range of textile and non-textile products in different fields such as automotive, packaging, horticulture, building, and construction. The bast fibers are suitable in building and construction as a form of geo-textiles, fiber board materials, insulation materials, reinforcement, filler, light-weight concrete, and bricks. High quality thermoplastic and thermosetting composite materials such as door panels, dashboards, seat backs, package trays, headliners and boot liners are produced with the help of bast fibers in automotive. Automotive and aircrafts industries have been actively developing different kinds of natural fibers, mainly on hemp, flax, and sisal and bio-resin systems for their interior components. High specific properties with lower prices of natural fiber composites are making it attractive for various applications.

The bast fibers are also used to produce non-woven fibers that are applied in various forms and products such as tissues and hygienic products, sorbents in diapers and disposables, insulation mat, filling material in mattresses, and geo-textiles. Biodegradable pots for plants, mulching materials, packing cloth for agriculture products, ship towing ropes, tea bags, currency notes, thermal under wears, stationeries, reusable containers, laboratory equipment, and loudspeakers are also manufactured by bast fibers. Therefore, it may face a renaissance, not only for old industrial products but also for the manufacturing of new type of products in the various fields such as technical textiles, industrial products, paper, and building materials [16–20].

Current annual requirement of jute, kenaf, and allied fibers distribute in various sectors such as food grade jute bags, packing materials, family need jute bags, jute geo-textiles, and automobiles. It provides work for more than 12 million of farmers, 1 million of industrial workers, and 0.6 million of jute artisans in more than 18 countries from Asia and Africa directly or indirectly.

The bast fibers have played a significant role for both consumer and manufacturer. Through dyes and finishes, the manufacturer can enhance the appeal and functionality of bast fibers, which ultimately increases the demand and sale of their end products. The bast fibers are also an important for consumers in term of wide range of value-added natural products. Apart from this, bast fibers can improve livelihood of the poor farmers who are involved in the cultivation of the plants, extraction, and processing of the fibers, which play a very important part for their economic life [21].

5. Advantages and drawbacks of bast fibers

The bast fibers have various properties such as comparable specific strength, heat, electrical, and sound insulating properties, good moisture absorbency, air permeability, comfort, low density, low energy requirement, lower pollutant emission, wide availability, better reactivity, and biodegradability. All these properties of the bast fibers are strongly influenced with various factors such as chemical composition, internal fiber structure, micro-fibril angle, and cell dimensions. These factors differ from plant to plant as well as from different parts of a plant. The properties of the bast fibers (cellulosic fibers) also depend on their type of cellulose, because each type of cellulose has its own crystalline organization. Due to their properties, the bast fibers cover a wide range of application from apparel and household fabrics to industrial materials.

One of the most important properties of bast fibers is their eco-friendly nature. Bast fibers are more environment-friendly in term of production and disposal of their products. So, we can say that the bast fibers have been introduced as an emerging "green" economy.

Few drawbacks of bast fibers are also available such as high moisture absorption, poor dimension stability, low thermal stability, low hygroscopicity, low surface energy, and rough structure along with high impurities content in bast fibers. Despite the drawbacks of bast fibers, they have been successfully used in certain applications in the field of insulation, composite, and geotextiles. But these drawbacks inhibit the growth of its applications [22].

However, to increase their applications and achieve better interface of bast fibers, the appropriate environment friendly surface modification methods can be utilize instead of physical and chemical methods for surface modification [1, 23–25].

6. Environment friendly methods for surface modification

Surface modification may be defined as the treatment to modify the surface of materials using physical, chemical, and biological methods for improving their properties [26].

By keeping the point in mind, world has also turned its attention to renewable and sustainable resources or environmental sustainability. Therefore, environment friendly methods for surface modification of bast fibers can be utilized. These methods introduced as green surface methods indicate to environment friendly processes, which are as follows:

6.1 Plasma treatment

Plasma treatment is introduced as a novel dry technique that significantly decreases toxic pollutant in the environment. This technique is suitable to modify the chemical structure along with topography of the surface of the bast fibers.

Basically, plasma is a type of ionized gas consisting of electrons (0–10 eV), ions (10–30 eV), photons, atoms, and molecules and is called as the fourth state of matter. Free electrons, photons, and ion clouds begin to be formed, and some atoms continue to remain neutral and the mixture of atoms, ions, and electrons form the plasma. Two different types of plasma are available for industrial purposes:

i. Thermal plasma: formed direct or alternating current or radio-frequency (RF) or microwave sources at high pressure.

ii. Cold or non-equilibrium plasma: specified by an electron temperature higher than the ion temperature.

The basic function of plasma is to exploit surface of a material by using different type gases. After treatment, reactive free radicals and groups are produced, surface energy is increased or decreased and surface crosslinking are introduced [27–29]. There are two types of interactions which are present on the surface of fibers in the case of plasma treatment.

i. Application of non-polymerizing gases such as helium, oxygen, air, and nitrogen, which creates chain scission on the surface that results in surface etching, cleaning, or activation.

ii. Application of polymerizing gases and precursors such as fluorocarbons, hydrocarbons, and silicon containing monomers, which creates plasma-induced polymerization or grafting.

6.1.1 Mechanism

In the mechanism of plasma treatment, energetic particles and photons generate on the surface of fibers and interact strongly with other substrates by using free-radicals, though various types of changes occur like changes in physical and chemical properties along with changes in the chemical structure of polymers. These changes become due to cleaning, ablation or etching, cross-linking, and grafting modification of surface chemical structure. All these processes, alone or in synergistic combination, improve the functionality of fibers [27].

6.2 Treatment with bacteria

Bacterial cellulose (unlike from the plant cellulose) is natural renewable polymer, synthesized from the bacteria in appropriate culture medium. Certain bacteria which belong to the genera such as *Acetobacter, Agrobacterium, Alcaligenes, Pseudomonas, Rhizobium*, *or Sarcina* are used for treatment of plant cellulosic materials. And, the most efficient bacteria for production of bacterial cellulose are *Acetobacter xylinum.* After treatment, the bacterial cellulose is endowed with unique properties such as high crystallinity index, high tensile strength, good chemical stability, and high water-holding capacity. Due to these properties, it is emerging as a biomaterial that has superior structural aspect to the plant cellulose.

6.2.1 Mechanism

In the optimum culture medium, the bacteria produces about 50–80 cellulose microfibrils ranging from 3.0 to 3.5 mm thickness, which are free from lignin, hemicellulose, and other substances [30].

6.3 Treatment with nanocellulose

Nanocellulose is defined as nanosized cellulose fibril that is a light solid substance obtained from plant resources. It is a pseudo-plastic in nature and also available as a fluids or gels form in standard conditions. The cross dimensions of nanocellulose are starting from 5 to 20 nm, and the longitudinal dimension ranges from a few tens of nanometers to several microns.

The specific properties of nanocellulose are light weight, high strength, and transparency. Hence, this nanocellulose is applicable in a wide variety of areas. Nanocellulose is commonly produced from wood pulp of any plant sources by using mechanical shearing methods such as pulverisette and cryo-crushing or combination of chemical and mechanical method.

6.3.1 Mechanism

Application of nanocellulosic is performed on the surface of bast fibers for enhancing their properties [31, 32].

6.4 Fungal treatment

This treatment ultimately increases the interfacial adhesion between fiber and matrix. Fungal treatment is done by the sterilization of bast fibers at 121.8°C for 15 min. Subsequently, the fibers treated with incubated culture of fungi for 2 weeks at 27.8°C. And then, the fibers were washed and dried. The species of fungi used were *Phanerochaete sordida* (D2B), *Pycnoporus* species (Pyc), and *Schizophyllum commune* (*S. com*) of the basidiomycetes group, *Ophiostoma floccosum* (F13) of the ascomycetes group, and *Absidia* (B101), a zygomycete. Fungal treatment gave higher crystallinity index as compared to the untreated fibers. Fungi treatment can provide low cost, highly efficient, and environmentally friendly alternatives to surface treatment of bast fibers.

6.4.1 Mechanism

Fungal treatment causes the formation of holes (pits) on the surface of fibers, which creates roughness on the surface of fibers by removing the lignin content and increasing the solubility of hemicellulose content.

6.5 Enzymatic treatment

Bio-grafting through enzymes is a comparatively novel modification method that includes grafting of organic molecules onto bast fibers. The purpose of biografting is to enhance the performance of bast fibers by improving the properties such as strength and stiffness, hydrophobicity, assistance to moisture, and microbial attack. Various enzymes such as *laccases, lipases*, and *peroxidases* are used surface functionalization of bast fibers.

6.5.1 Mechanism

The enzymes can oxidize in extensive range of natural polymers and generate reactive species such as phenoxy radicals, thereby increasing the reactivity of polymers [2].

7. Analysis of bast fibers

The molecular and morphological structure of bast fibers (before and after treatment) is analyzed by using the following:

1. SEM analysis: the SEM constitutes one of the oldest and most widely used instruments for surface analysis. It provides a three-dimensional visual image, and thus, the quantitative analysis is relatively straight forward [33].

2. FTIR analysis: it is another technique to examine the nature of molecular chains, crystallinity as a form of high crystallinity index, and their correlations with various bonds [34].

8. Future prospective

Lot of researches may be conducted at various levels such as production and extraction of plasma, bacterial cellulose, nanocellulose, fungi, and enzymes from natural resources, way of application on the surface of bast fibers and other related fibers, and defining its end products.

Development of new bio-composite materials with added functional properties such as in active and smart packaging system has created further scope for expansion of materials technology. Much research is expected for such biodegradable nano-composite materials to replace or reduce the use of the existing petro-based products. Another new approach is GM modification toward higher productivity, better quality, and higher application areas of natural bast fiber [35].

9. Conclusion

It can be concluded that these environment friendly methods are green approaches for modifying the surface of bast fibers. Through these methods, drawback of bast fibers can be improved and also the demand for application of bast fiber at commercial level can be increased. So, we can say that it is green concept-based approach toward sustainability of natural resources as a form of surface modified bast fibers.

Author details

Tayyaba Fatma
Department of Clothing and Textiles, College of Home Science, G.B.P.U.A. and T., Pantnagar, Uttarakhand, India

*Address all correspondence to: tfansari.ct@gmail.com

IntechOpen

© 2019 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Gopalakrishnan D. Reviews on Perception of Sustainable Green Consumption Practicesand it's Impact on Greener Lifestyles [Internet]. Available from: http://www.academia.edu/34432113/reviews_on_perception_of_sustainable_green_consumption_practices_and_its_impact_on_greener_lifestyles [Accessed: 06-02-2019]

[2] India. Ministry of Textiles (Government of India) on other Natural Fibres: Section VI [Internet]. Available from: http://texmin.nic.in/policy/Fibre_Policy_Sub_%20Groups_Report_dir_mg_d_20100608_6.pdf [Accessed: 03-07-2015]

[3] Tahir PM, Ahmad AB, Saiful A, Sayeed OA, Ahmad Z. Review of bast fibre retting. BioResources. 2011;**6**(4):5260-5281

[4] Klaus F, Breuer Ulf. Multifunctionality of Polymer Composites: Challenges and New Solution. William Andrew Applied Science [Internet]. 2015. Available from: https://www.sciencedirect.com/science/article/pii/B9780323264341000040?via%3Dihub [Assessed: 01-02-2019]

[5] NIIR Board of Consultants & Engineers. Natural Fibres: Handbook with Cultivation & Uses. Delhi: National Institute of Industrial Research; 2006

[6] Joseph ML. Introductory Textile Science. 5th ed. New York: Holt, Rinehart and Winston; 1986

[7] Tortora PG. Understanding Textiles. New York: Macmillan Publishing Co. Inc.; 1982

[8] Chen JY, Liu F. Bast Fibres: From plants to products. In: Singh BP, editor. Industrial Crops and Uses. UK: CAB International; 2010

[9] Angappan P, Gopalakrishnan R. Textile Testing. Komarapalayam: S.S.M. Institute of Textile Technology; 2002

[10] Cook JG. Handbook of Textiles Fibers: Natural Fibres. Cambridge England: Woodhead Publishing Limited; 2005

[11] Labarthe J. Textiles: Origins to Usage. London: The Macmillian Company & Collier Macmillian Limited; 1969

[12] Needles HL. Textile Fibers, Dyes, Finishes, and Processes. Park Ridge, New Jersey, U.S.A.: Noyes Publication; 1986

[13] Hollen N, Saddler J. Textiles. 3rd ed. London: The Macmillan Company/Collier Macmillan Limited; 1968

[14] Kirby RH. Vegetable Fibres: Botany, Cultivation and Utilization. Londaon: Leonard Hill [Books] Limited and New York, Interscience Publishers, Inc.; 1963. p. 9

[15] Pan NC, Day A, Mahalanabis KK. Chemical composition of jute and its estimation. Man-Made Textiles in India. 1999;**42**:467-473

[16] Kholiya R, Goel A, Kholiya D. Unconventional fibre plants: A source of sustainable livelihood. International Journal of Science Technology & Management. 2011;**2**(1):27-35

[17] Marques G, Rencoret J, Gutiérrez A, del Río JC. Evaluation of the chemical composition of different non-Woody Plant Fibres used for pulp and paper manufacturing. The Open Agriculture Journal. 2010;**4**:93-101

[18] Mitra BC. Commercial Fibre Crops and their Utilisation. New Delhi: Directorate of Information and Publication of Agriculture; 2008

[19] Mohanty AK, Misra M, Drzal LT. Surface modifications of natural fibres and performance of resulting biocomposites: An overview. Composite Interfaces. 2001;**8**(5):313-343

[20] Sanjay MR, Arpitha GR, Naik LL, Gopalakrishna K, Yogesha B. Applications of natural Fibres and its composites: An overview. Natural Resources. 2016;7:108-114. DOI: 10.4236/nr.2016.73011. [Assessed: 01-02-2019]

[21] International Jute Study Group. Report on World Jute & Kenaf Statistics: At a Glance (Jute, Kenaf other Bast and Hard Fibres: Farm to Fashion). Dhaka, Bangladesh [Internet]. 2012. Available from: http://jute.org/IJSG%20Publications/Jute%20&%20kenaf%20Stat%20at%20a%20glance_ijsg.pdf [Accessed: 13-07-2015]

[22] Sadrmanesh V, Chen Y. Bast fibres: Structure, processing, properties, and applications. International Materials Reviews. 2019;**64**(7):381-406. DOI: 10.1080/09506608.2018.1501171

[23] Kalia S, Vashishta S. Surface modification of sisal fibres (*Agave sisalana*) using bacterial cellulose and methyl methacrylate. Journal of Polymers and the Environment. 2012;**20**:142-152

[24] Kalia S, Thakur K, Celli A, Kiechel MA, Schauer CL. Surface medication of plant fibres using environment friendly methods for their application in polymer composites, textile industry and antimicrobial activities: A review. Journal of Environmental Chemical Engineering. 2013;**1**:97-112

[25] Khoshnava SM, Rostami R, Ismai M, Valipour A. The using fungi treatment as green and environmentally process for surface modification of natural Fibres. Applied Mechanics and Materials. 2014;**554**:116-122

[26] Khan A, Bhawani SA, Asiri AM, Khan I. Thermoset Composites: Preparation, Properties and Applications. Material Research Forum LLC: Millersville, PA; 2018

[27] Senthilkumar P. Surface modification of bast fibres by plasma treatment. Chemical Fibres International. 2017;**67**(2):94-95

[28] Shanmugasundaram OL. Application of plasma in textile industries. Textile Asia. 2006;**38**(5):44

[29] Zille A, Oliveira FR, Souto AP. Plasma treatment in textile industry. Plasma Processes and Polymers. 2014;**12**(2)

[30] Lustri Wilton R, de Oliveira Barud HG, da Silva Barud H, Peres Maristele FS, Junkal G, Agniezka T, et al. Microbial Cellulose—Biosynthesis Mechanisms and Medical Applications [Internet]. 2015. Available from: https://www.intechopen.com/books/cellulose-fundamental-aspects-and-current-trends/microbial-cellulose-biosynthesis-mechanisms-and-medical-applications [Accessed: 09-12-2015]

[31] Halib N, Perrone F, Cemazar M, Dapas B, Farra R, Abrami M, et al. Potential applications of Nanocellulose-containing materials in the biomedical field. Materials. 2017;**10**:977

[32] Jawaid M, Salit MS, Alothman OY. Green Biocomposites: Design and Applications. Green Energy and Technology [Internet]. 2017. Available from: https://books.google.co.in/books?id=e6gbDgAAQBAJ&pg=PA280&lpg=PA280&dq=future+scope+of+environment+friendly+surface+modification+method+for+bast+fibres&source=bl&ots=N8e5s0pJH2&sig=ACfU3U2jqMV0KQhMo9cK_3I4XOqGBl2C7w&hl=en&sa=X&ved=2ahUKEwjD7tX3p6fgAhWJso8KHdVCn8Q6AEwCnoECAcQAQ#v=onepage&q=future%20scope%20

of%20environment%20friendly%20 surface%20modification%20 method%20for%20bast%20 fibres&f=false [Assessed: 01-02-2019]

[33] Ugbolue SC. Fiber and yarn identification. In: Fan Q, editor. Chemical Testing of Textiles. Woodhead Publishing in Textiles; 2005. pp. 6-7, 14

[34] Bakar NA, Sultan MTH, Azni ME, Hazwan MH, Ariffin AH. Extraction and surface characterization of novel bast fibers extracted from the *Pennisetum purpureum* plant for composite application. Materials Today: Proceedings. 2018;**5**(10). (Part 2):21926-21935

[35] Mitra BC. Contemporary environment friendly composite materials: Biocomposites and green Co. Defence Science Journal. 2014;**64**(3):244-261. DOI: 10.14429/dsj.64.7323