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Focus on Bamboo and its Physical, Chemical Properties, and Dyeing Methods

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Abstract

Plant fibers, including bamboo fibers, are used in reinforced polymeric composite materials to promote environmental sustainability. Bamboo fibers offer mechanical characteristics, recyclability, and environmental friendliness, making them suitable for construction applications. Natural fibers, which are renewable and eco-friendly, can replace synthetic materials in various industries. Plant fibers consist of cellulose, hemicellulose, lignin, and pectin. The mechanical properties of fibers improve with increased cellulose content. Bamboo, a fast-growing grass with woody stalks, is used as a source of bast fiber and cellulose. It is abundant in various regions worldwide and has high tensile strength, making it a potential alternative to steel. Bamboo textiles are in demand due to their antibacterial properties, biodegradability, high moisture absorption capacity, and UV protection. Bamboo culms have a hollow cylinder structure with diaphragms and vascular bundles that provide strength. The microstructure of bamboo culms includes vascular bundles, bundle sheaths, xylem, and phloem. The chemical composition of bamboo fiber consists of cellulose, hemicelluloses, lignin, and minor components. Bamboo exhibits stiffness and toughness due to its lignin content, which acts as a bonding agent. Bamboo fiber extraction methods include mechanical extraction and chemical processing. Mechanical extraction techniques involve processes like steam explosion and retting to separate the fibers.

Keywords: Bamboo, Composition, Extraction, Treatment, Dyeability

Introduction

Plant fibers that are naturally occurring Reinforced polymeric composite materials have been employed to conserve the environment in various areas of our lives. Bamboo fibers, partisculary, have been used as reinforced polymer matrix composites in the construction industry due to their environmental sustainability, mechanical characteristics, and recyclability[1].

Natural fibers are renewable and eco-friendly materials with low density, low cost, and adequate mechanical qualities. As a result, numerous researchers are interested in replacing them with synthetic materials in order to protect the environment. Natural fibers are classified into three types based on their origin: plant fibers (sisal, hemp, flax, bamboo, etc.), animal parts containing protein (silk, hair, wool, etc.), and minerals[2]. Plant fibers are composed primarily of cellulose, hemicellulose, lignin, and pectin. Lignin and hemicellulose matrix held cellulose fibrils together in the structure of plant fibers[3]. The mechanical characteristics of fibers improve as the amount of cellulose increases. Cellulose fiber has been used in the construction of buildings, bridges, and automobiles as a reinforced polymer composite[1].

Between the 1920s and 1930s, the first natural fiber composite was employed as a component of an airplane to save weight[4]. According to certain studies, natural plant fibers are better for the environment than glass fibers; thus, the cellulosic fiber-reinforced composite can be replaced with glass fiber[5, 6].

Bamboo plants are massive, fast-growing grasses with woody stalks. Size, growth habit, sun tolerance, soil moisture requirements, and heat/cold temperature tolerance are all different. Several researchers have looked into bamboo as a source of

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bast fiber and cellulose by pulping the bamboo see **Figure 2 and Figure 2**[7].

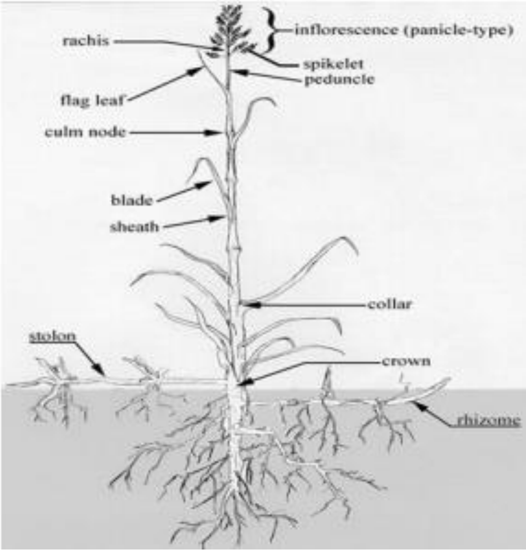

Figure 1: Structure of Bamboo Plant[8]

Figure 2: Bamboo fibers

The bamboo is grown in various continents of the world; it has been divided accordingly; Asia–Pacific bamboo region, American bamboo region, African bamboo region and European and North American region see Table 1 .Bamboo is a plentiful plant found in South America, the Middle East, and Asia.

Table 2 illustrates numerous species from various genera that have been discovered in the Asia region. Bamboo has a reasonably high tensile strength, which can exceed 370 MPa. As a result, bamboo is an appealing alternative to steel in tensile loading applications.

Bamboo textile goods are in high demand in the market because to their antibacterial qualities, biodegradability, high moisture absorption capacity, softness, and UV protection[9]. Because of the micro gaps in its profile, bamboo is an antibacterial, relatively smooth fiber with low pilling and wrinkling and good moisture sweat absorption. Bamboo fabrics require less dyestuff to be dyed to the required level than cotton fabrics since they absorb the dyestuff better and faster and show the color better[10, 11]. Bamboo clothing is extremely soft, breathable, quick drying, and thermally regulating. Bamboo cloth is anti-static and non-clinging. It has the super softness of cashmere and the translucent sheen (lustre) of silk, according to many people. Bamboo clothing is less likely to wrinkle than cotton apparel. While bamboo cloth may still require ironing after washing, it can be pressed at a lower temperature than cotton. At warm temperatures, shrinkage during washing and drying is minor. One method for reducing or eliminating wrinkling, which may apply to cotton and other textiles, is to simply place items in the dryer for two to five minutes to straighten the wrinkles caused by the spinning of the washer[12, 13].

Table 1: Bamboo regions along with country

Bamboo Region	Countries	Percentage
Asia Pacific	China, India, Burma,Thailand, Bangladesh, Cambodia, Vietnam, Japan, Indonesia, Malaysia, Philippines, Korea and Sri Lanka	65%
American bamboo region (Latin America, South America and North America)	Mexico, Guatemala, Costa Rica, Nicaragua, Honduras, Colimbia, Venezuela and Brazil and some European countries	28%
African bamboo region	Mozambique, Eastern Sudan	7%

Table 2: Species, Genera and Forest area of bamboo plant in several countries

Country	Species	Genera	Area(Km^2)
China	500	40	61,586
India	136	23	108,630
Myanmar	100	17	8,950
Thailand	60	13	8,100
Bangladesh	30	13	863
Cambodia	10	4	2,870
Vietnam	101	15	10,000
Malaysia	44	7	5,920
Phi;ippines	55	12	1.560
Japan	230	13	1,413

Bamboo culms have a hollow cylinder structure, and the inner side of each culm is split by many diaphragms that appear to be rings from the outside. The space between two rings is known as the "internode," and branches grow from it. The distance between each node varies depending on the species. Bamboo's culm wall is made up of several vascular bundles that provide strength to the culm. The height of the culm determines the number of internodes. As a result, average size, density, and number of vascular bundles are crucial factors for identifying bamboo species. Bamboo culm anatomy determines their physical qualities, that reflect their utility. Bamboo fiber density grows as the upper diameter of the bamboo culm decreases. As a result, the base section has lower strength but greater force resistance than the top section[14].

Bamboo culm microstructure comprises several vascular bundles embedded in parenchyma tissue and dispersed along the wall thickness. The essential elements of this plant are vascular bundles and bundle sheaths, which reinforce the bamboo culm and connect the nodes to the culm. Vascular bundles, that are bordered by fibrils (sclerenchyma cells), are more abundant on the culm wall's outer side and less abundant on the inner side. The size and density of vascular bundles varies from the bamboo culm's base to the top. Each vascular bundle is divided into two parts: xylem and phloem[15, 16].

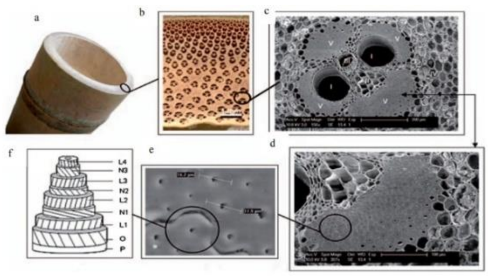

Figure 3: (a) Bamboo culm, (b) cross-section of bamboo culm, (c) vascular bundle, (d) fiber strand, (e) elementary fibers (f) model of poly lamellae structure of bamboo[**15**, **17**]

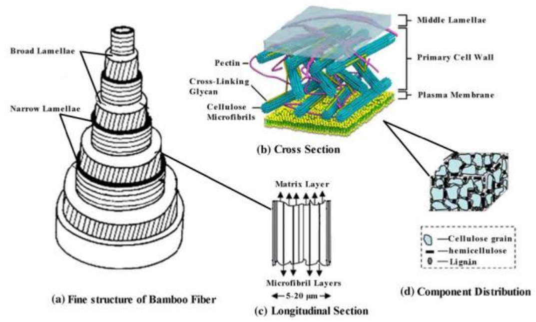

Figure 4: (a) Fine structure of bamboo, (b) cross section, (c) Longitudinal section, (d) component distribution[**15**, **18**]

The role of xylem is to transport water, whereas phloem transports nutrients and carbohydrates throughout the plant. A fiber strand, sclerenchyma cells, vessels, and sieve tubes with companion cells comprise each vascular bundle. Many fundamental fibers with hexagonal and pentagonal forms are arranged and linked together with lignin and hemicellulose to form the fiber strand. Figure 3 and Figure 4 depict the structure of a bamboo culm as well as a diagram of bamboo fiber architectures[1, 19, 20].

Cellulose

Chemical Composition of Bamboo

Bamboo fiber is composed of up of -cellulose, hemi-cellulose, and lignin, as well as some minor components.

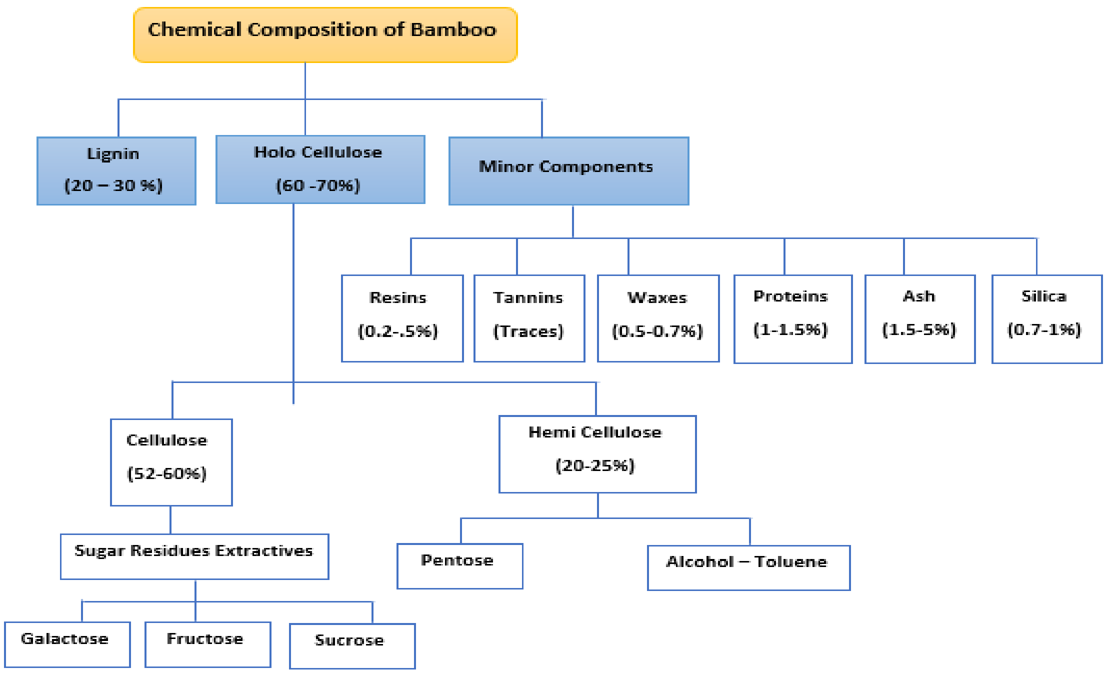

Figure 5: Average chemical composition of bamboo[21]

Table 3 and Figure 5 depicts the average chemical composition of bamboo. [22, 23]

Table 3: Chemical composition of the natural bamboo fiber

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

It has a crystalline and an amorphous structure. The extent of crystallinity of cellulose varies between species. Because of its high degree of polymerization and linear orientation, it offers rigidity to the plant and is generated by polymerization of D-anhydro glucopyanose units via 1, 4 -glycosidic linkage.

Bamboo is well-known for its organic and rich cellulose, which has great toughness, crystallinity, and hygroscopicity[24, 25]. Cellobiose, in fact, is one of the building components of cellulose. The cellulose molecule is a long chain molecule composed of a high number of glucose residues connected together via glycoside linkage on the structure see Figure 6. [26-35]

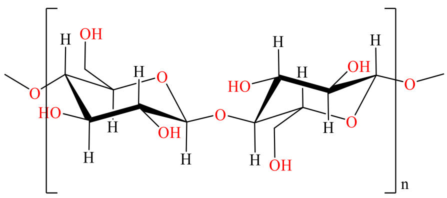

Figure 6: Structure of cellulose

In in general, bamboo has a cellulose concentration of 40-50%, which is identical to other best fibers (43-57%), grass fibers (33-38%), softwoods (40-52%), and hardwood (38-56%)[36]. The amount of glucose units in a cellulose molecule is characterized as the degree of polymerization (DP), and cellulose has a high degree of crystallinity. According to one source, the degree of polymerization in plant/cane fibres like bamboo and bagasse is the lowest (50-600) among plant fibres, depending on the determination method utilized, and it is 1050 of bleached bamboo.

Hemicellulose

It is a polymer similar to cellulose, but with a shorter chain length (DP>150). It is primarily constituted of pentosan with a trace of hexosan.

It dissolves in cold caustic soda (18% concentration). Jute's main polysaccharide is a backbone of -D - xylopyranose units with a terminal 4-O-methyl --D- gulcouronic acid residue linked through position two. When pentosan, a polymer containing pentose sugars such as xylan, araban, and others, is heated with high hydrochloric acid (13.15%), the pentose is first hydrolyzed to pentose sugars, which are subsequently dehydrated to furfural see **Figure 7**.

Whenever hemicellulose containing uronic furfural acid, like glucouronic, galactouronic, and so on, is heated with a strong hydrochloric acid solution (13.15%), the uronic acid solution hydrochloric acid solution is formed. Hemicellulose has a relatively large concentration of reducing aldehyde groups, which contributes to its relatively powerful reducing action when compared to native cellulose. The hemicellulose found in bamboo is primarily the amorphous portion of the fiber and is responsible for the acidic character and high moisture regain of the fiber, which is esterified with lignin. It is linear in the main chain, but appears to differ from the xylan found in gymnosperm forests in terms of branching and chemical characteristics. Furthermore, the bamboo xyIan contains 6-7% natural acetyl groups, a property shared by hardwoods[37, 38]

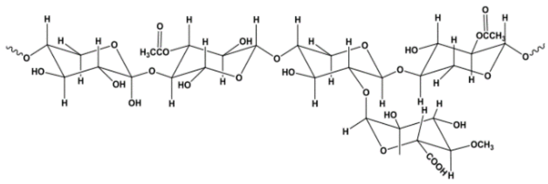

Figure 7: Partial structure of glucuronoxylan, a hardwood. Hemicellulose

Lignin

Besides cellulose, lignin is the second richest element in bamboo, and processors have concentrated on its chemical makeup and structure. Bamboo lignin is a typical grass lignin composed of three phenylpropane units pcoumaryl, coniferyl, and sinapyl alcohols linked together by biosynthetic patterns see Figure 8.[23, 39-41]

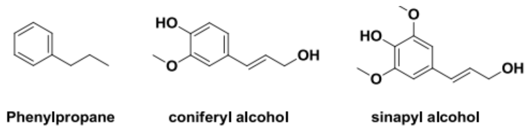

Figure 8: Building blocks of lignin

Throughout the bottom to the top of the same culm, the developing bamboo exhibits a range of lignification stages. Within each internode, lignification progresses downward from top to bottom and across from inside to outside. The lignification of epidermal cells and fibers occurs before that of ground tissue parenchyma throughout height growth. According to Higuchi et al., full lignification of bamboo culm occurs during one growing season with no extra ageing effects. There is also no variation in the composition of lignin between vascular bundles and parenchyma tissue[42].

Bamboo's stiffness is mostly owing to its lignin content, which works as a permanent bonding agent between cells, resulting in a composite structure with exceptional resistance to impact, compression, and bending. Lignin is a highly branched three-dimensional polymer that does not swell when exposed to common swelling agents[42].

Extraction of bamboo fber

Although bamboo fibers come from bamboo trees, they can be divided into two categories based on the extraction procedure and methods used[43]:

- Original bamboo fber that is extracted directly using mechanical and physical methods without the use of any chemical additives, hence the designation "Original" or often referred to as "Pure bamboo" or "Natural bamboo."
- Bamboo pulp fber, also known as bamboo viscose fber or regenerated cellulose bamboo fber, is made from bamboo fbers that have been removed using chemical additives.

Mechanical and chemical processing are the two forms of processing used to obtain bamboo fibers, with both initially incorporating bamboo strips. Splitting is often monitored by mechanical or chemical procedures, depending on the number of times the bamboo fibers are utilized and the weight to which they are subjected.

The chemical method does require alkali hydrolysis (NaOH) to produce cellulose fbers before multi-phase bleaching is performed by passing the alkali-treated cellulose fbers through carbon disulfide. This is the quickest method for producing bamboo fibers, and it is employed by the majority of businesses[44].

Mechanical extraction technique

This procedure entails many processes including steam explosion, retting, crushing, grinding, and rolling of bamboo in a mill to extract the fber for special uses like as composite reinforcements.

Steam explosion method

Steam explosion processes are a low-energy-consumption approach for separating the cell walls of the bamboo plant to produce a pulp.

The technique has been in use since 1962, and it is mostly used in the pulp industry. While it effectively extracts lignin from the plant's surface, the resulting fibers are black and hard[45]. According to one study, the steam explosion method cannot entirely remove lignin from bamboo fiber. However, only machine mixing is possible, and the lignin can be removed as a residue from the fbers to generate bamboo fber cotton (BFC). When compared to composites having simply bamboo fiber, the tensile strength of the BFC reinforced composite has a substantially higher weight percentage. The bamboo was then sliced and cooked in an autoclave for around 60 minutes at 175 °C and 0.7-0.8 MPa[46].

The identical process was done nine times to protect the cell walls from breakage before the fbers were cleaned with soap in hot water at 90-95 °C and dried for 24 hours in an oven at 105 °C. The steam was released promptly for 5 minutes, and the process was repeated to ensure ash removal, and the rest of the lignin content was condensed on the surface of the fbers, resulting in a reduction in adhesion between the resin and the removed fbers[47] . Bamboo fbers were softened through the steam explosion operation due to the cracking of the fbers' cell walls, allowing extraction. Crushing the fragile cell wall of the bamboo fber surface also reduces shear resistance, allowing for partial lignin breakdown. This lignin can be rinsed from the fbers ultrasonically and then treated with isocyanate to eliminate unexpended cells. The findings of the steam explosion revealed that extracted fber had a much higher tensile strength than isocyanate-treated fbers[48].

As the chemically treated fber has formed a very weak interface between the soft cells and the fbers, the tensile strength of the resultant fber-reinforced thermoplastic composites has been reduced to a higher extent. As a result, another treatment approach that improves the adhesion between the bamboo fiber and the matrix created is required[49, 50].

Retting process

In order to obtain the strips, the cylindrical section of the culm must be peeled. The bamboo bark is removed before the peeling process begins. The strips are stored in water-soaked bundles for at least three days before being squeezed and trimmed using a sharp-edged knife. The scraping procedure has a significant impact on fber quality, resulting in fewer fbers breaking along the length of fbers[51].

Another study discovered that raw bamboo is not scraped or combed, but rather chopped into multiple longitudinal fragments without the loss of the bamboo epidermis and node. The bamboo strips were rinsed with water, and the culms were fermented in water at room temperature for two months before aerobic and anaerobic retting was used to effectively separate the bundles from the culm. It was also discovered that the retrieved fber bundle was made up of a single fber that can inevitably grow to any length[52].

Crushing process

Bamboo fibers were extracted by cutting raw bamboo into tiny pieces using a roller crusher, then extracting coarse fiber with a pin-roller. The coarse fibers were defatted in a dehydrator for 10 hours at 90 °C before drying in a rotary drier. The disadvantage of using this method is that it leads to short fibers which become powdered following mechanical over-processing[53, 54].

Grinding process

Grinding entails cutting the bamboo culm into strips without nodes and soaking it in water for 24 hours. The wetted strips are then manually chopped into smaller pieces using a sharp knife. To generate a wide strip, an extruder can be used, whilst for longer strips, the bamboo can be chopped into little chips. It takes around 30 minutes to ground the bamboo chips[55, 56].

It is commonly done with a high-speed blender to guarantee that the bamboo fibers are in smaller sizes so that they may be separated subsequently with sieves of various sizes and apertures. Alternatively, the extracted fibers can be dried in an oven for 72 hours at 105 °C. To obtain long fibers, a strong tensile load is applied, resulting in increased transverse length. It has also been stated that the same process is being used to remove fiber in order to study the morphological and rheological behavior of the bamboo fiber composite. This grinding mechanism has also been employed in the manufacturing of dried bamboo strands and can be used to investigate Nano clay[57, 58].

Rolling mill process

The bamboo culm is sliced into smaller pieces from the nodes using this procedure. The strips are typically 1 mm thick and are soaked in water for 1 hour to allow fiber separation at very low speed and pressure.

The wrapped strips were then soaked in water for 30 minutes before being cut into little pieces using a sharp knife or razor blade. The fibers obtained range in size from 220 to 270 mm and are dried in the sun for a maximum of 2 weeks. It has been stated that bamboo strips can be obtained by compressing two pairs of steel cylinders, and the fibers can be retrieved without soaking in water. In general, this technique requires soaking the bamboo in water to soften the lignin, and the fbers can then be put through the roller to reduce their bonding strength. Typically, the fibers retrieved from this process range in length from 30 to 60 cm[59, 60].

Chemical extraction

This method involves reducing or removing the lignin content in primary fibers by the use of alkali or acid retting, chemical retting, Chemical Assisted Natural (CAN), or degumming. This treatment also has an impact on other bamboo microstructure components such as hemicellulose, pectin, and hemicellulose. The next section discusses the chemical techniques employed in various research.

Simultaneous extraction and degumming

Several researchers have used a combination of chemicals and enzymes to remove fibers, which are subsequently degummed to produce a finer and softer fiber. This is accomplished by removing the gummy and pectin content of the decorticated bamboo strips. It is critical to notice that the enzyme degrades the gummy material between the middle lamella and the cell wall, resulting in very excellent cellulose fiber separation[61].

Alkali or acid retting process

This technique of processing entails stripping the bamboo and then heating it for 5 hours in a stainless-steel vessel holding 1.5 M NaOH solution at 70 °C. Following this heat treatment, the alkaline-treated bamboo strips are moved to a pressing machine where the fibers are separated using steel[62, 63]. It is critical to notice that this extraction method causes minimal harm to the fiber. It has been reported that bamboo chips can be sized and steeped in 1 M NaOH for 2 hours at 70 °C. The stimulation of the cellulose and noncellulose components in this technique improves the separation of the bamboo fibers.

This method can be repeated numerous times under regulated pressure, allowing fiber to be extracted in the form of pulp[64].The downside of this extraction approach is the materialization or creation of larger fiber bundles as the extraction progresses. In another work, bamboo strips were steeped in 1 M NaOH for 72 hours before being extracted with trifluoroacetic acid (TAA) solutions. The obtained lignin was found to dissolve fully in both NaOH and TAA[65].

lignin remained in the middle lamella when soaked in NaOH, however it can be significantly eliminated when TTA is used. As a result, alkaline solutions provide better interfacial bonding of fiber composites than other procedures such as degumming or mechanical extraction[18].

Chemical retting process

It has been claimed that bamboo fibers can be removed from water and lignin using a chemical-assisted natural retting technique. The bamboo culm is first sliced into very thin chunks or slabs in a longitudinal section, following which the fibers are manually separated before being immersed in a solution of $Zn(NO_3)_2$ whose concentration ranges between 1 and 3%, with a liquor-to-bamboo ratio of 1:20. It has been assured that the temperature remains within 40 °C at a neutral pH for 16 hours before being boiled in water for 1 hour. A Bio-Oxygen Demand incubator is typically used to keep the temperature and pH stable. It has been discovered that this procedure enables more efficient lignin removal as compared to alkaline or acid retting processes. However, the moisture content of bamboo fiber has been found to be extremely high.

A further study showed that the bamboo culm was chopped into 2-cm chips and then roasted at 150 °C for 30 minutes. The chips were soaked in water for 24 hours at 60 °C, dried in air, and then rolled on a fat surface to remove any remaining contaminants[66].

This method is repeated, and the fber bundles are then soaked and boiled for 60 minutes at 60 °C in 0.5% NaOH, 2% $Na_5P_3O_{10}$, 2% Na_2SO_3, and 2% NaSi Solutions with a bamboo to liquor ratio of 1:20. The bamboo fber was rinsed in hot water prior to acid treatment with 0.5% diethylenetriamine pentacetic acid and 0.04% xylanase acid for 60 minutes at 70°C and pH 6.5.

The bamboo fbers were then boiled again for 60 minutes using the same process described above, but this time only 0.7% NaOH was employed. After repeating this method, the bamboo fbers were bleached for another 50 minutes in a polyethylene bag with 4% H_2O_2, 0.2% NaOH, and 0.5% NaSi [14].

Combined mechanical and chemical extraction process

This approach employs a combination of mechanical and chemical extraction. Mechanical extraction is often accomplished through the use of compression molding methods (CMM) and roller molding methods (RMM). Following the molding technique, chemical extraction can be performed using alkali and acid solutions[67]. In the following research, CMM was used to pressurize bamboo strips that had been immersed in a bed of alkaline solutions before a load of 10 tons was placed at both ends of the bamboo strips to pull and extract the fibers.

Bed thickness and compression duration are two critical parameters in getting high-quality fibers. The RMM method typically entails the use of two rollers fixed at both ends to fatten the bamboo strips, or one end can be made to rotate while the other end is fixed, and the use of chemical and mechanical processes to improve the separation of the strips into various sizes of bamboo fibers. The size of the compression mound and the diameter of the rollers are two critical elements in the operation of RMM since they determine the amount of fiber that can be extracted.

In another study, just a roller was used to separate the fibers, while nodes of the bamboo culm were detached and internodes were sliced longitudinally to form strips using a slicer. For 10 hours, the bamboo strips were immersed in NaOH solutions with concentrations of 1%, 2%, and 3% at 70 °C. The mechanical properties of fibers immersed in 1% NaOH were found to be superior to those of other concentrations. The alkali-treated strips fiber was extracted with a roller looser before being dried in an oven at 105 °C for 24 hours[68].

Wet Processes of Bamboo

Scouring

It optimizes the scouring condition of bamboo by using orthogonal experiments. Take the concentration, time, temperature and bath ratio of NaOH as the object of investigation see Table 4

Table 4: the design of the level of orthogonal experimental factor

Factor Level	NaoH	Time / min	Temperature / °C	Bath Ratio
1	**4.0**	**30**	**80**	**1 : 20**
2	**6.0**	**60**	**100**	**1 :30**
3	**8.0**	**90**	**120**	**1 : 40**

During orthogonal studies, the optimal arrangement for the bamboo fiber alkali boiling method is NaOH concentration of 6.0g/L, time of 60min, temperature of 100 °C, these four parameters, followed by degumming time, alkali concentration, and bath ratio[69].

and bath ratio of 1:20. Temperature has the highest influence on lignin removal among Bleaching of Bamboo

Bleaching

Bleaching is an essential step in the production of white shade from bamboo and its mixtures. When exposed to sunshine, bleached bamboo material, as other lignocellulose fibers, turns brownish yellow. Due to its high molecular weight and hydrophobic nature, the pale brown hue of bamboo is caused by residual lignin in the fiber.

Bamboo substance is bleached to generate various levels of whiteness ranging from light yellow to milky white by controlled treatment with selected oxidizing agents such as sodium hypochlorite, hydrogen peroxide in an alkaline pH, potassium permanganate, and sodium chlorite in an aqueous medium at neutral or slightly acidic pH. The lignin molecule is broken up by an oxidizing bleaching agent, which eventually introduces solubilizing groups into its fragments and fractures lignin-carbohydrate connections. It causes fragment breakdown in the subsequent post wash operation. There are two types of oxidizing bleaching agents: chlorine-containing agents and non-chlorine-containing agents see Table 5.

Bamboo bleaching also employs reducing bleaching agents such as sodium hydrosulphite, sodium sulphite, sulfur dioxide, sodium bisulphate, and others. However, due to the disadvantages of non-permanence of whiteness, they are not widely used.

The requirements for selecting the best bleaching agent for bamboo fibers are based on several critical factors, including equal weight, efficiency, reactivity, selectivity, and environmental implications.

One equivalent weight of an oxidative bleaching agent is required to perform a certain amount of oxidation. As a result, equivalent weight is an inverse measure of oxidative power. Equivalent chlorine is another way of describing a bleaching chemical's oxidizing activity. It is defined as the amount of chlorine in pounds (or kilograms) that has the same oxidizing power as one pound (kg) of the bleaching agent. As a result, equivalent chlorine is a direct measure of oxidizing power. Effectiveness, reactivity, and specificity are addressed in terms of comparable weight and equivalent chlorine see [70, 71].

Bleaching with sodium hypochlorite

Some sources provide thorough instructions for bleaching with sodium hypochlorite. To obtain white-colored bleached bamboo fibers, sodium hypochlorite can be used. De-lignified bamboo fiber strands can be bleached at room temperature for 1-2 hours with sodium hypochlorite with 5-8 g/l accessible chlorine. Sodium carbonate can be used to maintain an alkaline pH of 10-10.5. It is then properly washed with water and antichlored for 15 minutes at 60oC with 0.2% sodium sulphate. Finally, the fibers are cleaned and dried. The issue with this bleaching process is that pH around 7 are hazardous to cellulosic plant substrates[72].

Bleaching with sodium chlorite

Bamboo can be bleached effectively with a sodium chlorite solution. Its strands can be bleached for 90 minutes with 4% (mass/volume) sodium chlorite at boil, pH 3-4.5, and M:L:: 1:20. Formic acid can be added to maintain the bleaching bath's pH acidic. It is then properly cleaned and dried. Sodium chlorite is used to bleach and delignify lignocellulose materials such as jute, hemp, ramie, and bamboo. When treated with sodium chlorite, the lignin part dissolves while the carbs portion remains almost untouched[73].

Bleaching with hydrogen peroxide

Hydrogen peroxide has been frequently employed as an all-purpose bleaching chemical in high-yield bleaching procedures for textiles see Table 7.There are multiple explanations for obtaining high-yield bleached bamboo fibers, including:-

- It only affects chromophoric groups in lignin rather than delignification. As a result, cellulose and lignin are not degradable under ideal bleaching circumstances.
- Because the reaction products are non-ionic, it is known as an environmentally friendly bleaching agent. It decomposes to oxygen and water, reducing the bleaching chemical effluent problem.

The hydrogen peroxide bleaching procedure has several drawbacks as well[74]:

- Hydrogen peroxide degrades readily during the bleaching process because of its instability and the catalytic effects of certain metallic ions, such as iron, copper, etc. It raises the process's operating costs automatically.
- Bleaching requires high temperature and pH, which frequently results in tendering in the form of a considerable reduction of fiber strength[75-78].

Table 5: Classification of oxidizing bleaching compounds

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

Chemical Effect on the Mechanical Properties of Bamboo Fiber for Textile

Natural fiber treatment is required to ensure that the fiber generated is homogenous and prepared to be spun into textile goods. Fiber treatments are frequently classified into three types: mechanical, physical, and combination treatment. Chemical treatment is a common procedure for natural fibers to help enhance their mechanical and physical properties and to make the fiber for following textile processing with enhanced fiber quality and re-engineered properties to compete with synthetic fiber in the spinning process[64, 79].

Chemical treatment is a procedure that permanently modifies the fiber surface by grafting, bulking, or cross-linking polymers within the cell wall[80]. Chemical therapy is classified as acid or alkali treatment. Nitric acid is one of the acidic solutions used in acidic fiber treatment[81].Alkaline treatment, also known as mercerization, is the treatment most frequently used on natural fiber. It works by immersing the fibers in a known concentration of hydroxides such as potassium hydroxide (KOH) and sodium hydroxide (NaOH) as its fundamental work, resulting in changes in its chemical nature, increase in roughness topography, and degree of crystallinity through mechanism interaction between the fibers[82, 83].

Fiber–OH+NaOH Fiber–O $^{-}Na^{+}$ + H2O + impurities

Bleaching treatment, on the different hand, was typically used in post-processing of alkaline treatment to remove lignin content after preceding alkaline treatment's partial lignin removal. Shuhimi et al., (2017) stated in another application that the effectiveness of chemical treatment on natural fiber reinforced composite affected more effectively wear performance, reduced porosity, and enhanced fiber-matrix interfacial adhesion through enhanced adhesion, hydration, and internal curing procedure see **Table 8** [84, 85].

Furthermore, it aids in the removal of contaminants and chemically modifies the surface shape of fibers. According to Roslan et al., chemical treatment aids in the imposition of hydrophobicity properties on natural fiber by limiting the possibility of chemical components like cellulose, hemicellulose, lignin, and wax content attracting the water molecules, which could result in the loss of mechanical properties of bamboo fiber.

Furthermore, chemical treatments on bamboo, like the alkaline solution Sodium Hydroxide (NaOH), must be administered in a controlled concentration, as fiber treated with an excessive alkaline concentration proved to be weaker due to the unneeded removal of lignin and hemicellulose[86].

Bamboo fibers are principally constituted of holocellulose, lignin, and hemicellulose, and any chemical alteration on the surface of the fiber structure might disrupt its mechanical behavior.At suitable concentrations, alkaline treatment enhances the mechanical characteristics of the majority of bamboo fibers.

While the high concentration of alkali treatment reduced the tensile strength of bamboo fibers, it enhanced the elongation at break, converting the fiber from brittle to ductile and making the fiber more appealing for use in textiles.

When compared to mechanical treatment, chemical treatment significantly enhanced the tensile and surface morphology of bamboo fiber. When compared to bamboo fiber in a bundle, most single bamboo fiber has greater tensile qualities[87].

Surface modification processes of bamboo

Salinization treatment

The fibers are immersed in a 3:2 alcohol-water solution containing a silane-based adhesion promoter for 2 hours at a pH of about 4, washed in water, and dried in an oven. Organosilanes are the most common type of coupling agent used to join polymers to mineral fibers. The functional group in the coupling agent initiates the interaction with the polymer, either by copolymerization or the development of an interpenetrating network (IPN) in salinization[88].

Acetylation treatment

An acetyl functional group is introduced into an organic molecule using this approach. The primary purpose of acetylation is to coat the OH groups of fibers, which are responsible for their hydrophilic characteristic, with molecules that are more hydrophobic in nature. The fibers are acetylated by immersing them in glacial acetic acid for 1 hour, then in a mixture of acetic anhydride and a few drops of strong sulfuric acid for a few minutes, before being filtrated, washed, and dried in a vented oven[89, 90].

Benzoylation treatment

Fiber benzoylation enhances fiber-matrix adhesion by boosting composite strength, decreasing water absorption, and increasing thermal stability. The fiber is first processed with alkaline to activate the hydroxyl groups of the cellulose and lignin in the fiber, followed by 15 minutes in a 10% NaOH and benzoyl chloride solution. The fibers are then cleaned with water and dried in an oven at 80 °C for 24 hours after being soaked in ethanol for 1 hour to remove the benzoyl chloride[91].

Maleization treatment

Maleated coupling agents are often utilized to reinforce fillers and fiber reinforcements in composites. To produce superior interfacial bonding and mechanical qualities in composites, maleic anhydride is employed to alter the fiber surface as well as the polypropylene (PP) matrix. The process of maleic anhydride reaction with PP and fiber can be defined as activating the copolymer by heating to around 170 °C prior to fiber treatment and then esterifying cellulose fiber. This treatment raises the surface energy of cellulose fibers to a level much closer to the surface energy of the matrix. This improves the fiber's wettability and interfacial adhesion[89, 91].

Isocyanate treatment

This treatment method includes washing and drying sodium hydroxide-treated fibers. After soaking the fibers in carbon tetrachloride (CCl_4), a catalyst is added and the mixture is thoroughly mixed. With continuous stirring, the reaction can last for a long time at a temperature somewhat higher than room temperature. Fibers are then refuxed before being cleaned with distilled water and oven-dried at 100 °C.

Table 6: Equivalent and efficiency of various bleaching agents

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_2O_2	17	2.09	P	P	E	P	P
5	NaOCl	37.5	0.93	A	A	E	E	E
6	O_3	8	4.44	E	E	A	P	P

Table 7: General recipe for bleaching of bamboo using Hydrogen Peroxide

S. No.	Chemicals and conditions recommended	
1	Hydrogen Peroxide (50%)	3-8% (owf)
2	Sodium silicate	6-8% (owf)
3	Caustic soda	0.5-0.75% (owf)
4	Non-ionic detergent	0.2-0.5% (owf)
5	Temperature	85-90 ℃
6	pH	10.5-11
7	Time	1.5-2 hour

The isocyanate group reacts with the hydroxyl group on the fiber surface, improving interface adhesion with the polymer matrix[92].

Peroxide treatment

This surface treatment method comprises immersing the fibers in a solution of dicumyl (or benzoyl) peroxide in acetone for approximately thirty minutes, then pouring and drying them. Significant enhancements in the mechanical behavior of natural fibers, particularly fiber strength and stiffness, and thus the mechanical properties of the resulting composite, have been demonstrated in studies[92].

Enzymatic treatment

The application of enzymes in fiber treatment is becoming increasingly essential. The use of enzymes in natural fiber modification is currently expanding. The fact that enzymes are cheap and environmentally friendly is an important factor for this technology's popularity. The catalyzed reactions are quite particular and have a concentrated performance[93, 94].

Corona, cold plasma treatment

Corona discharge, often known as cold plasma treatment, is a physical treatment method used to activate surface oxidation. This method alters the surface energy of cellulose fibers. Numerous surface modifications can be performed by using various plasma gases. Surface cross-linking can also be added, and the surface energy can be increased or lowered, as well as reactive free radicals and groups created[91].

Physical properties of bamboo

Uster HVI SW 3.1.1.0 is used to test the strength, elongation, micronaire and uniformity index, moisture percentage, and other fiber characteristics of bamboo see Table 9 [11, 95].

Table 8: Chemical treatment on bamboo fibers associated to different studies

Name of Treatment	Chemical (s) used	Concentration	Ref.
Alkali treatment	Sodium sulphite (Na_2SO_3) Lissapol D	5, 10, 15, 20, 25% 0.5%	[48]
Alkali treatment	Sodium hydroxide (NaOH)	0%, 1%, 3%, 5%	[17]
Alkali treatment	Nitric Acid and potassium chloride (HNO_3 + $KClO_3$), sodium hypochlorite (NaClO), hydrogen peroxide and glacial acetic acid (H_2O_2 + HAC), and sodium hydroxide (NaOH)	65% HNO_3 +5% $KClO_3$	[96]
Alkali treatment	Hydrogen peroxide and glacial acetic acid	30% H_2O_2, 5 parts glacial acetic acid	[97]
Alkali treatment	Sodium sulphite (Na_2SO_3)	-	[98]
Alkali treatment	Hydrogen peroxide and glacial acetic acid	-	[99]
Alkali treatment	Hydrogen peroxide and glacial acetic acid	10% H_2O_2 : 10% glacial acetic acid	[100]
Alkali treatment	Sodium hydroxide (NaOH)	5% wt	[101]
Alkali treatment	Sodium hydroxide (NaOH)	6%, 8%, 10%, 15%, 25%	[102]

Solubility of Bamboo Pulp Fibers

The experimental reagents used were: hydrochloric acid at 15% and 37% concentrations, sulfuric acid at 40%, 60%, 70%, and 98% concentrations, nitric acid at 68% concentration, and sodium hydroxide at 5% concentration, as well as ethyl acetate, sodium hypochlorite, and carbon tetrachloride. A thermometer (10-100 symbol); a constant temperature bath (20-100 symbol) with six holes; an electronic balance beaker; a wood clip; forceps; a glass rod; a measuring cylinder; a dropper; and an Instron series 3365 electronic universal strength testing machine were required for the experiments.

Table 9: physical properties of bamboo fibre [11]

Physical Properties of Bamboo Fibre	
Strength (g/tex)	34.3
Elongation (%)	16.0
Short Fibre Index (12.7mm)	5.58
Uniformity Index (%)	92.7
UHML(mm)	38.745
ML (mm)	35.62
Moisture (%)	6.5
Micronaire	4
Dry Tenacity, cN/tex	22-25
Wet Tenacity, cN/tex	13-17
Crystallinity(%)	52-89

Table 10

The fiber of bamboo pulp is slightly soluble. Under 25°C, the bamboo pulp fiber was insoluble in 40% sulfuric acid and became somewhat soluble in 60% and 70% sulfuric acid concentrations. It was soluble in 98% sulfuric acid concentration. Bamboo fiber disintegrated at varying amounts of sulfuric acid when heated to 100°C. The fiber was somewhat soluble in sulfuric acid concentrations of 40% and 60%, but became soluble in concentrations of 70% and 98%. As a result, temperature and acid concentration have an uncontrollable effect on how fibers dissolve in sulfuric acid. The sulfuric acid resistance of bamboo pulp fiber was quite poor, as evidenced by the findings analysis.

The Dissolution of Fibers in a Hydrochloric Acid Solution

The dissolving conditions of bamboo pulp fiber at different temperatures and in different concentrations of hydrochloric acid see Table 11.

Bamboo pulp fiber was found to be insoluble in a 15% concentration of hydrochloric acid at 100°C.The bamboo pulp fiber was dissolved in 37% hydrochloric acid. It was insoluble in a 15% concentration at 25°C and marginally soluble in a 37% concentration. As a result, the hydrochloric acid resistance of bamboo pulp fiber was likewise extremely low.

The Dissolution of Fibers in a Nitric Acid Solution

The dissolving conditions of bamboo pulp fiber at different temperatures and in different concentrations of nitric acid.

It can be seen that bamboo pulp fiber was insoluble in a 68% concentration of nitric acid at normal temperatures. At 100°C, however, bamboo pulp fiber was marginally soluble . From **Error! Reference source not found.**, Table 11 and Table 12 it can be noticed that the resistance of bamboo pulp fiber to nitric acid was greater than its resistance to sulfuric acid or hydrochloric acid.

The Dissolution of Fibers in a Sodium Hydroxide and Ethyl Acetate Solution

Dissolution of Fibers in a Sulfuric Acid Solution

The dissolving conditions of bamboo pulp fiber at different temperatures and in different concentrations of sulfuric acid see

The dissolving conditions of bamboo pulp fiber in 5% sodium hydroxide and ethyl acetate at various temperatures see **Table 13**

Under normal temperature and heating conditions, bamboo pulp fiber was insoluble in a 5% sodium hydroxide and ethyl acetate solution. When exploring the dissolving conditions of bamboo pulp fiber in an ethyl acetate solution at higher temperatures, the ethyl acetate beaker must be heated in a closed electric furnace, with the fuming cupboard kept fuming throughout.

This will keep the solution or solvent from burning or exploding. According to the findings of the analysis, the alkali resistance of bamboo pulp fiber was good.

The Dissolution of Fibers in an Oxidation and Reducing Agent Solution

The dissolving conditions of bamboo pulp fiber and viscose fiber under different temperatures in carbon tetrachloride and sodium hypochlorite see Table 14.

It can be seen that bamboo pulp fiber did not dissolve in carbon tetrachloride, regardless of temperature or heating. As a result, the bamboo pulp fiber grew more resistant to oxidation. Under identical conditions, the bamboo pulp fiber remained insoluble when the temperature increased from normal to heating in a sodium hypochloride liquid.

Dyeing and Printing of Bamboo with Synthetic Dye

Shweta Tuteja Rakshit and Shally Agarwal pre-treated (1% to 5%) samples of bamboo fabric were dyed with all the three class of reactive dyes (vinyl sulphone group, bi-functional group and mono-chlorotriazine group).

As a result, modest concentrations of formic acid can be employed safely as a pre-treatment in dyeing bamboo fabrics with reactive dyes from all three classes (vinyl sulphone, mono-chlorotriazine, and bi-functional dyes). Formic acid concentrations of 1%, 2%, and 3% performed well in physical tests like tensile strength, crease recovery angle, and bending length.

The maximal optical density was found to be 1% for mono-chlorotriazine dye, 2% for bi-functional ME dye, and 3% for vinyl sulphone (remazol) dye in K/S readings. The color fastness test also revealed that a modest concentration of formic acid pre-treatment resulted in outstanding to good fastness capabilities on bamboo fabrics[103].

Larik, S.A., et al., Dyed bamboo fabric by CN method and US method with two reactive dye namely CI Reactive Black 5 (bis-sulphatoethyl-sulphone) and CI Reactive Red 147, (difluorochloropyrimidine).

This study discovered that ultrasonic energy may be efficiently employed for batchwise dyeing of bamboo cellulose fabric. When compared to conventional dying, the color output increased by 5-6% with no change in colorfastness. It demonstrated a significant advantage in terms of saving fixation temperature (10 ℃) and time (15 min), as well as amounts of sodium chloride (10 g/L) and sodium carbonate (0.5-1% o.m.f). Furthermore, ultrasonic dyeing posed less contamination to the effluent (minimum 29% TDS content and 13% COD)[104].

M. D. Teli and Javed Sheikh treated bamboo rayon fibres with acrylic acid and dyed with cationic dye .The result showed that Using a KPS initiator, bamboo rayon fabric was successfully grafted with acrylic acid. The following are the optimal conditions determined by the current work: The grafting temperature was 60°C, the grafting time was 3 hours, the KPS content was 1.5%, and the monomer:fibre ratio was 1:1. The grafted product improved in moisture recovery, which was boosted further when the samples were treated with NaOH after grafting. As a result, improved comfort attributes can be predicted from such materials. The grafted product demonstrated a multifold increase in cationic dyeing color strength, as well as a significant improvement in all fastness parameters[105].

Ruilin Tang., et al., treated bamboo fabric with chitosan and dyed with acid dye.

The result showed that chitosan is a promising fixing agent for bamboo dyeing especially in alkaline conditions. Chitosan acts as a link between acid dyestuff and bamboo via chemical reactions and electrical attraction.The addition of chitosan increased the dyeing rate, washability, and lightfastness of dyed bamboo[106].

Sönmez, S., M. Uzun, and A. Akgül printed bamboo jersey fabrics by thermal transfer printing system. The result showed that the Cyan, Magenta, Yellow, and Black colors printed on the Bamboo jersey fabrics do not alter in varied print temperature values and printing density after washing demonstrates that the printing density value is consistent. Both the print temperature and print brightness values of the wash process were unaffected. The print chroma values do not vary greatly as a result of varied print temperatures and washings. It has been demonstrated that the color universe obtained after printing maintains consistency[107].

Dyeing and Printing of Bamboo with Natural Dye

Manik Pulyani and Saransh Chauhan treated bamboo fabric with Aloevera and Banana Sap as Biomordant and dyed with Rheum emodi (Apsara Yellow Dye) and Rubia Cordifolia (Turkey Red Dye).

Method of Extraction bio mordant

Aloevera: Aloe vera plants, which grow between 1-2 feet tall, generate a slushy transparent gel that is said to be a powerful healing agent. The gel contains 18 different types of amino acids, as well as a minor amount of organic and inorganic substances. Water makes up over 96% of the gel. Fabrics dyed or polished with natural herbs can improve the wearer's health.

After being newly cut, the external skin of two aloevera leaves was peeled off. After that, each leaf was sliced into a small piece. The juice was extracted from the little bits using a blender.

The liquids were a pale olive color. It was then kept below room temperature for a period of time and after that it was used as a mordant.

Banana Sap: A thick, dusty-brown liquid known as banana pseudo-stem sap is naturally created as banana pseudo-stems grow. Tannins, phenolics, and aromatic amino acids were discovered during a phytochemical examination of sap. This research looks into the usage of banana pseudo-sap as a dyeing biomordant. The stems of banana trees were harvested. After the stem had been sliced into little pieces, it was blended with a blender. As a result, the banana sap turns crimson. It was then kept below the ambient temperature.

Table 10: The dissolution of fibers in a sulfuric acid solution

Concentration State	40%		60%		70%		98%	
	25℃	**100℃**	**25℃**	**100℃**	**25℃**	**100℃**	**25℃**	**100℃**
Solution	**I**	**SS**	**SS**	**SS**	**SS**	**S**	**S**	**S**

Note: S-soluble; SS-slightly soluble; P-partially soluble; I-insoluble

Table 11: The dissolution of fibers in a hydrochloric acid solution

Concentration state	15%		37%	
	25℃	100℃	25℃	100℃
solution	I	I	SS	S

Note: S-soluble; SS-slightly soluble; P-partially soluble; I-insoluble

Table 12: The Dissolution of Fibers in a Nitric Acid Solution

Concentration state	68%	
	25℃	100℃
solution	I	SS

Table 13: The dissolution of fibers in a sodium hydroxide and ethyl acetate solution

Concentration state	5% Sodium Hydroxide		Ethyl Acetate	
	25 ℃	100 ℃	25 ℃	100 ℃
solution	I	I	I	I

Table 14: The dissolution of fibers in an oxidation and reducing agent solution[108]

Concentration state	Carbon Tetrachloride		13% Sodium Hypochlorite	
	25℃	100℃	25 ℃	100 ℃
solution	I	I	I	I

Bamboo fabric was dyed using three methods: pre-mordanting, simultaneous mordanting, and post-mordanting. Bamboo cloths were immersed in a dye bath containing the necessary amount of extracted dye, mordant, and water for dyeing. The dyeing process took 90 minutes at 80oC. For the entire dyeing and mordanting procedure, 20% (owf) dye and 10% (owf) mordant concentrations were used. A laboratory beaker dyeing equipment with programmable temperature and time controls was used in a simultaneous dyeing and mordanting process with a material to liquid ratio of 1:50. For pre- and post-mordanting, two bath techniques were used. The material to liquor ratio was held at 1:50 in both dyeing and mordanting. For dyeing bamboo fabric, equimolar concentrations of 10% of each mordant (banana sap and Aloevera) are employed in combine mordanting.

The result showed that dyeing behavior of bamboo fabric with organic dyes and mordants was investigated. Red and yellow colors are obtained by dyeing Rubia Cordifoilia and Rheum Emodi with Banana Sap and Aloevera as biomordants alone and in combination. Because dyestuffs are more soluble at higher temperatures, a greater temperature may also result in a larger dye absorption. Natural mordants improve the color value (k/s) and the durability of washing and light treatment[109].

Mamatha G Hegde and Kiruthika A were treated bamboo fabric with natural mordant (Pomegranate and Onion peel) then dyed with natural dye (Teakwood bark).

Extraction of Dye solution from Teakwood bark:

Boil teakwood bark in water for around 90 minutes, stirring constantly see **Figure 9**.

Figure 9: Teak wood dye Extraction Process

Extraction of Mordant from Pomegranate and Onion peel:

Boil the pomegranate and onion peel individually for about 30 minutes in water. Using a cloth, filter the mordanting solution to get a clear mordanting solution.

Figure 10: Extraction of Mordant from Pomegranate and Onion peel

Dyeing Recipe:

Dye bath	1:30 ratio on the weight of material
Dye solution	25% on weight of material
Mordanting solution	5% on weight of material
Temperature	60 – 100-degree Celsius
Duration	60 – 90 minutes

Dyeing of Bamboo Fabric:

Excess water is removed from the scrubbed bamboo fabric. The dye solution is heated to around 40° Celsius. At this point, the fabric is immersed in the dye bath. To get uniform color all across the fabric, dyeing is done for 90 minutes at 100 degrees Celsius with constant stirring. Two separate mordant solutions are used to dye two pieces of bamboo fabric with teakwood bark dye extract. Dyed fabric is washed in plain water until no color bleeds through and then dried in the shade.

Eco-printing Process:

To determine which leaf leaves good color on the fabric, sample printing was done on cotton fabric with many types of leaves such as a rose-leaf, hibiscus leaf, gooseberry leaf, and basil leaves. Eco printing is a technique for reducing the use of synthetic dyes in cloth printing procedures. Eco printing is done on dried cloth after the bamboo fabric has been dyed. This is due to the low strength of bamboo fabric when wet. Fresh gooseberry leaves are haphazardly put on fabric. A clear plastic sheet is used to cover it.

For best results, apply equal amounts of pressure all over the leaves with a hammer or other tool. The plastic covering and leaves have been removed. The fabric is rinsed once more to remove any remaining leaves adhered to the fabric. The finished fabric has been eco-dyed and eco-printed.

The result showed that Bamboo fabric is a wonderful substitute for other fabrics. Bamboo fabric is simple to dye using natural dyes and designs. On the skin, the cloth feels very soft and silky. It will be an excellent fabric for infant clothes. Bamboo fabric has antibacterial characteristics, protects from UV rays, controls bacterial odor, the absorption rate is twenty times higher than cotton, the fabric is breathable, and helps to regulate body temperature[110].

Tengku Khamanur Azma Tg. Mohd Zamri ., et al., dyed bamboo fabric witn natural dye such as (Blue butterfly pea flower (BBPF), Red dragon fruit peel (RDFP)and Turmeric).

Preparation of samples:

Water extraction was used to create natural coloring. To maximize the surface area, the natural colors were mixed or ground into little bits about 1mm in size. The natural dye was then extracted at a ratio of 0.12 g/mL, which corresponds to 1.2 g of raw material to 10 mL of water. The mixture was then centrifuged for 15 minutes at 4 oC, 10000rpm. The supernatant dye was collected after the mixture was filtered. The mixture was centrifuged a second time for 10 minutes at 4oC, 12000rpm to check that there was no more sediment or precipitate in the dye solution. Finally, the supernatant was filtered through filter paper and the pH was adjusted as needed with HCl and NaOH.

The research on the equilibrium adsorption of three natural colors derived from turmeric, RDFP, and BBPF onto bamboo yarn were described in this work. The study included three isotherm models, namely the Langmuir, Freundlich, and Temkin isotherms. The isotherm models were then subjected to error analysis.

Adsorption isotherm studies found that Turmeric adsorption on bamboo yarn followed the Temkin models, followed by the Freundlich model for RDFP dye adsorption on bamboo yarn and the Langmuir isotherm for BBPF adsorption on bamboo yarn. To summarize, the natural dyes extracted from Turmeric, RDFP, and BBPF demonstrated that these natural dyes may be utilized as a dye for dyeing bamboo yarn and have the potential to replace the present synthetic dye[111].

Conflict of Interest

The authors declared no competing interests in the publication of this article

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Exploration of Bamboo Fabrics with Natural Dyes for Sustainability

Table 15: Natural dye for bamboo [112]

S.N.	Species (Family Name)	Common Name	pH Value	Colour Obtained	Colour Application
1	Caealpinia Sappan	Sappan Wood	5-7	Jaipur Pink	Very Good
2	Punica Granatum- (Lythraceae)	Pomegranate Peel	3-5	Mallow Gold	Good
3	Rheum Emido	Indian Ruharb	3-5	Apsara Yellow	Good
4	Nyctanthes tristis (Oleaceae)	Night Jasmine	3	Prime Rose Yellow	Very Good
5	Indigoferatinctoria (Febaceae)	Indigo	11-12	Indigo Blue	Very Good
6	Quercus Infectoria	Oak Tree Fruit	5	Gallnut	Very Good
7	Tagetes Erecta	Mari Gold	5	Sun Yellow	Good
8	Bixa Orellana	Annatto	9	Candy Orange	Excellent
9	Terminalia cha	Myrobalan	5	Cadar Yellow	Very Good

10	Rubia Cardifolia	Heart Leaved Madder Roots	5-7	Turkey Red	Good
11	Butea Monosperma	Purging Nut	5-6	Cuttack Silver	Good
12	Laccifer Laca (Keer)	Sheel Lac	5	Wine Red	Very Good
13	Allium Cepa	Onion Skin	6-8	Onion Peel	Excellent
14	Pterocarpus Sandal	Sandal Red	5	Barn Red	Good

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نظرة شاملة عن البامبو من حيث التركيب، الاستخراج، المعالجة، القابلية للصباغة

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المستخلص

تستخدم ألياف البامبو كألياف نباتية في مواد البوليمر المركبة المعززة لتعزيز الاستدامة البيئية. توفر ألياف البامبو الخصائص الميكانيكية وقابلية التدوير والصديقة للبيئة، مما يجعلها مناسبة لتطبيقات البناء. يمكن أن تحل الألياف الطبيعية، التي هي متجددة وصديقة للبيئة، محل المواد الاصطناعية في مختلف الصناعات. تتكون ألياف النبات من السليلوز والهيمي سيليولوز واللينين والبكتين. تتحسن الخصائص الميكانيكية للألياف مع زيادة محتوى السليلوز. يُستخدم البامبو، وهو نبات عشبي سريع النمو بسيقان خشبية، كمصدر لألياف القصب والسليلوز. إنه وفير في مناطق مختلفة حول العالم ويتميز بقوة شد عالية، مما يجعله بديلاً محتملاً للفولاذ. تحظى الأقمشة المصنوعة من البامبو بطلب كبير بسبب خصائصها المضادة للبكتيريا وقابليتها للتحلل البيولوجي وقدرتها العالية على امتصاص الرطوبة وحماية من الأشعة فوق البنفسجية. تتميز أعمدة البامبو بتركيبة أنبوبية مجوفة مع فواصل وحزمات أوعية توفر القوة. يتضمن الهيكل المجهري لأعمدة البامبو حزم الأوعية وغلاف الرزق والأنسجة الخشبية والبازيم. تتكون التركيب الكيميائي لألياف البامبو من السليلوز والهيمي سيليولوز واللينين والمكونات الطفيفة. يعرض البامبو صلابة ومتانة بفضل محتواه من اللينين الذي يعمل كوكيل تصاق. تشمل طرق استخراج ألياف البامبو التقنيات الميكانيكية والمعالجة الكيميائية. تشمل تقنيات الاستخراج الميكانيكية عمليات مثل انفجار البخار وعملية الجفاف لفصل الألياف.

الكلمات المفتاحية: البامبو، التركيب، الاستخراج، المعالجة، القدرة على الصبغ.