EFFECT OF SURFACE MODIFICATION OF HIMALAYAN NETTLE FIBER AND CHARACTERIZATION OF THE MORPHOLOGY, PHYSICAL AND MECHANICAL PROPERTIES

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Abstract:

The process of retting bast fiber plants for the production of long fiber has presented major challenges. Water retting, dew retting, chemical extraction, and micro-organism (fungi, enzymes) techniques were applied to the extraction of natural fibers. The two nettle samples were extracted with water retting for 14 days and dew retting for 4 weeks. This research investigated the effects on the traditional retting process of nettle fiber by fungi and bacteria formation in lignocellulosic. The latter biological extraction methods successfully degraded the lignin and pectin materials of the fiber and increases the cellulose content. These extraction methods produced high quality fiber and tensile strength at a low cost. This study determined the chemical, physical, and mechanical characteristics such as fiber cellulose, non-cellulosic content, tensile strength, tenacity, and elongation break to see how treatments affected them. The treated fiber surface morphology was characterized using scanning electron microscopy. To evaluate functional group alterations, Fourier-transform infrared spectroscopy was used on the fiber specimen.

Keywords:
Cellulose; Fungi; Bacteria; Nettle fiber; Tensile strength

1. Introduction

Retting is the decomposition of organic material such as lignin and pectin, which links fiber bundles to other cells in plants, biologically by either fungi or bacteria. Plant fibers are classified into bast, leaf, seed, and fruit. The fiber material comes from plants such as nettle, jute, hemp, kenaf, flax, roselle, ramie, etc. Bast fibers are found in the outside layer, inside layer, phloem, or stem encircling the plant. The nettle is a high fiber yielding plant that grows primarily in the Indian Himalayas but also in Nepal, Europe, and other Asian countries. Urtica dioica, also known as common nettle or stinging nettle, is a flowering plant in the Urticaceae family [1].

Due to a lack of cotton during World War I, the German army made nettle fiber clothes. Retting is the major problem in extracting nettle fiber. Because the nettle fibers are primarily constructed of cellulose, they are referred to as "natural cellulosic fibers." Retting breaks down the fiber bundles, allowing the fibers to be continuously treated in order to obtain the finest fiber for products like textiles. In this process, nettle fiber bundles are degraded. The non-cellulose components like pectin, hemicelluloses, lignin, and waxes are attached to the surrounding bark and woody core. The nettle fibers become longer, finer, and stronger, and they are used to make handicraft Products.

Excessive retting may result in low-quality fiber [2]. The majority of bast fiber extractions are done using two methods. The water retting fiber separation method involves placing nettle stems in reservoirs of water to allow an anaerobic bacteria’s pectinolytic enzyme to separate the fibers. The bacteriological action can be divided into at least three stages: the first creates the bacterial culture, the second accomplishes pectin degradation, and the third concludes the activity. The dew retting process is the most suitable method for producing fiber in the industrial sector. Nettle stems are arranged in a field, and the pectin is broken down by pectinolytic microbes, primarily aerobic fungi. This procedure is dependent on atmospheric moisture and temperature, both of which are uncontrollable. The focus of this research is to study the bio-softening of nettle fibers using natural microorganisms that attack surface cell wall components. It also keeps the environment clean by avoiding the use of caustic soda chemicals for fiber extraction. Our research focuses on the bio-softening of nettle fiber via natural

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resources and also determines the physical and mechanical properties, nettle fiber surface SEM analysis, and FTIR spectra of bio-softened nettle fiber [3–5].

2. Materials and methods

2.1. Materials

The nettle grows in the Himalayan region of Nagaland (250-39'-47" N, 940-38'-09" E). The nettle plant is harvested from October to December, and it grows more than 3 meters tall in a Himalayan area above 1500–2000m, as shown in Figure 1. The fibers are found in a wide ring in the external section of the stalk, divided by collenchyma cells rather than in bundles. By dry weight, the stem contains 3.5–13.2% fiber. The moisture content of nettle is 16%, cellulose 68.10%, hemicelluloses 14.12%, lignin 10.45%, and pectin and gum 6.02% [6].

2.2. FTIR Spectra analysis

The FTIR spectrum of the nettle fiber samples was analyzed using the ABB Bomen MB3000 spectrophotometer, which is used to analyze hydrogen bonds, the structure of natural fiber, and the chemical composition of nettle fiber. The near contact between fiber samples and the attenuated total reflectance (ATR) crystal was constructed by using a pressure clamp. In the range of 4000–600cm⁻¹, all spectra were collected with 32 scans and 4cm⁻¹ resolution [1-3].

2.3. Physical and Mechanical properties of nettle fiber

The physical and mechanical characteristics of water and dew retted nettle fiber, such as fiber length, diameter, fineness, tenacity, tensile strength, Young’s modulus (E), and elongation break % were measured using the standard textile testing instrument, Unistretch 250, and a micrometer microscope. The total length of the nettle fiber sample used for testing was 120mm [4, 5].

2.4. Scanning Electron Microscopy

The morphology and structure of water and dew retted nettle fibers samples were observed by field emission SEM (JEOL JSM 6390) and an accelerating voltage of 5 to 10KV. The high-quality nettle fiber SEM images were collected at different magnifications (100,000x). Prior to SEM inspection, the samples were placed on aluminum stubs with carbon tape and then sputter coated with platinum and palladium to make them conductive [6-8].

2.5. Bacterial treatment of Nettle fiber

The water retting method produces a uniform length of high-quality fiber. The dry nettle fiber samples are soaked in cold water for 7–14 days. The retting trials were carried out in 10-liter plastic tanks at a temperature of 35 °C. As shown in Figure 2, the water was changed with fresh cold water to remove dirt and impurities, one with bacterial inoculum and the other a control sample. Over retting weakens the fiber strength, while under retting makes fiber separation difficult. As a result, retting time maintenance is critical. At the start of the process, spores were added to water tanks. A total of 16 water-retted fiber samples were collected, 8 of them retted with bacterial inoculum that degrades the pectin and lignin and eight control samples. After that, nettle bark is peeled and dried for 48hrs. The bark was rinsed in running water and beat with a wooden mallet to remove impurities and soften the fibers for 2 hours [4-6].

2.6. Fungi effect of Nettle fiber extraction

The dew retted nettle stems were harvested and uniformly spread in the fields where fungus, sunlight, and atmospheric air and dew caused the stem’s cellular tissues and sticky compounds that wrap the fibers to break. For the dew retting process and colonization of fungi, warm places and Cellulose, pectinase, and xylanases are recommended. These are prevalent in locations with limited water resources. As retting organisms, fungi penetration is thought to be the
most important enzymatic activity. In dew retting, Rhizomucor pusillus and Fusarium lateritium stood out for their strong lignin degradation, ability to attack noncellulosic cells without harming any cellulose, ability to penetrate the round surface of the stem, and effective fiber release from the core [4,9]. During this process, soil and phyllosphere microorganisms proliferate on the plants, resulting in partial stem tissue disintegration and improved fiber quality, as shown in Figure 3.

3. Results and discussion

3.1. Chemical composition analysis

During water and dew retting process, bacterial and fungi formation degraded fiber lignin in the nettle fiber stems. The cellulose, hemicellulose, and lignin content in the raw nettle was 65.27%, 9.53% and 3.7% respectively. The degradation of lignin and hemicellulose was observed at 2.8% and 8.4% for bacterial method and 2.1% and 7.3% for dew process. The change in values reflects the increase in fiber softness and cellulose content 86.4% and 84% shown in Figure 4. Both bio-organisms improved the color and fineness of the fiber to their maximum ability in 30 days. There was no visible change in color until 30 days elapsed. The samples that incubated for 30 and 45 days showed no significant difference in lignin breakdown [10].

3.2. Physical and Mechanical Properties

The nettle fiber length was measured using a calibrated centimeter scale. The raw fiber length measured up to 250cm. After treatment, the fiber length measured 200cm for water retted fibers and 175cm for dew retted fibers. The microbial treatment methods could increase fiber fineness up to 58 dtex and reduce fiber diameter from 40 mm to 32 mm, as shown in Figure 5 (D). From Table 1, the tenacity of microbial treated nettle fiber decreased over raw nettle from 45.72 to 38.20 cN\text{tex}. This reduction in tenacity could be related to the selective removal of lignin, which causes microfibril compaction and lowers the tensile strength of bio-softened nettle. Notice that from Table 1. The tensile strength and elongation breaks improved in treated nettle compared to raw nettle. The raw fiber had a 2.86% elongation, but the fiber treated with fungi had a 3.32% elongation, and the fiber treated with bacteria had a 3.80% elongation. As a result, softening did not degrade the fiber quality [12-14]. This enhancement in tensile properties is likely to improve fiber spinnability and strengthen nettle yarn’s ability to withstand being woven.

3.3. FTIR analysis of treated nettle fiber

The hydroxyl (OH) form of cellulose, lignin, and hemicellulose had a strong peak observed between 3500–3300 cm\(^{-1}\) that is specific to compounds. The peak at 2878–2746 cm\(^{-1}\) was representative of the stretching vibration of CH found in cellulose and hemicellulose the band at 1620 cm\(^{-1}\) may be linked to the presence of water in the fibers. The peak at 1636 cm\(^{-1}\) was indicative of hemicellulose’s carboxyl group [12].

Table 1. Mechanical properties of Nettle fiber

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tensile strength (Mpa)</th>
<th>Tenacity (cN\text{tex})</th>
<th>Elongation break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw nettle</td>
<td>1880</td>
<td>45.72</td>
<td>2.86</td>
</tr>
<tr>
<td>Water retted</td>
<td>3270</td>
<td>39.68</td>
<td>3.32</td>
</tr>
<tr>
<td>Dew retted</td>
<td>3850</td>
<td>38.20</td>
<td>3.80</td>
</tr>
</tbody>
</table>

Figure 3. A) Dew retting B) Water retting nettle fiber

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The CH₂ deformation vibrations in lignin and pectin symmetric bending of the cellulose are related to the absorption band at 1450 cm⁻¹. The bending vibrations of the CH and CO vibration of the aromatic rings' methyl and methylene groups in cellulose bands measured at 1273 cm⁻¹ and 1196 cm⁻¹, respectively. The CO and OH stretching vibrations of the polysaccharide in cellulose were related to the intense peak vibrations detected at 1026 cm⁻¹. Finally, the creation of the glycosidic area is defined by the peak CH deformation in the cellulose bond structure between 895 cm⁻¹ and 897 cm⁻¹ [11-13].

3.4. SEM analysis of treated nettle fiber

The water and dew treated nettle fiber surface morphologies are shown in Figure 6. After biological treatment, the surface morphologies visibly changed. In comparison to raw nettle fibers, treated nettle fibers have a distinct degree of protrusion. The SEM figures show the nettle yarn's twisting mechanism at the breaking point is smooth. The presence of protrusions in treated nettle fibers contributes to the tensile characteristics by improving the mechanical connection between the fiber and the matrix during tensile loading [14]. A nettle fiber matrix, which is made up of hemicellulose, lignin, and pectin (which have various characteristics), becomes highly anisotropic. The existence of the gradient in the radial direction indicates that the anisotropy of the matrix may have imparted a twisting moment on the fibers.

Figure 4. A) Cellulose (B) hemicellulose (C) Lignin (D) Physical properties

Figure 5. FTIR spectrum analysis of Nettle fiber

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4. Conclusion

In this study, nettle fibers were treated with bacteria and fungi media. The treatments mainly degraded lignin and pectin material, and they increased the cellulose content by 86.4%. The treated nettle fiber surface was smooth and strong. The physical and mechanical characteristics, the FTIR spectrum, and the SEM analysis of nettle fiber were analyzed through the results. The nettle fiber is superior in tensile properties compared to other bast fibers, indicating that it’s suitable for use as an industrial fiber. The length and strength of the fibers factor in its processing, both in spinning (then weaving and knitting) and nonwoven technologies. The flexural hardness of the fiber decreased after biological treatment, making it suitable for spinning. The nettle fiber is blended with other natural fibers like cotton to produce a smooth yarn to make clothing materials. In future research, nettle fiber will be tested with enzymatic materials to see if it takes less time to degrade lignin and produces higher tensile strength.

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References


