TEKSTİL VE KONFEKSİYON

VOL: 35, NO. 2
DOI: 10.32710/tekstilvekonfeksiyon.1533949

Spinnability of Hemp Fibers after Ultrasonic Retting and Treatment with Laccase Enzyme

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ABSTRACT

Hemp (*Cannabis sativa L.*) is a plant that has been used in yarn production for thousands of years. Its natural fibers are used in the textile, paper, and bio-based composite industries. Different retting methods are used to obtain fibers from the hemp plant. The study aims to investigate yarn production possibilities not only for twine and rope but also for high-value-added textile materials. Within the scope of the research, the extracted fibers of Samsun's local hemp were retted with hydrogen peroxide in an ultrasonic environment and then treated with laccase. The resulting fibers were characterized. It was observed that the extracted fibers, which were retted at 60°C for 60 minutes with 10 g/l H_2O_2, 8 g/l NaOH, and 0.5 g/l stabilizer, gained spinnability after treatment with laccase. Ne12/1 open-end (82.5% cotton/17.5% hemp) yarn was spun with the fibers (mean length 14.58 cm (cut into 30 mm for spinning) and mean fineness 198.9 dtex). Their YI E313 and WI CIE were 34.42 and -66.30, respectively. The antibacterial effect of raw hemp fiber and hemp fiber of the yarn before spinning against *S.aureus* and *E.coli* was examined using the ASTM 2149 method. As a result of the trial, 33.10% and 88.00% antibacterial effects against *S.aureus* and 15.22% and 70.24% against *E.coli* were detected in raw hemp and processed hemp fiber, respectively. In conclusion, ultrasonic retting with the aid of hydrogen peroxide and after laccase treatment enabled the spinning of the yarn because laccase softens fibers. Therefore, laccase treatment of retted fibers is suggested for easy spinning of yarn.

ARTICLE HISTORY
Received: 26.08.2024
Accepted: 26.05.2025

KEYWORDS

Hemp yarn. Laccase. Scutching. Spinnability. Antibacterial activity

1. INTRODUCTION

One of the oldest fiber crops, hemp (*Cannabis sativa* L.), reached its peak production in Europe from the 16th to the 18th century. Its cultivation declined quickly during the 19th century, but in current years has revealed a growth due to a demand for non-food crops in farming systems and a renewed interest in the use of natural fibers for textile goods [1]. Hemp stems contain two types of fibers which are primary fibers and secondary fibers (Figure 1). The bundles of primary fibers are occurred during primary growth in hemp. The cambial meristem produces secondary fibers and they are appeared after finishing of primary fiber production [2]. The bundles of primary fibers are useful for textile industry [3]. Hemp is a versatile plant that has been cultivated for centuries, with applications across a wide range of industries. Its fibrous stem is the most widely used part of the plant. It has proven to be a valuable resource in fields such as paper production, textile manufacturing, construction, agriculture, medicine, automotive, and composites. The long and strong fibers of hemp are particularly remarkable. They can be spun into threads, woven into fabrics, or made into ropes, twines, canvas, and other materials. These fibers possess a range of beneficial

To cite this article: Mehrizi M K, Körlü A, Çelik P, Şahiner A. 2025. Spinnability of hemp fibers after ultrasonic retting and treatment with laccase enzyme. *Tekstil ve Konfeksiyon*, 35(2), 144-154.

properties, including high tensile strength, durability, and resistance to degradation. One of the most promising applications for hemp fibers lies in the production of insulating products and fiber-reinforced composites. It is due to their low density and excellent specific mechanical properties, which make them ideal for use in a variety of structural applications. In addition to these uses, hemp is also an attractive crop for energy and biofuel production, thanks to its high productivity and high cellulose content. It makes it an ideal candidate for sustainable and environmentally friendly fuel sources, further adding to its value as a versatile and multi-purpose crop [4-12]. Fiber attained from the hemp entails of a high amount of cellulose (60–70%), lignin (5–8%), and hemicellulose (20%), with a minor amount of pectin, fats, and waxes [13].

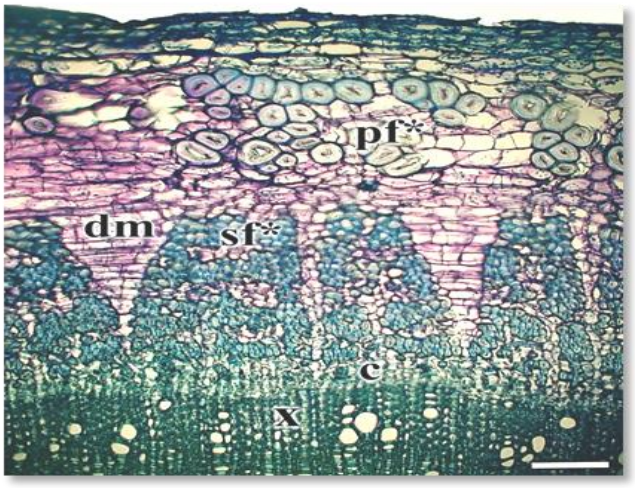


Figure 1. Cross-section of hemp stem (c: cambium; pf*: primary phloem fibers with thickened cell wall; sf*: secondary fibers with thickened cell wall; x: xylem; dm: dilatation meristems). It is reproduced under a Creative Commons CC BY license from Anastasia [14]

It is critical to note that the physical and chemical properties of hemp fiber and the methods for its extraction play a crucial role in utilizing it for different products. There are various techniques for extracting hemp fiber, including enzymatic, microbiological, chemical, and physical methods. Among these methods, dew- and water-retting systems are the most commonly used ones, which are carried out by pectinolytic enzymes secreted by indigenous microflora [15]. Dew retting involves spreading hemp stems on the ground and allowing aerobic fungi to break down the pectins surrounding the fiber. On the other hand, water retting involves soaking the stems in water, which helps break down the outermost layer and enhance the absorption of moisture and pectinolytic bacterial community. It is worth noting that water retting generally produces higher quality fiber than dew-retting, but it can also cause environmental pollution [16-18]. The retting process is indeed quite complex and can be influenced by various factors such as microbial content and environmental conditions. If the degradation process is carried out for longer, separation can be made easier, whereas over-retting can weaken the fiber. The physical properties and applications of a fiber, which are defined by the proportion of its main components (cellulose, hemicellulose, and lignin), are also dependent on the retting process. Fibers with a high cellulose content are particularly well-suited to applications such as textiles, paper, and others, as this provides them with the necessary strength and stability [19, 20]. Besides the retting process, other factors that also reportedly contribute to fiber quality and quantity are morpho-anatomical traits, the cellular biochemical composition of hemp, changes in the hemp stem from vegetative to the flowering stage, genotype, environment, management, and their interaction, also affect the raw fiber quality and yield [21-23]. The quantity and quality parameters of hemp have been extensively studied. For instance, fiber yield, and mechanical behavior such as tensile strength, compression, elastic modulus, thermal properties, bundle architecture, etc have been widely evaluated [24- 28]. On the other side, Tripa et al. (2023) bleached the hemp yarn and found that the bleaching process improved the mechanical properties of the yarn [29]. Gedik and Avinc (2018) compared the bleaching of hemp fabric with hydrogen peroxide and peracetic acid. They informed that peracetic acid achieved relatively high whiteness values, reaching up to 68.13 on the Stensby whiteness index, without causing significant fiber damage [30]. In this study, due to the disadvantages of conventional hemp fiber extraction methods (Table 1), hemp stems were retted with hydrogen peroxide with ultrasound technology to extract easy spinnable fiber in a short time eco-friendly. Ultrasound technology has two functions during the wet process of the textile materials. They are;

- Removal of impurities from the textile materials
- Diffusion and insertion of molecules and nanoparticles into textile materials [31]. Therefore, Ultrasound technology was used during the chemical retting process to enhance the reaction rates with cavitation.

Table 1. Disadvantages of hemp fiber conventional extraction methods ~~[32]~~

Methods	Disadvantages
Decortication	• Risk of developing byssinosis [32] • Hard fibers for the spinning process
Microbiological retting	• Long retting time • Uncontrolled retting conditions • Water pollution • Smell • Biological hazards for workers [32]

The objective of the research was the study of the effect of laccase after ultrasonic retting of the hemp stems on the physico-mechanical properties of fibers.

2. MATERIALS AND METHODS

The native hemp (Figure 2) was harvested from Samsun, Turkey, in October 2022. Before retting, the stems were cut into about 26 cm length.

The stems were retted with hydrogen peroxide (Figure 3) in the ultrasonic tank (40 kHz) according to recipes in Table 2. The experimental plan (Tables 2 and 3) was designed based on preliminary experiments and technical limitations. The ultrasonic tank was not suitable for boiling temperatures, so the retting temperatures were 50 and 60°C.

Figure 2. Stems ready for retting

This study proposes an alternative method to the conventional retting process. Conventional retting allows the fiber bundles to loosen and separate from hemp stems [33]. Since the non-cellulose parts are removed in the retting process, an increase in the cellulose content in the fiber occurs [34]. The easy separation of hemp fiber bundles from the stem also increases the amount of fiber to be obtained. Bleuze et al. (2020) also suggested the extracted fiber mass as an evaluation method for the retting process [35]. In addition, the hackling process of easily peeled fibers and the removal of non-fibrous bark parts were easier than others. The easy separation of fibers from the plant stem is a critical parameter in fiber extraction. Therefore, the best results with recipes coded R1, R2, and R5 are obtained. The recipes supplied the easy removal of fibers from the stem, the soft handle of the fibers, and the processing time (Figure 4).

Figure 3. Ultrasonic retting of stems

Table 2. The recipes for retting of hemp

No	H_2O_2 (g/l)	NaOH (g/l)	Stabilizer (g/l)	Duration (min)	Temperature (°C)
R1	10	8	0.5	30	60
R2				60	
R3				120	
R4				180	
R5		4		30	50
R6				60	
R7	12	2		30	
R8				60	
Washing processes after retting					
W1	Washing the hemp with water containing 1 g/l detergent at boiling temperature for 10 minutes				
W2	Rinsing the hemp with water at boiling temperature for 5 minutes				
W3	Rinsing the hemp with lukewarm water for 5 minutes				
W4	Rinsing the hemp with running water				
Peeling away the fibers from the stem					
Drying of the extracted fibers at room temperature					
Scutching of the extracted fibers					

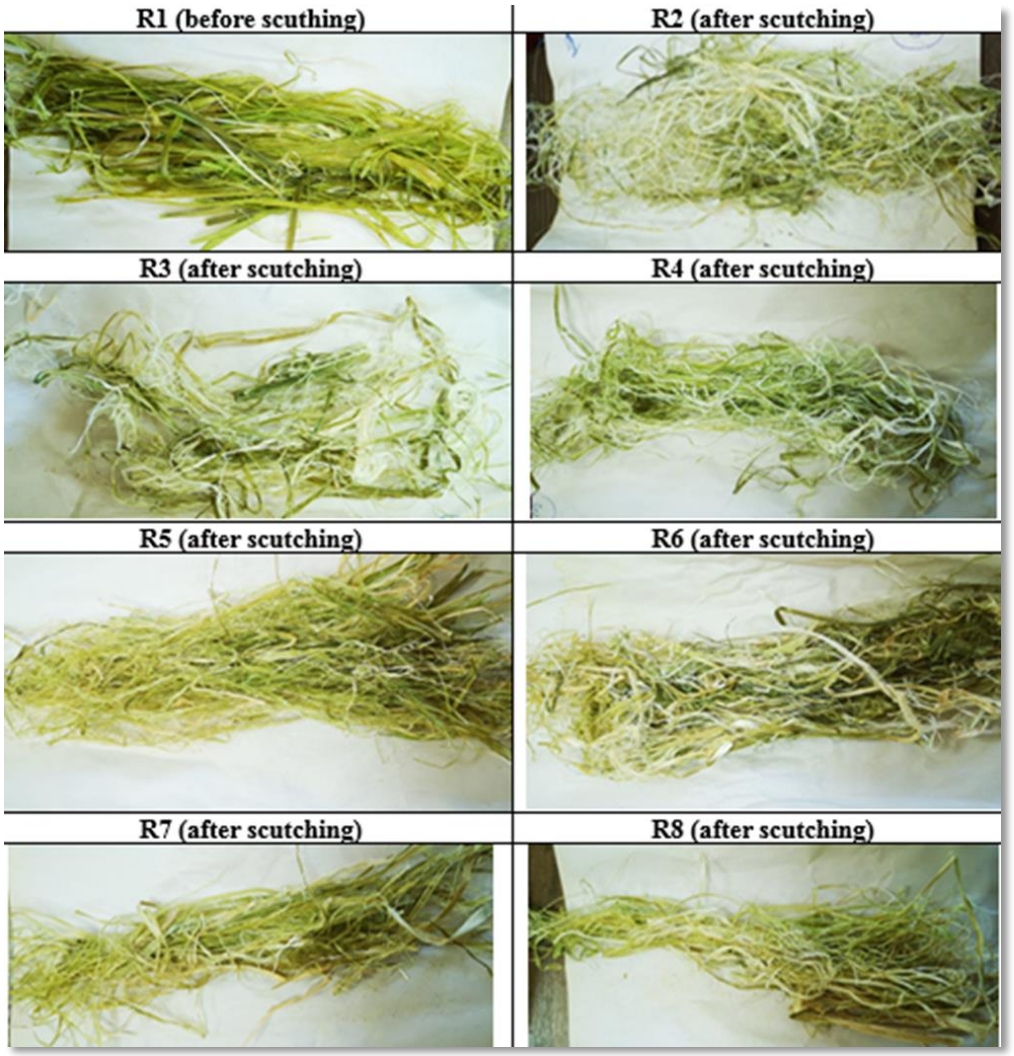


Figure 4. The retted hemp fibers

After retting, the selected samples (R1, R2 and R5- Figure 5) were treated with laccase in the sample dyeing machine (Thermal trademarked). The recipes are in the Table 3.

Fiber length measurements were performed based on the measurement of single fibers according to TS 715 ISO 6989. The color values (CIEL*a*b*), the whiteness (WI E 313 (D65/10◦) and yellowness (YI E 313 (D65/10◦) of the treated fibers were determined by a Hunterlab Ultra Scan PRO model spectrophotometer (Reston, VA, USA). Fourier transform infrared spectroscopy (FTIR) of the samples was carried out with a Perkin Elmer Spectrum 100. Photographs of the fibers' appearances were taken using a light microscope (Carl Zeiss) with 10× magnification. Determination of antibacterial properties of the raw and treated hemp fibers was according to ASTM 2149. For this purpose, efficacy tests were carried out against two bacteria, one gram-positive and the other gram-negative. *Staphylococcus aureus* ATCC 6538 and *Escherichia coli* ATCC 25922 cultures were acquired from Kwik-Stik (Microbiologics Inc, USA). The organisms were cultivated in Tryptic Soy Broth (Merck Millipore) and incubated aerobically at 37 °C for 24 hours. Before conducting the antibacterial test, microbial suspensions were adjusted to 0.5 McFarland using a densitometer (Grant Instruments, Cambridge, UK). One gram of hemp sample was added to 100 mL of buffer solution, and 1 mL of *S. aureus* and *E. coli* suspension (with a final concentration of $1.5x10^5$ – $5.0x10^5$ cfu mL^{-1}) was inoculated. The samples were then incubated at 37 °C and 100 rpm in a shaking incubator. After 0 minutes and 24 hours of contact time, tenfold serial dilutions were performed, and 1 mL of each dilution was plated onto Tryptic Soy Agar (Merck Millipore) using the pour plating technique. Following a 48-hour incubation period at 37±1°C, the colonies on the agar plates were enumerated, and the log10 reductions were calculated. The study aims to examine new methods for obtaining spinnable hemp fibers. After the characterization of the treated fibers with the test methods above, the spinning trial was carried out to examine the spinnability of hemp fibers. The length of the fibers was cut into 30 mm to be spun by blending with cotton fiber. Shirley trash analyzer device (Figure 6a) and Textechno MDTA-3 device (Figure 6b) were used to spin the yarn. Finally, the slivers were spun at the Rieter M1 open-end machine (rotor diameter 46 mm, rotor speed 45,000 rpm, αe= 3.8).

Table 3. Recipes for laccase treatment

No	Laccase (%)	pH	Temperature (°C)	Duration (min)
L2	6	5	50	60
Washing processes after laccase treatment				
W1	Washing the hemp with water containing 1 g/l detergent at boiling temperature for 10 minutes			
W2	Rinsing the hemp with water at boiling temperature for 5 minutes			
W3	Rinsing the hemp with lukewarm water for 5 minutes			
W4	Rinsing the hemp with running water			
Drying of the treated fibers at room temperature				
Scutching of the treated fibers				
Hackling of the scutched fibers (Figure 5)				

Figure 5. The hemp fibers treated with laccase

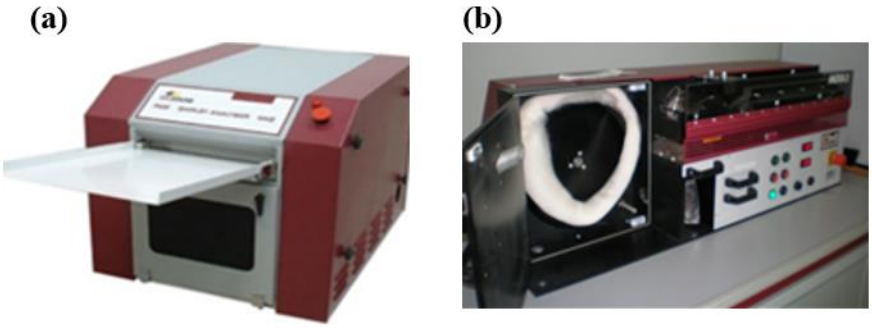


Figure 6. (a) Shirley trash analyzer, **(b)** MDTA 3-Microdust and Trash analyzer

3. RESULTS

Succeeding of the retting process is evaluated with empirical methods. Mechanical properties, color and handle of the stems are tested empirically. These properties show the fiber quality slightly. Controlling retting conditions for the fiber application field is difficult [36]. Therefore, the best recipes (Table 1) were empirically selected according to the handle of the stems and extracting the fibers from the stem easily. Then, the fibers from the best recipes were characterized.

3.1 Fiber Characteristics

3.1.1 Fiber Lengths and Fineness

Recipe coded R2 was the severe. Therefore, hydrogen peroxide removed the lignin and pectin from hemp [37, 38]. The fibers were separated easily from the stem and fiber bundles. After the retting process, laccase treatment also caused the removal of the waste lignin from the fibers. At the end of the laccase treatment, the fibers were softer than untreated fibers with laccase. On the other hand, the fibers coded R5L2 coded hemp fibers were shorter and finer than the others. This sample's retting condition was milder than

the others. The sample coded R5L2 was found to have a stiffer handle than other samples, even after the laccase process, due to more moderate retting conditions. For this reason, it is thought that slightly more fiber damage occurs during the scuthing and hackling processes. The retting conditions are not the only parameter for fiber length and fineness. The fiber fineness was determined by the gravimetric method (TS 2874 EN ISO 1973), and 3 tests were performed for each fiber type. The fiber length of hemp fibers was performed by TS 715 ISO 6989. Fiber characteristics depend on hemp plants' properties, growing conditions, and fiber extraction methods—mechanical processes (scutching and hackling) after retting greatly affect fiber length and fineness. As seen in Figure 7, fiber bundles were separated during the hackling process, and the fibers were finer and shorter. It means that deep mechanical processes caused the shortening after the optimal retting process so that cottonization of the fibers.

Standard deviation and coefficient of variation (%) of the fiber specification are also important for textiles. The lowest values were obtained from the fibers coded R2L2. Therefore, the best recipe was R2L2 for spinning and these fibers were spun into yarn (Table 4).

In addition, to see the effect of the laccase treatment, the fiber strength and breaking elongation (%) values were measured (Table 5). The fiber strength and elongation at break values were tested by TS EN ISO 5079 (Textile fibers — Determination of breaking force and elongation at break of individual fibers) and 30 measurements were made. After laccase treatment, the fibers became softer than before. Because laccase removed lignin from the fibers. Therefore, the elasticity (%) of the fiber improved. It is an advantage to spin the yarn.

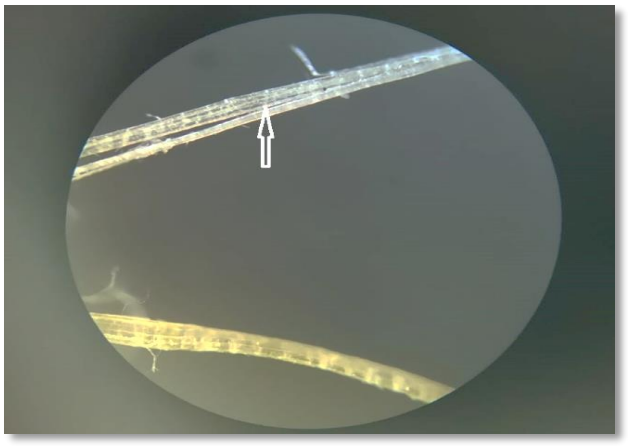


Figure 7. Importance of hackling process on fiber fineness

3.1.2 Microscopic Appearance of the Fibers

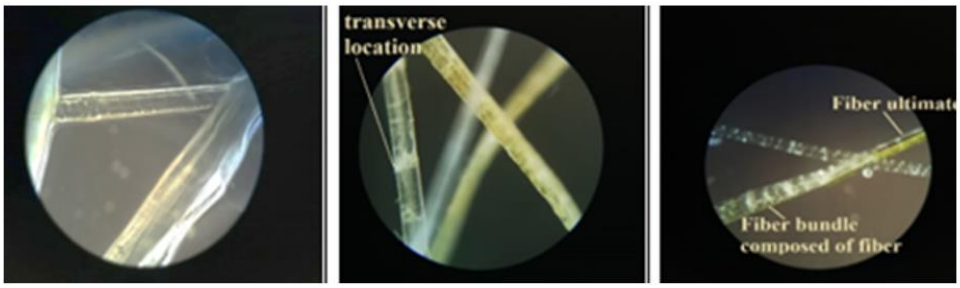
All the fibers had transverse nodes or striations (Figure 8) like other bast fibers. As Wang and Wang (2005) informed, the nodes did not occur regularly during the growth of the hemp plant. The morphologies of the nodes and the fissures on the hemp fibers depended on fibril cell growth. The transverse nodes and fissures were created by the folding and dislocation of some internal cellular layers. The dislocations of the inner cellular layers had significant effect on the dimensions of the nodes. The thicker node regions could cause fiber deformation easily. However, the fissures on the fibers could contribute to the hemp fibers moisture absorption and desorption rapidly [39].

Table 4. Fibers specification

CODES	R1L2	R2L2	R5L2
Length (Mean) cm	13.81	14.58	12.46
Standard deviation	5.41	3.16	4.08
Length CV%	39.16	21.70	32.72
Fiber fineness dtex	235.97	198.90	172.07
Standard deviation	1.23	0.90	0.78
Fiber fineness CV%	37.70	31.01	35.98

Table 5. The fiber strength and breaking elongation (%) values of R2L2 fibers before and after laccase treatment.

	R2 (Before laccase treatment)	R2L2 (After laccase treatment)
Fiber strength cN/tex	42.88	56.66
Fiber strength CV%	8.59	6.49
Fiber breaking elongation (%)	1.72	3.13
Fiber breaking elongation CV%	6.38	2.22



(a): R1L2 (b):R2L2 (c):R5L2

Figure 8. Microscopic appearance of the treated fibers

With the aid of ultrasound technology, the transverse locations on the fibers caused the penetration of the retting bath containing hydrogen peroxide and caustic soda into fibers easily. However, chemical concentration and retting time had a critical effect on the extraction of fibers from the hemp stem. In Figures 8a and c, fiber bundles can be seen easily. In Figure 8c, fiber bundles are clearer. Because the fibers in Fig 8c were retted moderately (10 g/l H_2O_2, 4 g/l NaOH for 30 min. at 50°C).

In contrast, the fibers in Fig 8b were retted under heavy conditions (10 g/l H_2O_2, 8 g/l NaOH for 60 min. at 60°C). The heavy treatment condition caused effective retting. Chemicals could easily penetrate fibers through the transverse locations through ultrasound and swelling of fibers with caustic soda. In addition, laccase could penetrate fibers easily and remove lignin from fibers. Therefore, ultimate fibers can be seen clearly in Fig 8b.

3.1.3 Color Values

There are three main criteria for use of hemp fiber in textile industry. They are purity, fiber position and color. Preferred color of the fibers is generally white, blonde or light color [40]. It is an advantage to use hydrogen peroxide during the retting process. Because hydrogen peroxide removes lignin and pectin efficiently during the alkali-hydrogen peroxide treatment in addition to bleaching [41, 42]. Lignin is a complex amorphous polymer. It is composed of propane benzene crosslinked by ether bonds and C-C bonds. These units combine to form the macromolecule by various bindings, with ether linkage being formed, amounting to two-thirds up to three-fourths. Additionally, Lignin can react with H_2O_2 in three different forms. They are reactions of the benzene ring and side-chains and benzene ring and side-chains cracking simultaneously. The lignin-benzene ring's constitutional unit is originally colorless but turns into a colored substance during boiling process. In alkali media, peroxide destroy the quinine structures and they are converted into colorless structures. And then, they are disintegrated into low-molecular aliphatic compound. Lignin is colored by nature due to the conjugated double bond in the side-chains. Peroxide can give damage to side-chains and they turn into colorless and following side-chains are disintegrated. Nonconjugated double bonds can also be separated by H_2O_2. All these can separate the lignin out from cellulose [42]. On the other side, mechanical processes and laccase treatment also supported removal of lignin from the fibers. It is considered that removal of lignin from the fibers causes lightening of the fiber color. Because lignin is pale yellow colored as informed by Glasser (2019) [43]. All the treated fibers were blonde (Fig. 5). As seen in Table 6 fibers coded R5L2 are lighter (L*) and more brightness (C*) than the others. According to color values (a* and b*), R2L2 is blueish green and R5L2 is reddish yellow. R5L2 is on yellow-red area of the CIELab color space because of h* value is 86.95. However, R1L2 and R2L2 are on yellow-green area.

Especially in studies on pulp and paper, a relationship between yellowing and lignin has been established, and the cause of yellowing has been investigated [44-48] and found a direct relationship between some chromophoric groups' concentration and lignin's concentration. They suggested that the oxidation of the α, β-unsaturated aldehydes is the mechanism of chromophore removal by the peroxide [48]. Gellerstedt (2007) explained the chemistry of bleaching and post-color formation in kraft pulps. Radical species support the oxidation of lignin during the peroxide process, and they oxidize the polysaccharides. At boiling temperature, quinone methide is formed from phenolic benzyl alcohol structures. The lignin side chain is broken and fragmented in the further reaction steps. The delignification causes an increase in fiber brightness [47]. Based on this information, the yellowing and whiteness indexes could give an idea about the lignin content in this study. Fibers coded R2L2 are whiter and less yellow than the others because R2L2 is treated harder than R1L2 and R5L2 (Table 1). So, an enormous amount of the lignin is removed from the fibers coded R2L2.

Table 6. Color values, whiteness and yellowness indexes of the samples

ID	L*	a*	b*	C*	h	WI CIE (D65/10°)	YI E313 (D65/10°)
R1L2	56.78	-1.22	17.11	17.20	94.18	-93.74	42.55
R2L2	59.89	-1.52	14.29	14.44	96.42	-66.30	34.42
R5L2	63.29	1.13	19.92	19.97	86.95	-92.91	47.57

3.2 FTIR Analysis

FTIR analysis is useful for researchers to provide further information on the super-molecular structure. It is used to determine the chemical compositions of treated hemp fibers. The FTIR spectra of the samples show the typical shape of the hemp spectrum with presence of the characteristic absorption bands corresponding to cellulose, hemicellulose, pectin and lignin. R2L2 which was evaluated as the best sample has different %T values from the other samples (Figure 9).

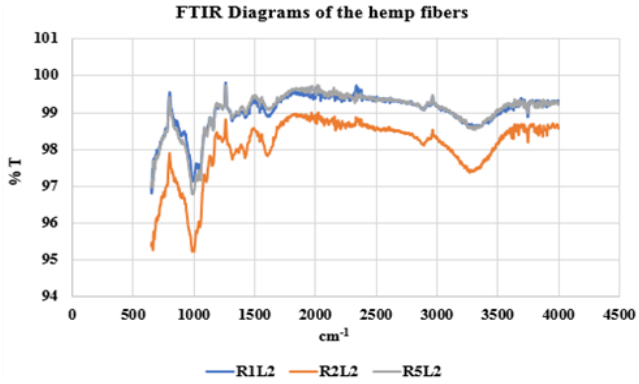


Figure 9. FTIR diagrams of the treated hemp fibers

Laccase treatment has an important effect on removing lignin. Therefore, R2L2 has different %T values from R2 (Figure 10)

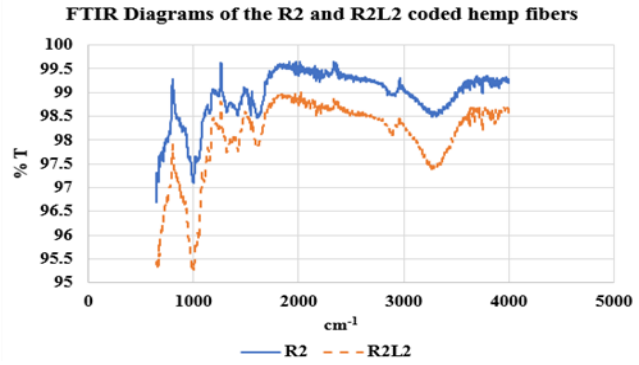


Figure 10. FTIR diagrams of the R2 (retted) and R2L2 (Retted and treated with laccase) hemp fibers

The larger stretch from 3600 to 3200 cm^{-1} represents the O–H stretching, which is a characteristic peak of crystalline cellulose. C–H stretching is found near 2850–2890 cm^{-1} and 700–800 cm^{-1}. They are related to aliphatic and aromatic compounds. O=C=O is near 2400 cm^{-1}. The C=O peak between 1730-1735 cm^{-1} is attributed to the C=O stretching of ester groups and carbonyl in pectin and hemicellulose. The C=C stretching from 1600 to 1740 cm^{-1} is attributed to the cellulose compounds. A stretch from the presence of C–C aromatic rings appears near 1435–1475 cm^{-1}. C–O stretching and deformation are notable at 1215 and 1060 cm^{-1}, while the stretching vibration near 1160 cm^{-1} from the C–O–C functional group is associated with lignin. The characteristic peaks of lignin occur at 1510 cm^{-1} and 1550 cm^{-1}. Both of them indicate stretching of the C=C of the aromatic ring [49, 50].

3.3 Antibacterial Activity

In our study, the antibacterial effect of raw hemp fiber and processed hemp fiber against *S.aureus* and *E.coli* was examined using the ASTM 2149 method. As a result of the trial, 33.10% and 88.00% antibacterial effects against *S.aureus* and 15.22% and 70.24% against *E.coli* were detected in raw hemp and processed hemp fiber, respectively. The most effective antibacterial compounds in the cannabis plant are phytocannabinoids. Leaves and flowers exhibit the highest cannabinoid content, while stems and fibers possess comparatively lower levels. Additionally, male plants typically contain lesser cannabinoid concentrations compared to their female counterparts [51]. The observed modest antibacterial efficacy of the hemp fibers in our study may be attributed to these inherent variations. In another study conducted to determine the effectiveness of hemp fibers and textiles processed from fibers against clinical bacterial isolates, no antibacterial effect was detected [52]. In our study, relatively higher efficacy was detected in processed hemp. It is thought that the high effectiveness may be due to the release of the cannabinoid compound in the fibers with the effect of the ultrasonic retting process.

3.4. The Yarn Spinnability

The study aims to examine new methods for obtaining spinnable hemp fibers. After the characterization of the treated fibers with the test methods above, the spinning trial shown in Figure 11 was carried out to examine the spinnability of hemp fibers. Firstly, after hackling, the hemp fibers were cut to 30 mm for spinning in a short staple spinning system. Because thick and hard hemp fibers will cause problems during spinning, the hemp fibers were passed through the Shirley trash analyzer device (Figure 6a) twice to remove the hard parts of the hemp fibers. Then, 17.5% hemp/82.5% cotton blend slivers were produced at the Textechno MDTA-3 device (Figure 6b). Finally, these slivers were spun at the Rieter M1 open-end machine (rotor diameter 46 mm, rotor speed 45,000 rpm, αe= 3.8), and Ne12/1 open-end yarn was obtained.

The linear density of yarn was measured by TS 244 EN ISO 2060. The yarn tenacity and elongation at break values were determined by the standard of TS EN 150 2062.

The test results are given in Table 7.

Table 7. The yarn specifications

	R2L2
Yarn count (Ne)	11.58
Yarn count CV%	2.61
Yarn tenacity (cN/tex)	6.90

Yarn tenacity CV%	9.4
Breaking elongation %	8.67
Breaking elongation CV%	4.85

Figure 11. The spinning trial stages

4. CONCLUSION

The study aims to explore yarn production possibilities for high-value textile materials. In the first step of the research, hemp stems were retted with hydrogen peroxide in the ultrasonic tank. Easily separation of fibers from the stem is a crucial factor in fiber extraction. The most successful results were obtained with recipes coded R1, R2, and R5, which made it easier to remove fibers from the stem, provided a softer fiber, and reduced processing time. Then, the fibers extracted from the R1, R2, and R5 recipes were treated with laccase. After laccase treatment, the standard deviation and coefficient of variation (%) of the fiber specification are also important for spinning. The lowest values (3.16 – 21.7 % for fiber length and 0.9 -31.01% for fiber fineness) were obtained from the fibers coded R2L2. Therefore, the best recipe was R2L2 for spinning, and these fibers were spun into yarn. The fiber became softer after laccase treatment because of the removal of lignin from fibers. Therefore, the elasticity (%) of the fiber is enhanced. It is an advantage to spin the yarn. According to these results, since the R2L2 sample gave optimum results in spinning trials, it was decided to continue the spinning trials with this sample. However, although it can be spun, it has been observed that there are excessive yarn breaks, and these breaks are caused mainly by thick hemp fibers. Therefore, these hemp slivers were passed twice through the Shirley analyzer device to separate the finer and coarse fibers. The finer hemp and cotton fibers were blended again in the MDTA device to obtain 1-meter slivers. Ne12/1, 82.5% cotton/17.5% hemp, and open-end yarn were produced by these slivers. The hemp ratio was determined by weighing the amount of waste (an average of 6.76%) of the separated MDTA device. Hydrogen peroxide bleached the fibers and removed lignin from the fibers during the retting. After retting processes, laccase treatment also caused residual lignin from the fibers. It is seen in the FTIR diagram (Figure 10). The best whiteness (-66.30) and yellowness (34.42) values were respectively obtained from R2L2, like fiber standard deviation and coefficient of variation (%). The preferred color of hemp fibers is generally white, blonde or light. Therefore, the treated fibers with the R2L2 recipe have the advantage. An interesting result is antibacterial activity. In the study, treated hemp fibers showed higher effectiveness. This increased effect may result from the ultrasonic retting process, which helps release the cannabinoid compound in the fibers. In conclusion, ultrasonic retting of hemp in an alkali hydrogen peroxide bath can be an alternative to conventional retting processes like water and dew retting. The fibers are bleached by hydrogen peroxide. Therefore, fibers do not need bleaching in further processes. It is more ecological than conventional methods, and man can control conditions during the chemical retting.

Acknowledgement

The authors gratefully acknowledge the support of the Turkish Scientific Research Council (TUBITAK) for the 2221 program (Fellowships for Visiting Scientists and Scientists on Sabbatical Leave)

Conflicts of Interest The authors declare that there are no conflicts of interest

Authors' contribution Conceptualization, Data curation, formal analysis, investigation, writing—original draft, and writing—review & editing were performed by all authors.

Data Availability The authors declare that the data supporting the findings of this study are available within the paper.

REFERENCES

1. Liberalato D. 2003. Prospect of hemp utilization in the European textile industry. *Agroindustria*, 147–148.
2. Manian AP, Cordin M, Pham T. 2021. Extraction of cellulose fibers from flax and hemp: a review. *Cellulose* 28, 8275–8294.
3. Yazıcıoğlu G, Pamuk Ve Diğer Bitkisel Lifler, İzmir. 1999. Tekstil Mühendisliği Bölümü Mühendislik Fakültesi, Basım Ünitesi.
4. Struik PC, Amaducci S, Bullard MJ, Stutterheim NC, Venturi G, Cromack HTH. 200. Agronomy of fibre hemp (Cannabis sativa L.) in Europe. *Ind. Crop Prod* 11, 107-118.
5. Karus M, Vogt D. 2004. European hemp industry: Cultivation, processing and product lines. *Euphytica* 140, 7-12.
6. Mwaikambo LY, Ansell MP. 2006. Mechanical properties of alkali treated plant fibers and their potential as reinforcement materials. I. hemp fibers. J. Mater. Sci 41(8), 2483-2496.
7. Prade Th, Svensson SE, Andersson A, Mattsson JE. 2011. Biomass and energy yield of industrial hemp grown for biogas and solid fuel. *Biomass and Bioenergy* 35(7), 3040-3049.
8. Satya P, Maiti R. 2013. Bast and leaf fibre crops: kenaf, hemp, jute, Agave, etc. In: Biofuel crops: production, physiology and genetics.
9. Célino A, Fréour S, Jacquemin F, Casari P. 2013. The hygroscopic behavior of plant fibers: A review, *Front. Chem* 1.
10. Delaney TW, Madigan T. 2014. Beyond Sustainability: A Thriving Environment. Mcfarland & Company, USA.
11. Salentijn EMJ, Zhang Q, Amaducci S, Yang M, Trindadea LM. 2015. New developments in fiber hemp (Cannabis sativa L.) breeding. *Ind. Crop. Prod* 68, 32-41.
12. Zimniewska M, Goślińska-Kuźniarek O. 2016. Evaluation of antibacterial activity of flax fibers against the Staphylococcus aureus bacteria strain. *Fib Text in East Europe* 24(2),120-125.
13. Amaducci S, Gusovius HJ. 2010. Hemp–cultivation, extraction and processing. In: Industrial applications of natural fibers: structure, properties and technical applications.
14. Snegireva A, Chernova T, Ageeva M, Lev-Yadun S, Gorshkova T. 2015. Intrusive growth of primary and secondary phloem fibres in hemp stem determines fibre-bundle formation and structure, *AoB PLANTS* 7(1).
15. Bengtsson E. 2009. Obtaining high quality textile fibre from industrial hemp through organic cultivation. First cycle, G2E. Alnarp: SLU, Horticulture.
16. Henriksson G, Salumets A, Divne Ch, Pettersson G. 1997. Studies of cellulose binding by cellobiose dehydrogenase and a comparison with cellobiohydrolase, *Biochem J*, 833-838.
17. Donaghy JA, Levett PN, Haylock RW. 1990. Changes in microbial populations during anaerobic flax retting. *J. Applied Bacteriology* 69(5), 634-641.
18. Xu J. 2010. Analysis and design of hemp fiber decorticators. University of Manitoba (Canada).
19. Reddy N, Yang Y. 2005. Long Natural Cellulosic Fibers from Cornhusks: Structure and Properties. *AATCC review* 5(7), 24-27.
20. Jankauskienė Z, Butkutė B, Gruzdevienė E, Ceseviciene J, Fernando AL. 2015. Chemical composition and physical properties of dew-and water-retted hemp fibers. *Ind Crop Prod* 75, 206-211.
21. Amaducci S, Zatta A, Pelatti F, Venturi G. 2008. Influence of agronomic factors on yield and quality of hemp (Cannabis sativa L.) fibre and implication for an innovative production system. *Field Crop Res* 107(2), 161-169.
22. Marrot L, Lefeuvre A, Pontoire B, Bourmauda A, Baley C. 2013. Analysis of the hemp fiber mechanical properties and their scattering (Fedora 17). *Ind Crop Prod* 51, 317-327.
23. Salentijn WMJ, Petit J, Trindade LM 2019. The complex interactions between flowering behavior and fiber quality in hemp. *Front Plant Sci* 10.
24. Khan MdMR, Chen Y, Laguë C, Landry H, Peng Q, ZhongW. 2010. Compressive properties of Hemp (Cannabis sativa L.) stalks. *Biosyst Eng* 106(3), 315-323.
25. Rey RD, Serrat R, Alba J, Perez I, Mutje P, EspinachFX. 2017. Effect of sodium hydroxide treatments on the tensile strength and the interphase quality of hemp core fiber-reinforced polypropylene composites. *Polym* 9(8), 377.
26. Bourmaud A, Malvestio J, Lenoir N, Siniscalco D, Habrant A, King A, Legland D, Baley Ch, Beaugrand J. 2017. Exploring the mechanical performance and in-planta architecture of secondary hemp fibers. *Ind Crop Prod* 108, 1-5.
27. Vandepitte K, Vasile S, Vermeire S, Vanderhoeven M, der Borght WV, Latr´e J, Raeve AD, Troch V. 2020. Hemp (Cannabis sativa L.) for high-value textile applications: the effective long fiber yield and quality of different hemp varieties, processed using industrial flax equipment. *Ind Crop Prod* 158.
28. Parcesepe E, Masi RFD, Lima C, Mauro GM, Pecce MR, Maddaloni G. 2021. Assessment of mechanical and thermal properties of hemp-lime mortar. *Materials* 14(4), 882.
29. Tripa S, Kadınkız N, Kanwal A, Nazeer M A., Nazir A, Tripa F, Uzun M. 2023. Analysing the Impact of the Bleaching Process on Wet Spun Hemp Yarn Properties. *Sustainability*, 15(24), 16894.
30. Gedik G., Avinc O. 2018. Bleaching of hemp (*Cannabis sativa L.*) fibers with peracetic acid for textiles industry purposes. *Fibers and Polymers*, 19, 82-93.
31. Körlü A, Bahtiyari MI. 2021. Ultrasound Based Wet Processes in Textile Industry. In: Rather LJ, Haji A, Shabbir M, Innovative and Emerging Technologies for Textile Dyeing and Finishing, Wiley, New York.
32. Davidson M, Reed S, Oosthuizen J, O'Donnell G, Gaur P, Cross M, Dennis G. 2018. Occupational health and safety in cannabis production: an Australian perspective. *Int J Occup Environ Health* 24(3-4),75-85.
33. Decker A, Drean JY, Sarazin V, Harzallah O. 2024. Influence of Different Retting on Hemp Stem and Fiber Characteristics Under the East of France Climate Conditions. *Journal of Natural Fibers*, 21:1, 2350621.
34. Poonsawat T, Sae-Bae P, Bunphami M, Wetchaiyac T, Tatamaneerat P. 2016. Effect of Water and Chemical Retting on Properties of Hemp Fibre and Hybrid Hemp/Cotton Spun Yarn. *Journal of Engineering and Applied Sciences*, 11(9), 1991-1995.
35. Bleuze L, Chabbert B, Lashermes G, Recous S. 2020. Hemp harvest time impacts on the dynamics of microbial colonization and hemp stems degradation during dew retting. *Industrial Crops & Products*, 145, 112122.
36. Réquilé S, Duigou AL, Bourmaud A, Baley Ch. 2018. Peeling Experiments for hemp retting characterization targeting biocomposites. *Ind Crop Prod* 123(1), 573-580.
37. Petrova SN, Yu. Volkova I, Zakharov AG. 2003. Oxidative Delignification of Flax Fiber. Russian J Appl Chem 76, 1344–1347.
38. Kessler RW, Kessler W. 2003. Removing Pectin and Lignin During Chemical Processing of Hemp for Textile Applications. *Text. Res. J* 73(8),664-669.
39. Wang HM, Wang X. 2005. Surface Morphologies and Internal Fine Structures of Bast Fibers. Fib Polym 6, 6-12.
40. Bouloc P. 2013. The Industrial Hemp Economy. P. Bouloc, S. Allegret, L. Arnaud (Ed.), Hemp: Industrial Production and Uses.
41. Khristova P, Tomkinson J, Jones GL. 2003. Multistage peroxide bleaching of French hemp. Ind Crop Prod 18(1), 101-110.
42. Qu LJ, Zhu ShF, Liu M, Wang ShY. 2005. The mechanism and technology parameters optimization of alkali-H2O2 one-bath cooking and bleaching of hemp. *J Appl Polym Sci* 97(6),2279 - 2285
43. Glasser WG. 2019. About Making Lignin Great Again —Some Lessons From the Past. *Front. Chem* 7.

44. Heitner C, Scaiano JC. 1993. Photochemistry of Lignocellulosic Materials ACS Symposium Series; American Chemical Society: Washington, DC.

45. El-Sakhawy M. 2005. Effect of bleaching sequence on paper ageing, *Polym Degradation Stab* 87(3),419-423.

46. Plazonić I, Malnar L, Džimbeg-Malčić V, Barbarić-Mikočević Z, Bates I. 2018. Changes in the optical properties of hemp office papers due to accelerated ageing. 9th International Symposium on Graphic Engineering and Design.

47. Gellerstedt G. 2007. The Chemistry of Bleaching and Post-Color Formation in Kraft Pulps. In Proceedings of the 3rd International Colloquium on Eucalyptus Pulp (ICEP), Belo Horizonte, Brazil.

48. Douek M, Goring DAI. 1976. Microscopical studies on the peroxide bleaching of Douglas fir wood. *Wood Sci.Technol* 10, 29-38.

49. Wallace Ch, Afzal MT, Saha GC. 2019. Effect of feedstock and microwave pyrolysis temperature on physio-chemical and nano-scale mechanical properties of biochar. *Bioresour.Bioprocess* 6(1).

50. Fang G, Chen HG, Chen AQ, Mao KW, Wang Q. 2017. An efficient method of bio-chemical combined treatment for obtaining high-quality hemp fiber. *BioRes* 12(1), 1566-1578.

51. Kampf G. 2020. How long can nosocomial pathogens survive on textiles? A systematic review. *GMS Hyg Infect Control*.

52. Yuksek A, Havuz SG, Karaduman NS, Simsek H, Honca M. 2022. An investigation on the antimicrobial activity of hemp fiber and fabrics against common nasocomial infection agents. *J Cukurova Anesth Surg* 5(2),137-144.