



## RESEARCH PAPER

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# FTIR Analysis of Enzymatically Biopolished Eco-friendly Jute-Cotton Union Fabrics

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## Abstract

Enzymatic treatment on jute-cotton union fabric is ecofriendly way of biopolishing. This study explores the eco-friendly bio-polishing of jute-cotton union fabrics using free enzymes under various treatment conditions. The study analyzed the physical properties of the treated fabric, revealing minimal degradation and increased fiber accessibility. The treatment was measured using Attenuated Total Reflectance Fourier-Transform Infrared Spectroscopy (ATR-FTIR), providing insights into the chemical bonds and functional groups on the fabric molecule. The treated fabric performance was studied at 3, 6 and 12 h at room temperature. Fabric of a jute-cotton union fabric is improved by all of the treatments, as reflected through FTIR readings. The results showed that the treated fabric was of good quality, as protruding fibers were removed during the bio-polishing process.

**Keywords:** FTIR; Jute-cotton union fabric; Bio-polishing; Enzymatic; Eco-friendly; Analysis

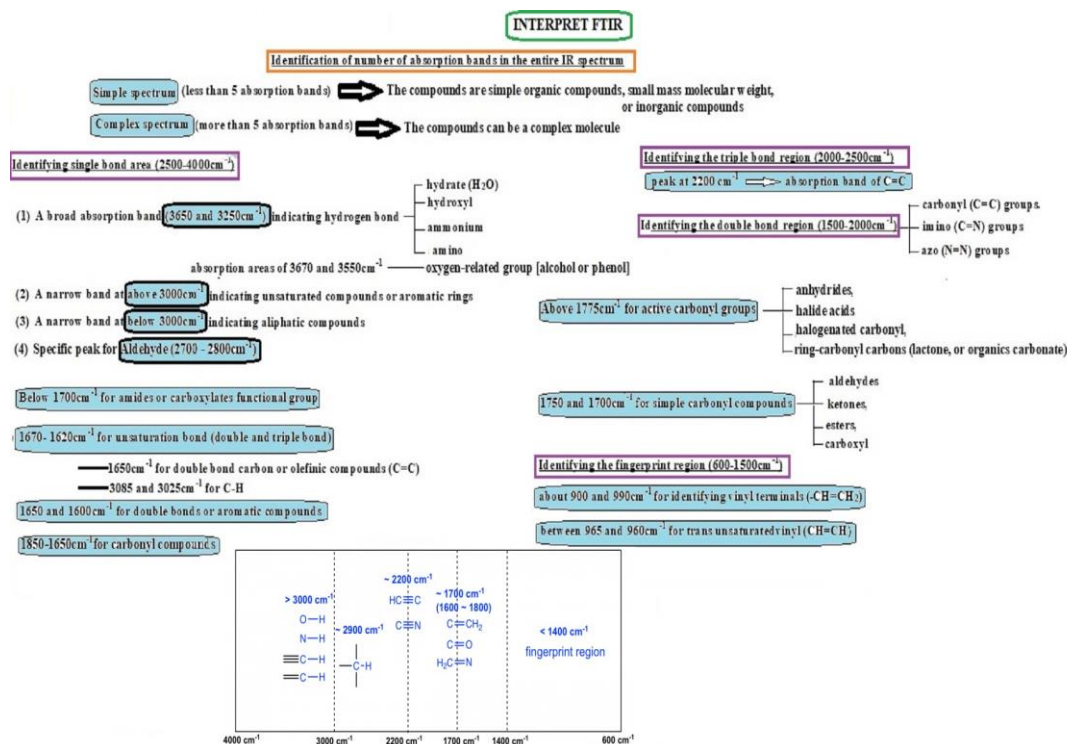
## Introduction

In addition to being utilized in coarse textiles, carpets, and backings, jute fibers are also employed in garment textiles to absorb moisture. They are located in the inner woody core and epidermises of the plant and are removed from its skin or bast. The cellulose and hemicellulose filaments that make up the fibers are bound together by a matrix of pectin and lignin. According to Roul (2009), jute fibers are made up of 59–72%  $\alpha$ -cellulose, 12–15.9% hemicelluloses, 11.8–14.2% lignin, 0.2–0.5% pectin, waxes, protein, and mineral and nitrogenous substances. The hemicellulose component is composed of pentosan (xylan: 12–14%), polyuronide (4–5%), and acetyl groups (3.2–3.5%) (Alia et al., 2009). Only a small portion of these fibers are frequently used to create garment fabrics since jute is one of the most hygroscopic natural fibers.

Within the stem are several fiber bundles, each containing distinct filaments of cellulose and hemicellulose fiber cells. The filaments are held together by the matrix of lignin and pectin. Pectin is removed during the retting process to help separate individual fibers from fiber bundles. Multiple "ultimate" cells, or cells with an average length of 2 to 6 mm, form a single jute strand. These cells are held together by lignin, which provides the fiber its stiffness and protects it from biological attacks. In loom-state woven fabrics, non-cellulosic ingredients introduce unwelcome colors, and hydrophobic waxes stop the dye from seeping through. Kerosene oil and other residual batching oils are eliminated to protect the environment. Other than lignin, scouring eliminates impurities, leaving jute fibers wettable with water or aqueous solutions (Dumas and Miller, 2003). Although jute-blended yarns have been researched for a variety of uses, spin-mixing them needs to be done carefully (Koranne et al., 2013; She et al., 2010). In contrast to traditional finishing techniques that involve harsh chemicals, researchers have studied bio-polishing (Koranne et al., 2013). This advanced technology is utilized in the textile industry to eliminate fuzz, pilling, and increase fabric sheen. Immature fibers poking their heads above the surface of textiles induce pilling and a dulling of the sheen (Andreas et al., 2000). Protruding fibers are removed by cellulase hydrolysis, which modifies the surface and mechanical properties. Because of the enzyme's reduced size, cellulose chains are broken by enzymatic techniques, which lowers the weight and strength of the fabric (Lee and Fan, 1980, Sankarraj and Nallathambi, 2017).



Researchers employ Fourier transform infrared (FTIR) as a vital analytical tool to analyze a wide range of materials, including films, fibers, liquids, solutions, pastes, powders, and gases. Chemical vibrations in materials may be identified with this fast, sensitive, and precise approach. For identifying the chemical composition of textiles and the durability of modifiers on fabric surfaces, FTIR-spectroscopy is very helpful.



**Figure 1.** FTIR Analysis Procedure (Nandiyanto et al., 2019)

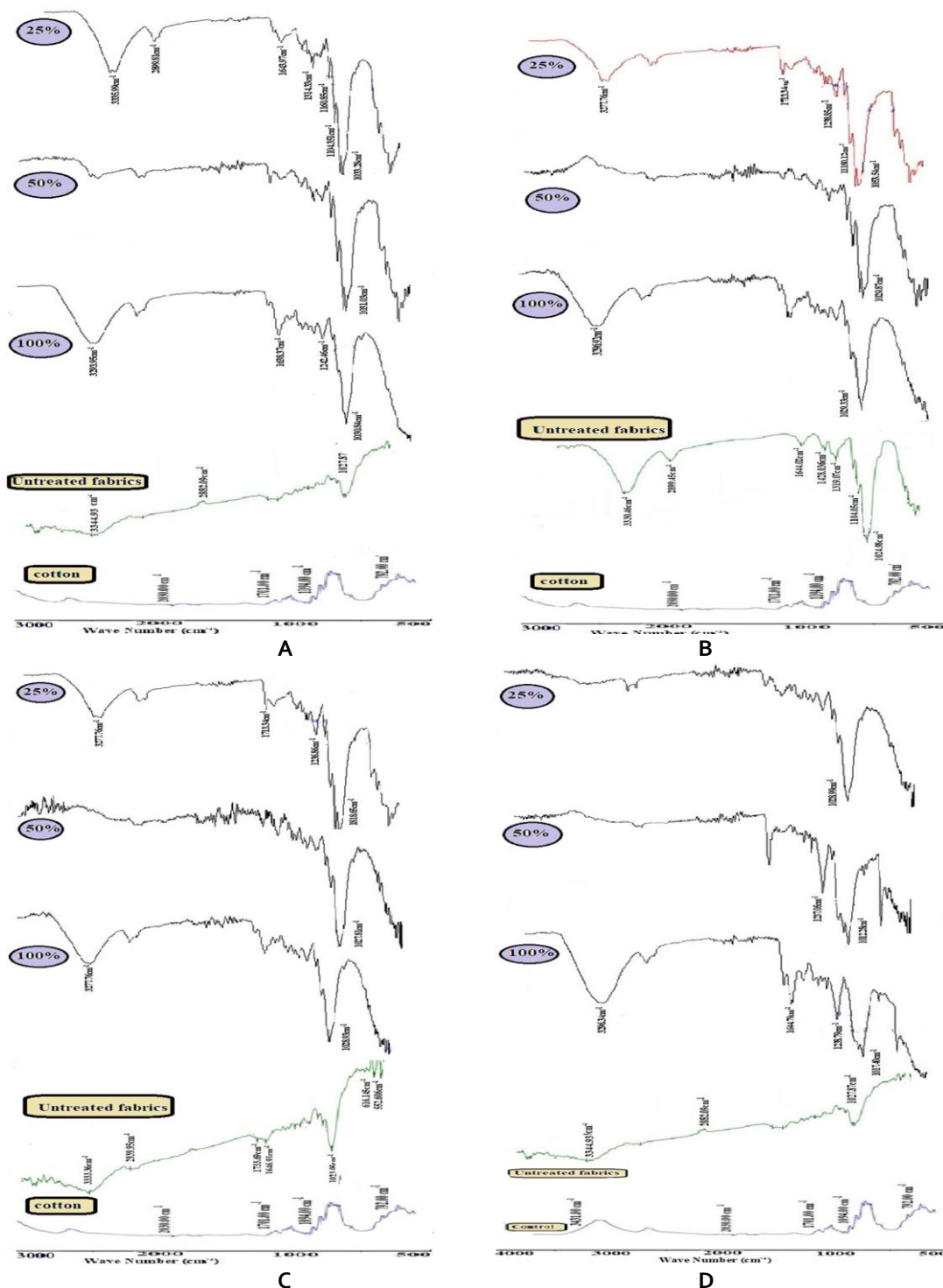
Recent advancements in FTIR spectroscopy and related optics have made it possible for molecules to absorb infrared radiation and change their dipole moment. Quantum mechanics suggests that complex molecule vibration and rotation are involved in this process (Jaggi and Vij, 2006). The binding force constant and atom mass of a molecule define the absorption band in its FTIR spectra. Locating vibration bands connected to certain bonds or functional groups, aids in the identification of unknown substances. The wave numbers ( $\text{cm}^{-1}$ ) associated with absorption band locations are proportional to the absorbed energy. Functional groups absorb between 4000 and 1500  $\text{cm}^{-1}$ , but double and triple bonds have greater wave numbers. Since previous research indicated that FTIR could be used to ascertain the lignin content of wood and jute fibers, FTIR data was utilized to qualitatively evaluate the lignin content of the different treated jute textiles (Sirikwanpong et al., 2010; Bandyopadhyay et al., 1999).

The far-IR (less than 400  $\text{cm}^{-1}$ ), mid-IR (400–4000  $\text{cm}^{-1}$ ), and near-IR (4,000–13,000  $\text{cm}^{-1}$ ) spectrums make up the infrared spectra. Although the mid-IR spectrum is the one used in sample analysis the most, the far- and near-IR spectra are equally valuable in providing information about the samples being studied. The four sections that comprise the mid-IR spectrum are the single bond area (2,500–4,000  $\text{cm}^{-1}$ ), the triple bond region (2,000–2,500  $\text{cm}^{-1}$ ), the double bond region (1,500–2,000  $\text{cm}^{-1}$ ), and the fingerprint region (600–1,500  $\text{cm}^{-1}$ ) (Nandiyanto et al., 2019). The current study examined the impact of biopolishing jute-cotton union textiles using free cellulose enzyme. Using ATR-FTIR spectroscopy, the hydrolysis of cellulose results in a decrease in O-H stretching. This study focused on the analysis of FTIR in the mid-IR spectrum of the enzymatically bio-polished jute-cotton union fabrics.

## Materials and methods

### Materials and Apparatus

The jute-cotton union fabric used in the present research was hessian cloth and was supplied by Latif Bawani Jute Mills Ltd (Dhaka, Bangladesh). Commercial liquid cellulose enzyme with an activity of 60IU/ml was purchased from United Alacrity, Chennai. The activity of cellulose enzyme was measured using UV spectrophotometer at 540 nm by DNS method (Gonzaacut et al., 2024). Jute-Cotton union fabrics with EPI/PPI and count of each was given in Table 1.



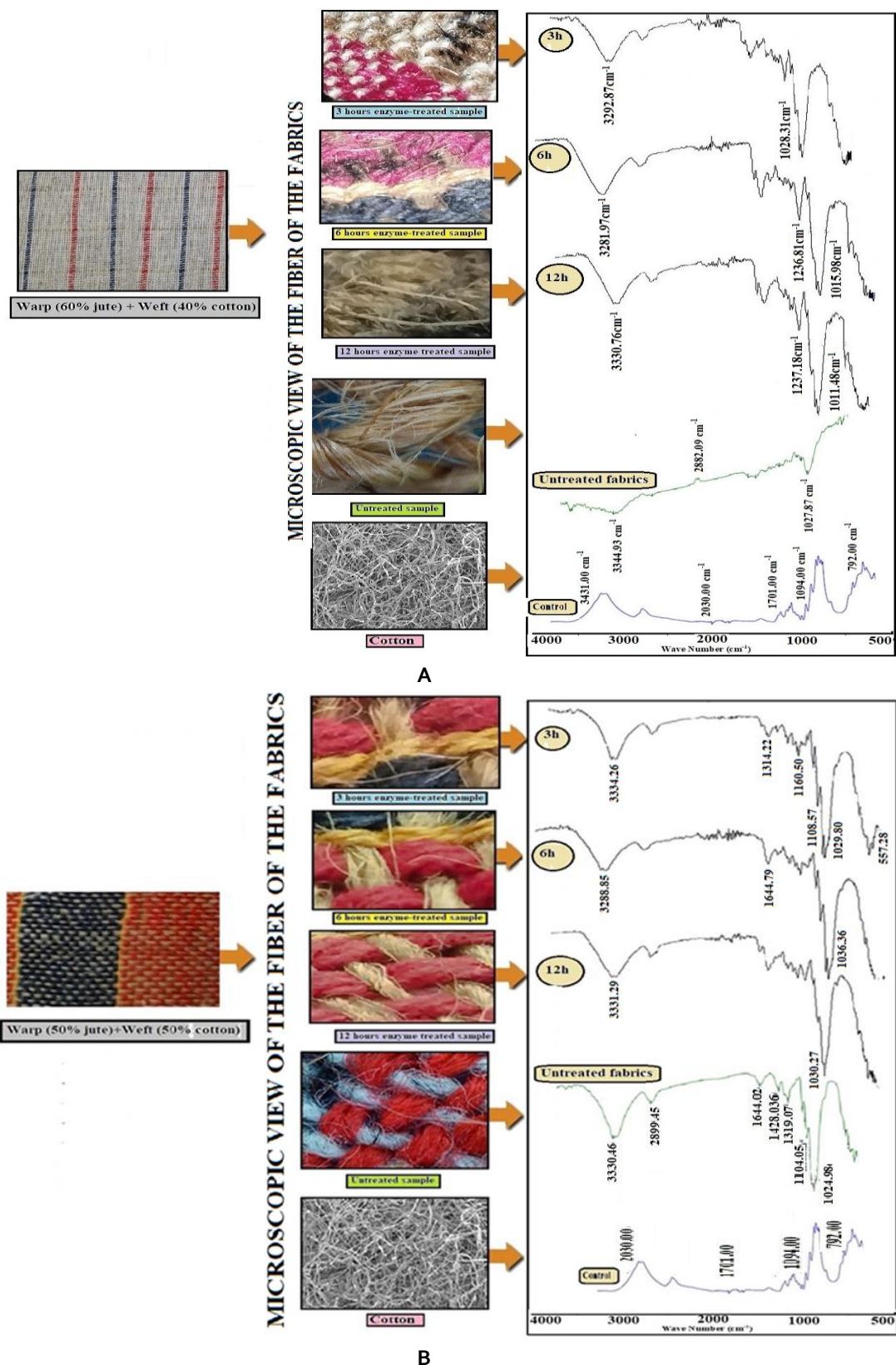
**Figure 2.** Spectra of jute-cotton union fabric of control and enzymatically treated with different concentrations of samples. (A) 60% jute+40% cotton; (B) 50% jute+50% cotton; (C) 70% jute+30% cotton; (D) 40% jute+60% cotton.

**Table 1. Specification of different Jute-Cotton union fabrics samples**

Sample	Type	EPI/ PPI	Count
Sample-1	Warp (60% jute); Weft (40% cotton)	30/21	Warp 12 lbs/spy; Weft 8 Ne
Sample-2	Warp (50% jute); Weft (50% cotton)	11/13	Warp 3 lbs/ spy; Weft 8 Ne
Sample-3	Warp (70% jute); Weft (30% cotton)	11/10	Warp 9 lbs/ spy; Weft 12 Ne
Sample-4	Warp (40% jute); Weft (60% cotton)	12/8	Warp 10 lbs/ spy; Weft 18 Ne

### Experimental design

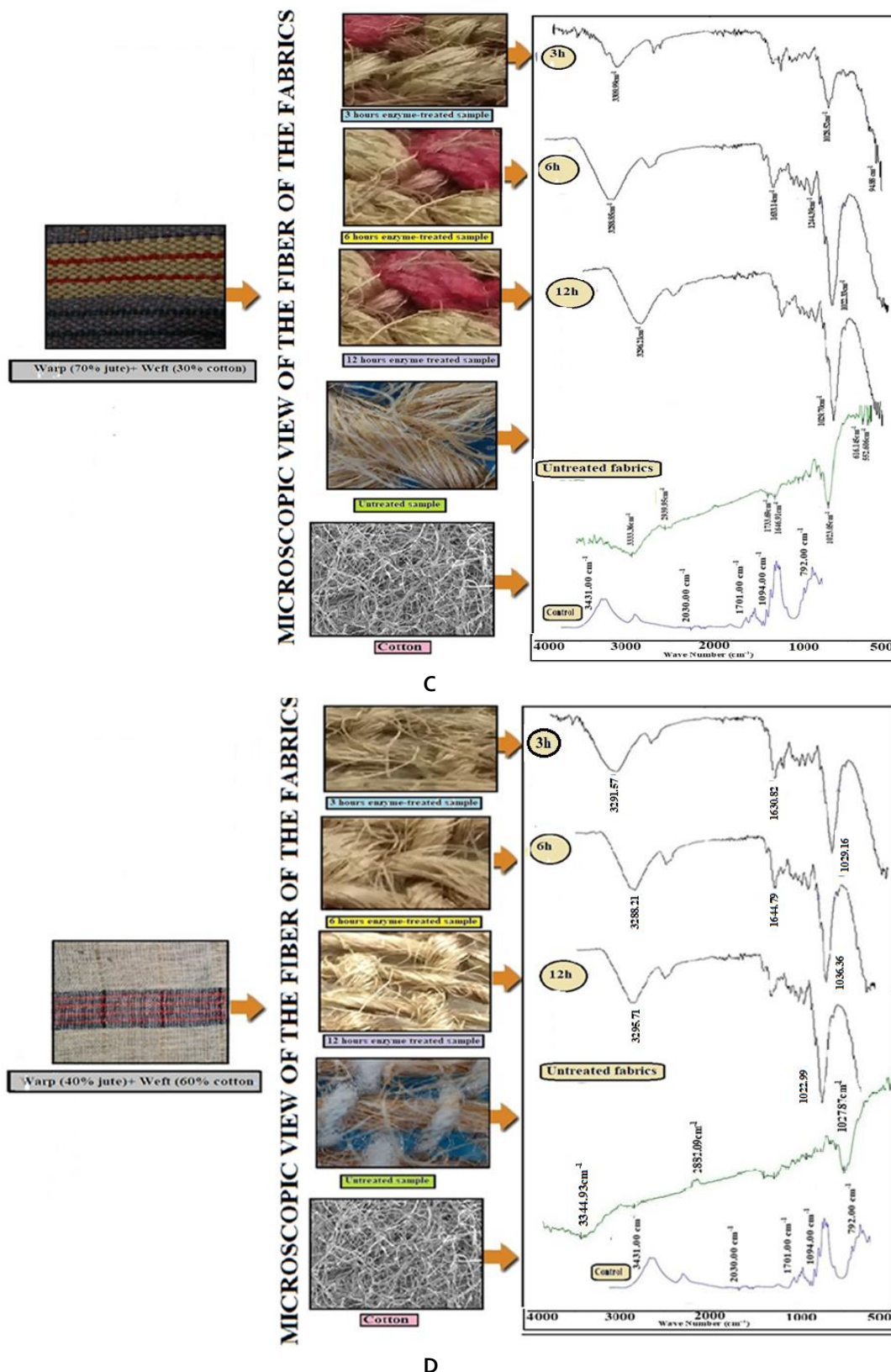
Design of experiments (DOE) is an effective tool for maximizing the amount of information gained from a study while minimizing the amount of data collected. During the bio-polishing process, select two different factors and three levels for each factor. The independent variables used were treatment time (3, 6 and 12) hours and enzyme concentration (100%, 50%, and 25%) (Beltran and Wang, 2006).



**Figure 3.** FTIR analysis of jute-cotton union fabrics at different time interval. (A) Sample 1 (60 jute + 40 cotton); (B) Sample 2 (50 jute + 50 cotton)

#### Bio-polishing of jute-cotton union fabric using cellulose

Enzymatic treatment of jute-cotton union fabrics was carried out using free cellulose enzyme. For bio-polishing, three concentrations (100%, 50% and 25%) of cellulose enzyme on-weight of fabric (owf) and time intervals (3, 6 and 12 h) were used. After the treatment, the jute-cotton union fabrics were thoroughly rinsed with deionized water to remove abraded or digested fibers, followed by heat deactivation of the remaining cellulase enzyme on fabrics for 10 min at 80°C dried for further characterization. Each experiment was replicated three times.



**Figure 3.** FTIR analysis of jute-cotton union fabrics at different time interval. C) Sample 3 (70 jute + 30 cotton); D) Sample 4 (40 jute + 60 cotton)

#### **FTIR analysis**

FTIR measurement techniques were used in the laboratory of Department of Fabric Engineering, Bangladesh University of Textiles, Dhaka, Bangladesh for the analysis of enzymatic treated various types of jute-cotton union fabrics. FTIR spectrum for the samples was obtained by Shimadzu FTIR (Model Prestige 21, Shimadzu Corporation, Japan) with an attenuated total reflectance (ATR) attachment at a resolution of  $4\text{ cm}^{-1}$  for 32 scans in the range from the region  $650\text{ to }4,000\text{ cm}^{-1}$  absorbance. The FTIR measurements were examined and evaluated by the functional group of the jute-cotton union fabrics.

## Results and discussion

The ATR-FTIR method, which measures infrared spectra in absorbance mode, is helpful for elucidating structural relationships. The structural and functional qualities of cotton fabric are changed by the hydrolytic assault of cellulase on cellulose, which impacts hydrogen bonding (Fig. 1). The change in hydrogen bond by the treatment was measured and analyzed by the Attenuated Total Reflectance Fourier-Transform Infrared Spectroscopy (ATR-FTIR). Following biopolishing, the functional groups and its quantified frequencies in jute cotton union fabrics treated with different enzyme concentrations union fabric of control and enzymatically treated samples at spectrum between 3,600 and 3,000  $\text{cm}^{-1}$  were observed in Fig. 2 and Table 1, with minor variations in absorption bands and peak intensity due to O-H stretching that has been somewhat lessened depending on the enzyme concentration. According to the study, FTIR spectra intensity is decreased by greater enzyme concentrations.

**Table 1.** Functional group and its quantified frequencies in jute cotton union fabrics treated with different enzyme concentrations (Coates et al., 2000)

Sample	Enzyme concentration	Wave number ( $\text{cm}^{-1}$ )	Appearance	Functional Group	Compound Class	
Cotton fabrics		3431.00	strong, broad	O-H stretching	alcohol	
		2030.00	medium	C=C stretching	allene	
		1701.00	strong	C=O stretching	conjugated aldehyde	
		1094.00	strong	C-O stretching	secondary alcohol	
		792.00	medium	C=C bending	alkene	
Sample 1: Warp (60% jute) + Weft (40% cotton)	100%	3293.95	medium	N-H stretching	secondary amine	
		1638.37	medium	C=N stretching	imine / oxime	
		1242.46	strong	C-O stretching	aromatic ester	
		1030.84	strong	S=O stretching	sulfoxide	
	50%	1031.03	-	-	-	-
		25%	3335.99	medium	N-H stretching	secondary amine
			2899.81	C-H stretching	alkane	-
			1643.97	C=N stretching	imine / oxime	-
			1314.33	strong	S=O stretching	sulfone
			1160.85	strong	C-O stretching	tertiary alcohol
			1104.35	strong	C-O stretching	secondary alcohol
			1033.28	strong	S=O stretching	sulfoxide
3344.93	medium		N-H stretching	aliphatic primary amine		
Untreated Sample 1		2882.09	medium	C-H stretching	aldehyde	
		1027.87	-	-	-	
		3296.92	strong, sharp	C-H stretching	alkyne	
Sample 2: Warp (50% jute) + Weft (50% cotton)	100%	1029.33	strong	S=O stretching	sulfoxide	
		1029.87	-	-	-	
	25%	3277.76	strong, sharp	C-H stretching	alkyne	
		1713.34	strong	C=O stretching	aldehyde	
		1238.85	medium	C-N stretching	amine	
		3330.46	3330.46	strong, sharp	C-H stretching	C-H stretching
Untreated Sample 2		2899.45	2899.45	medium	C-H stretching	
		1644.02	1644.02	medium	C=N stretching	
		1428.03	1428.03	medium	O-H bending	
		1319.07	1319.07	medium	O-H bending	
		1104.05	1104.05	strong	C-O stretching	
		1024.98	1024.98	-	-	
		3277.76	strong, sharp	C-H stretching	alkyne	
Sample 3: Warp (70% jute) + Weft (30% cotton)	100%	1028.93	-	-	-	
		1027.81	-	-	-	
	25%	3277.76	strong, sharp	C-H stretching	alkyne	
		1713.34	strong	C=O stretching	aldehyde	
		1236.86	medium	C-N stretching	amine	
		1018.65	-	-	-	
Untreated Sample 3		3333.36	medium	N-H stretching	aliphatic primary amine	
		2939.95	medium	C-H stretching	alkane	
		1733.68	strong	C=O stretching	aldehyde	
		1646.91	medium	C=C stretching	conjugated alkene	
		1023.06	-	-	-	
		616.14	strong	C-Br stretching	halo compound	
		552.60	strong	C-I stretching	halo compound	
		3296.34	strong, broad	O-H stretching	carboxylic acid	
Sample 4: Warp (40% jute) + Weft (60% cotton)	100%	1644.70	medium	C=C stretching	conjugated alkene	
		1238.79	strong	C-O stretching	alkyl aryl ether	
		1017.40	-	-	-	
		1237.05	medium	C-N stretching	amine	
	50%	1012.28	-	-	-	
		1028.99	-	-	-	
		3344.93	medium	N-H stretching	aliphatic primary amine	
		2882.09	medium	C-H stretching	aldehyde	
		1027.87	-	-	-	
Untreated Sample 4		3344.93	medium	N-H stretching	aliphatic primary amine	
		2882.09	medium	C-H stretching	aldehyde	
		1027.87	-	-	-	

Prominent peaks are seen in fingerprint areas between 650 and 1520  $\text{cm}^{-1}$ , which indicate aromatic skeleton in lignin and C-H deformation in polysaccharides (Jose et al., 2001, Bandyopadhyay et al.,

1999). -OH groups, C-O-C vibration in polysaccharide, C-O stretch in polysaccharide, and C-H deformation in cellulose is associated with the peaks at 1,233  $\text{cm}^{-1}$ , 1,158  $\text{cm}^{-1}$ , 1,052  $\text{cm}^{-1}$  and 896  $\text{cm}^{-1}$ .

**Table 2.** Functional group and its quantified frequencies in jute cotton union fabrics treated with enzyme at different time interval (Coates et al., 2000)

Sample	Time interval	Wave number ( $\text{cm}^{-1}$ )	Appearance	Functional Group	Compound Class
Cotton fabrics (Control)		3431.00	O-H stretching	alcohol	intermolecular bonded
		2030.00	C=C stretching	allene	-
		1701.00	C=O stretching	conjugated aldehyde	-
		1094.00	C-O stretching	secondary alcohol	-
		792.00	C=C bending	alkene	trisubstituted
Treated Sample 1: Warp (60% jute) + Weft (40% cotton)	3h	3292.87	strong, broad	O-H stretching	carboxylic acid
		1028.31	strong	C-F stretching	fluoro compound
	6h	3281.97	strong, sharp	C-H stretching	alkyne
		1236.81	strong	C-F stretching	fluoro compound
		1015.98	-	-	-
	12h	3330.76	medium	N-H stretching	aliphatic primary amine
		1237.18	-	-	-
		1011.48	-	-	-
Untreated Sample 1		3344.93	medium	N-H stretching	secondary amine
		2882.09	medium	C-H stretching	alkane
		1027.87	strong	C-O stretching	primary alcohol
		3334.26	medium	N-H stretching	secondary amine
Treated Sample 2: Warp (50% jute) + Weft (50% cotton)	3h	1314.22	strong	C-F stretching	fluoro compound
		1160.50	-	-	-
		1108.57	strong	C-O stretching	aliphatic ether
		1029.80	strong, broad	CO-O-CO stretching	-
		557.28	-	-	-
	6h	3288.85	strong, sharp	C-H stretching	alkyne
		1644.79	strong	C=C stretching	alkene
		1036.36	strong	S=O stretching	sulfoxide
	12h	3331.29	strong, broad	O-H stretching	carboxylic acid
		1030.27	strong	C-F stretching	fluoro compound
	Untreated Sample 2		3330.46	strong, sharp	C-H stretching
2899.45			medium	C-H stretching	alkane
1644.02			medium	C=N stretching	imine / oxime
1428.03			medium	O-H bending	carboxylic acid
1319.07			medium	O-H bending	phenol
1104.05			strong	C-O stretching	secondary alcohol
1024.98			-	-	-
				3309.99	medium
Treated Sample 3: Warp (70% jute) + Weft (30% cotton)	3h	1028.52	strong	C-F stretching	fluoro compound
		94.88	-	-	-
	6h	3288.85	strong, sharp	C-H stretching	alkyne
		1633.14	medium	C=N stretching	imine / oxime
		1244.39	medium	C-N stretching	amine
	12h	1022.33	strong	C-F stretching	fluoro compound
		3296.21	strong, broad	O-H stretching	carboxylic acid
		1029.70	strong	C-F stretching	fluoro compound
Untreated Sample 3		3333.36	medium	N-H stretching	aliphatic primary amine
		2999.95	medium	C-H stretching	alkane
		1733.69	strong	C=O stretching	aldehyde
		1646.91	medium	C=C stretching	conjugated alkene
		1023.06	-	-	-
Treated Sample 4: Warp (40% jute) + Weft (60% cotton)	3h	3291.57	strong, broad	O-H stretching	carboxylic acid
		1630.82	strong	C=C stretching	alkene
		1029.16	strong	S=O stretching	sulfoxide
	6h	3288.21	strong, broad	O-H stretching	carboxylic acid
		1644.79	strong	C=C stretching	alkene
		1036.36	strong	S=O stretching	sulfoxide
	12h	3295.71	strong, broad	O-H stretching	carboxylic acid
		1022.99	strong, broad	CO-O-CO stretching	anhydride
	Untreated Sample 4		3344.93	medium	N-H stretching
2831.09			medium	C-H stretching	aldehyde
1027.87			-	-	-

According to Tucker et al. (2001), the height of peaks in jute fibers that have been scoured and bio-scoured with xylanase exhibit a decrease in fiber lignin concentration. This suggests that cellulose hydrolysis mitigates O-H stretch and enzyme digestion through the weak point area. Similar values were found for treated and untreated jute-cotton union fabric illustrated in Fig 3 and Table 2, where the functional groups and their quantified frequencies in jute cotton union fabrics treated were determined. The treated sample changed the structural and functional characteristics of the fabric; O-H stretching was responsible for the absorption bands in the 500-3000  $\text{cm}^{-1}$  and 3000-2800  $\text{cm}^{-1}$  regions. These variations in the absorption of particular vibrational bands revealed variations in the concentrations of the enzymatic treatment removed some lignin from jute fiber and the developed treatment could be an eco-friendly alternative to the alkaline bio-scouring of jute fabrics. This study shows that the amorphous region was more prone to enzymatic attack than the crystalline regions. The enzymatic treatment increases the accessible surface area of fiber (Sankarraj and Nallathambi, 2017).

Hemicellulose, fatty debris, and leftover jute batching oil are eliminated from fibers and textiles by bio-polishing procedures (Raju, 2014, Guha, 2021). By binding jute fiber cells together, lignin increases the mechanical load-bearing strength. Treatment with cellulase increases the whiteness index, however excessive bleaching removes the brown hue naturally. By detecting the absorption of mid-infrared light, FTIR spectra are utilized to determine the identities of functional groups and molecules. Materials classified as organic, polymeric, or inorganic can be identified using this approach. For researchers, FTIR is an essential analytical method that provides fast, sensitive, and reliable findings when used to describe a wide range of materials, including liquids, solutions, pastes, powders, films, fibers, and gases (D'Souza et al., 2008; Jaggi and Vij, 2006). FTIR analysis is effective for identifying molecular vibrations because it employs infrared light to affect the atomic vibrations of materials, allowing for particular absorption or transmission of energy. Radiation in the mid-infrared (MIR) range is absorbed by chemical bond vibrations, with distinct absorption frequencies assigned to each functional group. Using algorithms, Fourier transform infrared spectra (FTIR) may investigate the molecular functional group structure and biological makeup (Corte et al., 2010). With the ability to quickly acquire spectra from tiny samples, the FTIR approach provides excellent sensitivity for analyzing early response to stimuli and fingerprinting global cellular characteristics under particular conditions (Alvarez-Ordóñez et al., 2010). The N-H absorbance band in cotton fabric often appears between 1,680 and 1,630  $\text{cm}^{-1}$ ; however, the absorbance band of the C=O stretching vibration typically appears between 1,640 and 1,550  $\text{cm}^{-1}$ , depending on the groups it links. The chemical in issue is confirmed by FTIR testing. Group frequencies and molecular fingerprint frequencies are the two categories of absorbance bands. Group frequencies, which are observed above 1,500  $\text{cm}^{-1}$  in the infrared spectrum, are distinctive to particular functional groups. Less trustworthy for identification, molecular fingerprint frequencies are indicative of the molecule as a whole. Higher wavenumbers imply weaker H bonds, which suggests overall protein disordering. The location of amide I bands in proteins reveals the degree of hydrogen bonding (Yang and Yen, 2002). Consequently, the consequences and effects of enzymes on protein structure need more analysis. Fabric testing involves various measurements like fabric weight, width, shrinkage, and color fastness (Sankarraj and Nallathambi, 2017). A confirmatory test that yields a positive identification of a chemical is FTIR testing. The analysis of both organic and inorganic chemicals is one of its common uses in industry. Since FTIR makes it easier to detect functional groups in textile materials, it is very important for identifying components in textiles. Researchers may distinguish between distinct functional groups in molecules by using the % transmittance in FTIR, which correlates to vibrational modes in certain chemical bonds.

## Conclusion

When jute fiber union textiles were studied using FTIR, bio-polishing- a finishing technique that improves the fabric's quality by eliminating oil, wax, and fat- was discovered. The study looks into several approaches to enhance the structural and physical qualities of jute-cotton union fabric by enzyme treatment. According to the study, cotton fabric that has been bio-polished loses weight and absorbency, whereas fabric that has been treated with enzymes maintains its characteristics and improves surface modification. The results of FTIR research provide a quick and effective way to identify changes in molecular structure constitutions caused by enzymes, possibly providing physiological effects of enzymes. Although classic cotton and viscose dressings are still available and popular, the usefulness of new forms of cellulose and its derivatives using environmentally friendly enzymes opens new wound treatment options. Characterization of cellulose samples utilizing XRD, TG/DSC, and SEM will be the main focus of future study.



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#### Author Contributions

ZA conceived the concept, wrote and approved the manuscript.

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#### Competing interest

The author declares no competing interests.

#### Ethics approval

Not applicable.



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