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Enzymatic Effect of Bio-Polishing of Different Types of Jute-Cotton Union Fabrics

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Abstract
The performance of the bio-polishing of jute-cotton union fabrics was evaluated by assessing their weight loss, thermo-stability and microscopic observation using the xylanase enzyme. At 65°C and pH 7, xylanase showed its greatest activity. Jute cotton union textiles lost more weight at 100% applied enzyme dose and less weight at lesser enzyme concentrations over time. In optical microscopic images of the surface of jute cotton union fabrics scoured with enzyme, debris of impurities and particles on the fibre surface were observed with partial removal of gummy substances from the fibre surface. The weight loss was higher in 100% applied enzyme dose which gradually decreased with lower applied enzyme dose. In the thermo-stability test, four different fabrics showed very different thermal conductivity values out of which, sample-2 showed a higher thermal conductivity than the others. The created procedure could be applied in industry as a green bio-scouring method.

Keywords: Jute-cotton union fabrics; Xylanase, Bio-polishing; Weight loss; Thermal conductivity

Introduction
Jute is natural fibers which are cheap, renewable and abundantly available in Bangladesh. Jute fibres are mainly used in the manufacturing of sacking and coarse cloths, carpets, and carpet backings. A small portion of jute fibres is used in apparel-making fabrics, usually blended with cotton fibres that provide cotton fabrics with high moisture absorbency as jute is one of the highest hygroscopic natural fibres (Ardon et al., 1996). They can be degraded by micro-organisms after their disposal. Natural fibres have distinct advantages during processing. Besides these advantages, natural fibre composites have some drawbacks which limit their wide-scale usage; such as they are not uniform like man-made fibres, and their properties can change batch-to-batch regarding their origin, growing and harvesting conditions. There are also compatibility problems between hydrophilic fibres and hydrophobic resin, which results in a poor fibre-matrix interface. Researchers attempted to solve the aforementioned problems of natural fibre composites to widen their usage. Most of them have tried to solve the interface problems through fibre modification by chemical or physical methods. These methods include NaOH treatment, graft copolymerization, acetylation, corona treatment etc. Enzymatic treatment of fibres is an alternative environment-friendly method that can be implemented instead of chemical methods which are in many cases harmful to the environment and worker's health (Heikinheimo, 2002).

Enzymatic treatment of fibers to improve the fibre-matrix interface of natural fibre composites has been the subject of a relatively small number of works and needs to be investigated in detail. A finishing process to improve fabric quality and reduce fuzziness and pilling properties of cellulosic fibre is called bio-polishing. In this pretreatment process oil, wax, and fat are removed from fabric (Raju, 2014). So fabric weight will be reduced slightly (in case of good souring 4%-8%) and the absorbency of fabric will be higher for removing oil, wax, fat etc. Absorbency tests are determined by Drop test, Spot test, Immersion test and column test.

This process involves the action of cellulose enzyme to discard micro fibrils of cotton which in turn obtain a cooler, cleaner, lustrous, soft fabric. Bio polishing involves the use of enzymes to shear off the micro fibres of cotton and other cellulose materials to produce fabrics with superior softness, drape and resistance to pilling.

The ability of the fabric to transfer the heat from the higher temperature to the lower temperature surface by conduction is termed the thermal conductivity of the fabric. The thermal conductivity of a fabric is the ratio of the heat energy transferred per second per unit surface area of the fabric to the temperature difference. Thermal conductivity is among the important thermal properties of a fabric, which is also related to the breathability of the fabric. Thermal conductivity is defined as the ability of a material to conduct heat from one side to the other. It is represented by the thermal conductivity coefficient λ. Smaller λ indicates that the material has stronger heat insulation and preservation. A material's thermal conductivity is the number of Watts conducted per meter thickness of the material, per degree of temperature difference between one side and the other (W/mK). As a rule of thumb, the lower the thermal conductivity the better, because the material conducts less heat energy (Baxter, 2002). A fabric with a high thermal conductivity permits the transfer of heat from a hot side, such as the human body to a cooler side such as the air on the other side of clothing (Abitha et al., 2015). Traditional textiles typically have a low thermal conductivity, such as 0.07 W (mK) for cotton and 0.087 W (mK) for silk. Textile materials like cotton fabric have very low electrical conductivity with a typical surface resistivity of 10^7–10^{16} Ω/m², which can be considered as low conductive materials. Textiles with higher thermal conductivity include leather (0.1 to 0.15 W/mK) and linen (0.188 W/mK) (Frydrych et al., 2002).

The weight of a fabric depends on the thickness of the threads it's made of, the density of the weave or knit, as well as its composition. The dyeing or printing process can also affect the weight. The thicker or bulkier the fabric, the heavier it will tend to be. Fabric weight influences other fabric properties such as thickness, flexural rigidity, bending rigidity, drape, air permeability and thermal properties (Islam and Ahmed, 2016). Lightweight fabrics have the advantage of being versatile, comfortable and feeling cool and fresh. They can be layered as and when required and can be made into any clothing item be it a dress, blouse, skirt or even pants (Heikinheimo, 2002).

In our Institute, diversified jute products as decorative, table clothes, wall covers, curtains, apparel, different types of jute bags etc. are produced but these need to be bio-polish by enzymatic means to increase their appearance, value as well and acceptability of competitive market. From this point of view, the project has been taken and attempts were made to improve the fibre-matrix interface of jute fibre-products by enzymatic treatments. The present purpose of the study is to develop a method of Bio-polishing by enzymatic means for jute-cotton union fabrics and optimize the different parameters (pH, temperatures, etc.) of enzymes used in bio-polishing for jute-cotton union fabrics.

Materials and methods

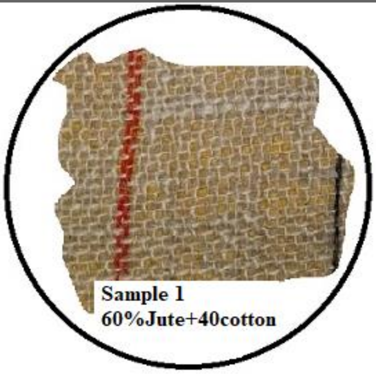
Materials

The jute-cotton union fabrics used in the present study were collected from the weaving department of Bangladesh Jute Research Institute, with different specifications (Table 1). The enzyme used in this investigation was xylanase from Dyadic International Inc. (USA).

Xylanase assay

Xylanase activity was quantified using the 3,5-dinitro salicylic acid (DNS) assay for reducing sugars according to the method by Dhaver et al. (2022). The reaction included 600μl of 1% (w/v) of beechwood xylan (1g in 100ml of 50mM citrate buffer pH5.0) in 15ml test tubes to which 66.67μl of the culture supernatant was added. The reaction mixture was incubated in a water bath at 55°C for 15 minutes and terminated by the addition of 1ml DNS reagent followed by heating for 5min at 100°C in a water bath. One unit (U) of xylanase was defined as the amount of enzyme that released 1µmol xylose as reducing sugar equivalents per minute under the specified assay conditions.

Table 1. Different types of Jute-cotton union fabrics and their specifications

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

Determination of optimum pH and temperature

The pH optimum was determined by measuring enzyme activity between pH 4.0-10.0. The following buffers were used: 0.1M sodium citrate buffer (pH 3.0–5.0), 0.1M potassium phosphate buffer (pH 6.0–8.0) and 0.1M Glycine NaOH buffer (pH 9.0–10.0). Enzyme assays were conducted as previously described ("Xylanase assay"). For determination of the optimum temperature, the reactions were carried out at the optimum pH between 40 to 80 °C with intervals of 5°C. The pH stability of the enzyme was determined by incubating the enzyme in the optimal pH buffer for 4h at 55°C with aliquots removed every 30 minutes. A substrate control was also incubated for 4h. Thereafter, xylanase activity was assayed using the DNS method and reported as residual activity (%). Temperature stability was determined by incubating the enzyme in the optimal pH buffer at optimal temperature for 4h with aliquots collected every 30 minutes. The activity was assayed and reported as residual activity (%) (Dhaver et al., 2022).

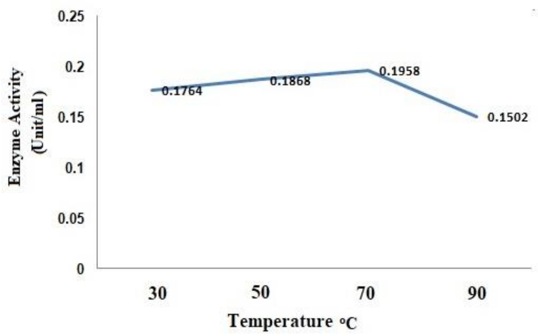


Fig. 1a. Determination of optimum temperature of xylanase enzyme

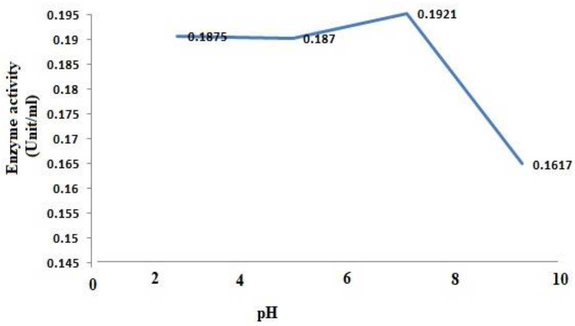


Fig. 1b. Determination of optimum pH of xylanase enzyme

Enzymatic bio-polishing of jute fabrics

All treatments were carried out using tap water and a 1:20 materials-to-liquor ratio at optimum pH and temperature. The bath was set at the optimum pH of 7.0 and the required amount of water was taken in the pot, jute-cotton union fabric samples were then introduced into the pot. The temperature of the bath was then raised to an optimum 65°C at 2°C/min and held for 1 day. After completion of the scouring treatment, the bath was cooled to 45°C at 2 °C/min and the liquor was drained. The samples were washed twice with hot and cold water.

Evaluation of fabric properties

The weight loss, whiteness index and wettability of jute-cotton union fabrics after bio-scouring were assessed. The assessment of weight loss of jute fabric during bio-scouring was carried out by the gravimetric method. The oven-dried (at 105°C) jute fabric sample was weighed before and after the bio-scouring process. The weight loss was calculated according to the following equation:

$$Weight\ loss = \frac{W_1 - W_2}{W_1} \times 100 \qquad (1)$$

where W_1 and W_2 are the oven-dry weight of jute fabric before and after the treatment respectively Raju (2014). The improvement in hydrophilicity of the jute fabrics by enzymatic treatments was assessed by the contact angle measurement. The contact angle was measured by using a Contact Angle Measurement Apparatus (Model 190, USA). For each sample, the contact angle was measured at six places and the average contact angle was reported. For each sample, the first measurement was taken immediately after placing the drop of water and then at 15s intervals measurements were taken until 45s. To assess the bio-scouring performance, the wettability of the fabric was also measured using the drop test before and after the bio-scouring process according to the AATCC Test Method 39-1998: Evaluation of wettability at room temperature (AATCC, 1980). In this method, a water droplet is placed on the fabric and the time taken between the contact of a water droplet with the fabric and the complete disappearance of the water droplet into the fabric was counted as the wetting time. The average values of five readings were reported.

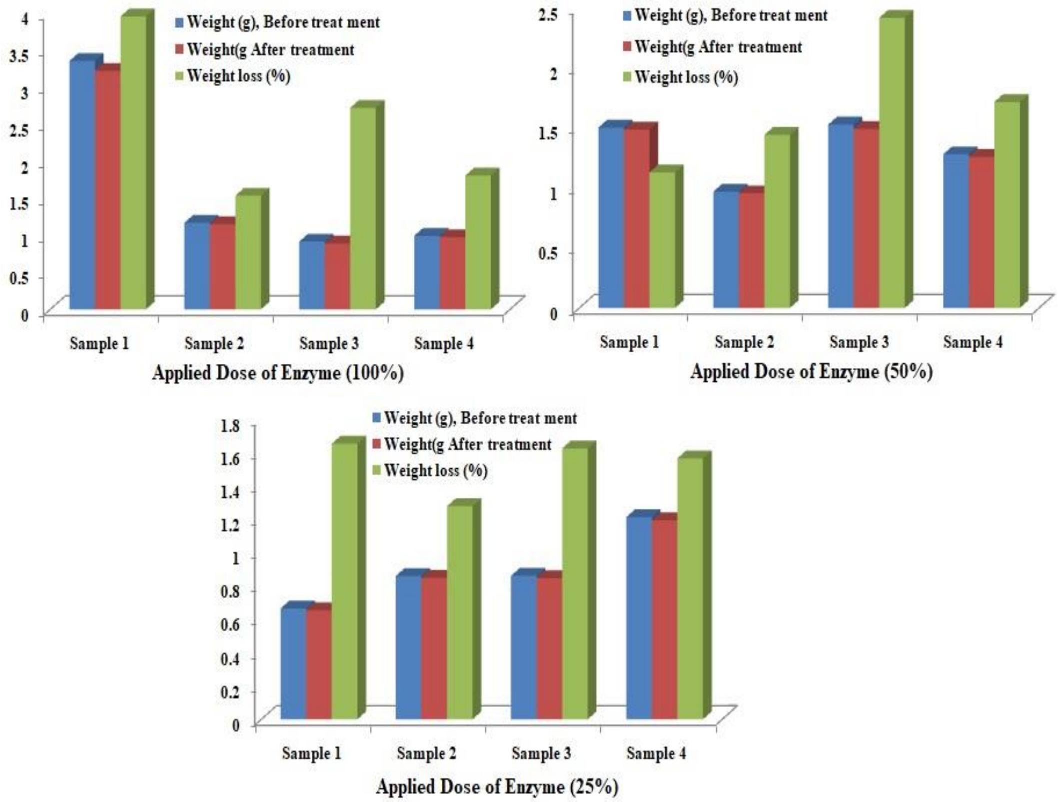


Fig. 2. Weight loss (%) of jute fabrics during bio-polishing

Results and discussion

Optimum pH and temperature

The experiment was carried out at different reaction temperatures ranging from 40 to 79°C to find the optimal temperature of the xylanase. The highest activity of xylanase was observed at 65°C and pH 7 (Fig. 1). Thermal stability data illustrated in Figure 1 shows that the enzyme retained >70% activity at 65°C for 24h. A similar result was reported by Mojsov (2016). However, in that study, the enzyme was subjected to treatment for 24h and was stable for 1 h. The advantages of enzymes that prefer high temperatures are well known because the solubility of the reagents and products is increased, the viscosity is reduced, and the mass transfer rate is higher (Dhaver et al., 2002). When looking for enzymes for industrial uses, stability and activity at high temperatures are highly desirable.

Effect on weight loss of fabric using enzyme

The effect of various enzymatic treatments on the weight loss of jute was shown in Figure 2 where it was observed that the weight loss was higher in 100% applied enzyme dose which gradually decreases with lower applied enzyme dose.

The weight loss occurred not only by the removal of hemicellulose, proteins and fatty matter available in jute fibres but also by the partial removal of lignin (Singh et al., 2016). The standard range of weight loss is 4-8%; so 100 % enzyme dose is moderate scouring (Raju, 2014). The strength loss of jute fabrics increased with an increase in the applied dose of the enzymes. The weight loss was further increased during bleaching but the trend was similar to the weight loss that occurred in the bio-scouring process. It is evident that there is a correlation between the whiteness index and the weight loss data for the various enzymatic treatments (Singh et al., 2016; Raju, 2014). Weight loss of cotton knitted fabric is directly related to the relevant process loss during wet processing. It is an important factor for production. For higher production, it is necessary to control the fabric from excessive weight loss in knit processing. This can be achieved by following all the parameters of production accurately and by minimizing process losses. If the standard parameters are followed accurately and necessary precautions are taken for knit batch processing, fabric weight loss can be optimized (Islam and Ahmed, 2016; Uddin, 2010).

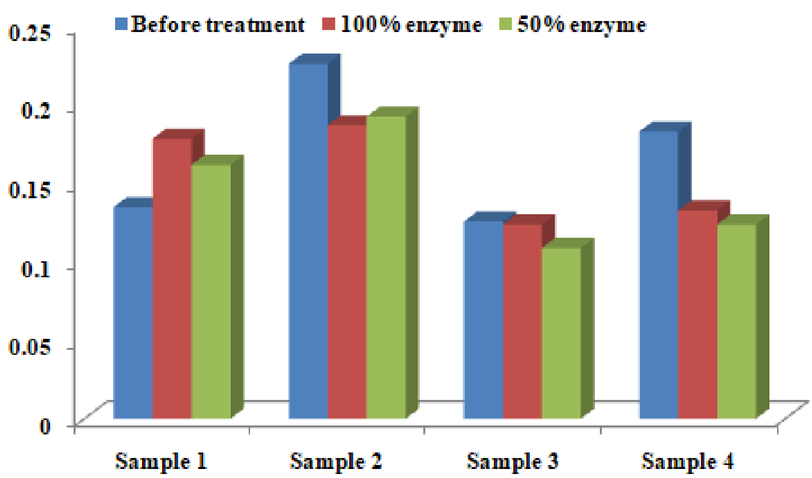


Fig. 3. Thermal conductivity of different samples

Thermal conductivity

The results revealed that these four different fabrics have very different thermal conductivity values (Fig. 3) whereas Sample 2 shows a higher thermal conductivity than the others. Cotton fibre has the ability to conduct heat energy, minimizing any destructive heat accumulation. Hence cotton fibres can withstand hot ironing temperatures. However excessive heating on cotton fibre chars and burns them indicates that cotton fibre is not thermoplastic. Cotton is a great thermal insulator- as long as it's dry. Once wet, cotton becomes a poor insulator and does a poor job of preventing hypothermia -hence the old adage, "Cotton kills". The majority of summer clothing is made of cotton fibres for their soft, comfortable and highly moisture-absorptive features. However, cotton has a lower thermal conductivity than many synthetic fibres and other natural fibres, which confines its effective heat transfer. Usually, silk fabrics have the lowest thermal conductivity, while linen fabrics have the highest thermal conductivity, therefore, on a hot summer day, a linen shirt will be much more comfortable than a silk shirt. However, silk would do the best job of keeping our warm on a cool day (Abitha et al., 2015)

Thermal conductivity is one of the important thermal properties of a fabric. This can be thought of as how well a fabric breathes, i.e. a fabric that has a high thermal conductivity, can easily let heat pass from a hot side to a cooler side (Baxter, 2002; Frydrych et al., 2002). The thermal conductivity of materials is temperature-dependent. Materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation. Thermal conductivity is incredibly important to clothing manufacturers because the comfort that it imports and the characteristics that it lends to the clothing item will determine whether that piece of clothing will be comfortable for us to wear. Clothing made out of materials with low thermal conductivities are excellent choice for cold weather, since they do not readily transport our body heat to the environment and therefore help to keep us warm (Frydrych et al., 2002). Fabrics with higher thermal conductivities feel much cooler, while those with low thermal conductivities feel much warmer (Baxter, 2002).

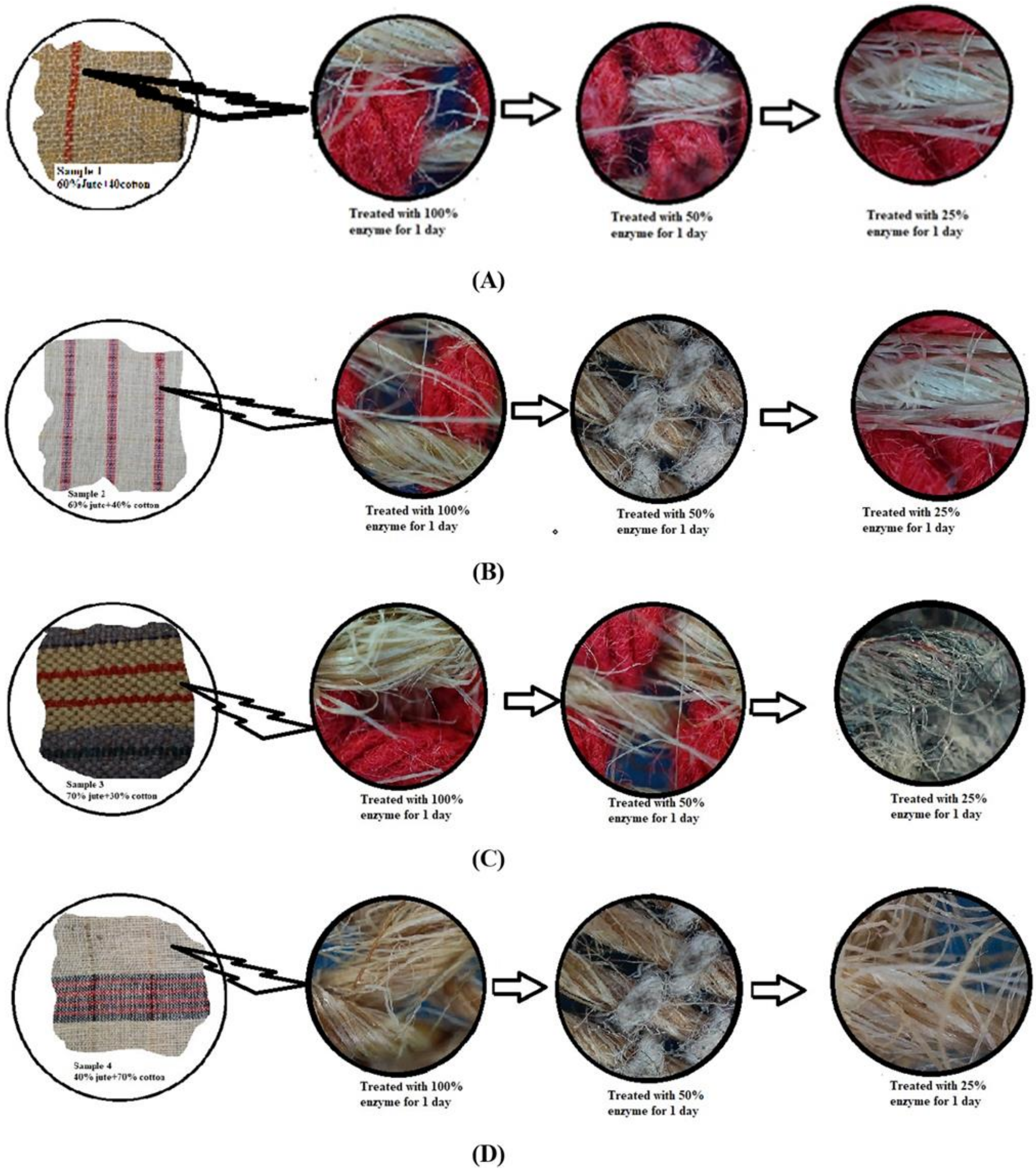


Fig. 4. Optical microscopic images of jute fabrics scoured with various enzymes at different concentrations of enzyme- (A) Sample-1, (B) Sample-2, (C) Sample-3, (D) Sample-4.

Most conventional textile fibres such as cotton typically have a lower thermal conductivity, which traps more of a person's body heat inside their clothing. Due to the additional air concentration that is present in cotton fabrics, they have a low thermal effusively. Although cotton is a good insulator, it has poor elasticity and quickly absorbs moisture making its thermal properties only efficient in stable conditions (Fatemeh and Nazanin, 2019; Frydrych et al., 2002). Thermal fabrics can be used not only for wine bags, bottle bags, lunch box bags, champagne cooler bags, reusable bags, bags for life, tea cozies, kettle warmers, oven mitts and picnic bags. A knit fabric is constructed to trap warm air between the yarns, often in a waffle or honeycomb texture which can be used in receiving blankets, bedding, and clothing for adults and children. Thermal fabric is great for all kinds of bag projects where you need to keep the bag contents hot or cold (Abitha et al., 2015).

Scanning microscopy

The optical microscopic images of the surface of fabrics scoured with enzyme are shown in figure-4 where debris of impurities and particulates on the fibre surface are visible with partial removal of gummy substances from the fibre surface. The surface of fibres scoured with enzymes is relatively clean. It is evident that the treatment caused the formation of grooves on the fibre surface because of the partial removal of lignin. The removal of fat, hemicellulose and the degradation of cellulase at the fibre surface by the action of enzyme dislodged some of the cross-linked lignin and therefore increased the hydrophilicity of the fibre surface as the time taken for complete wetting of the fibre surface was considerably decreased. The contact angle measurement results showed that the surface of fabric treated by the enzymatic treatment exhibited super-hydrophilicity. On the other hand, xylanase did not cause any fibre breakage and the surface of the fibres was comparatively clean without any fragments.

The complex bio-polishing treatments used to treat fibres and fabrics are primarily to remove residual jute batching oil, hemicellulose, and also fatty matter. Lignin binds jute fibre cells together and provides mechanical load-bearing strength. Therefore, complete removal of lignin will disintegrate the fibres to cells and only a small percentage of lignin is removed to improve the exhaustion of dyes into the fibre and to provide uniform dyeability but a high level of bleaching is used to destroy their natural brown colour. Scouring means the removal of non-cellulosic material present on the surface of the cotton. The process of use of enzymes is energy-saving and does not require any special equipment for heat resistance, pressure or corrosion. Their efficiency, high biodegradability and the mild conditions of working mark their use in a wide range of industrial applications. Enzymes work only on renewable raw materials. Fruit, cereals, milk, fats, cotton, leather and wood are some typical candidates for enzymatic conversion in the industry (Mojsov, 2016). Out of the 7000 enzymes known, only about 75 are used in the textile industry (Quandt and Kuhl, 2001). Enzymes used for bio-scouring, destroy the cotton cuticle structure by digesting the pectin and removing the connection between the cuticle and the body of cotton fibre whereas cellulase destroys the cuticle structure by digesting the primary wall cellulose immediately under the cuticle of cotton. Enzymatic scouring results in a very soft handle compared to a harsh feel in alkaline scouring process. It also minimizes health risks hence operators are not exposed to aggressive chemicals (Dhaver et al., 2002).

Scouring is necessary for the loom state jute fabrics in order to make them suitable for dyeing and finishing by improving their wettability by removing non-cellulosic matters from the fibre. The scouring process is also necessary to remove the non-cellulosic matters and batching oils from jute fibre. Biopolishing is a finishing process in textile that enhances fabric quality by decreasing the pilling tendency and fuzziness of (cellulose) knitted fabrics. This finishing process is applied to cellulose textiles that produce permanent effects by the use of enzymes. This process removes protruding fibers and slubs from knitted fabrics, significantly reduces pilling, softens fabric hand and provides a smooth fabric appearance. The success of the subsequent chemical processes such as bleaching, dyeing or printing, and finishing very much depends on the efficiency of the scouring process. The traditional scouring process causes a high loss of tensile strength of the fibre. Moreover, it produces highly alkaline effluent that needs to be neutralised before discharging to watercourses. A large volume of water and acetic acid is used to neutralise the alkali-scoured fabric. To comply with the increasingly stringent environmental regulations and also to save energy, water, and chemicals, it is necessary to look for an eco-friendly scouring process (Agarwal et al., 1998; Choe et al., 2004; Agrawal et al., 2008; Calafell, 2004).
In previous studies of jute and its fabrics, Alam et al. (2022) tried to ascertain the effect of process variables on chemical treatment of jute fiber, Rashid et al. (2023) fabricated a composites by incorporating jute sliver in unsaturated polyester (UPE) resin; Hossain et al. (2023) studied the strength behavior of handmade paper by sizing material rosin where it was noticed that use of rosin along with wax always lowered the strength. Ahmed (2022) explain that the jute fiber can be used to make sturdy hessain or burlap, gumy cloths and many other useful value added materials substituting hazardous plastics which are eco-friendly having natural UV protection, completely biodegradable and recyclable fiber. Whereas, Morshed et al. (2022) studied the application and fastness analysis of natural dyes on cotton knitted fabric with references to measure color fastness to four criteria; like color fastness to wash, color fastness to perspiration, color fastness to light and color fastness to rubbing. The use of enzymes not only provides us with an eco-friendly environment but also saves a lot of money by reducing water and energy consumption thus reducing the cost of production.

Enzyme-producing companies are also coming up with more new technologies and products in this area. The major limitation in the use of enzyme processing is the high cost of enzymes. This technology can still become a widely and extensively used technology if its cost can be managed. In textile processing, the enzyme can be successfully used for preparatory and finishing processes like de-sizing, scouring and bleaching and is appropriate to create a cleaner and greener environment and product. Enzyme-treated fabrics were more fibrillated. The yarn twist opened after enzymatic treatments. Enzyme-treated fabrics were hairier due to the removal of adhesive substances like hemicelluloses, lignin, pectin and oils. This increased the surface area and resulted in a stronger fibre-matrix interface due to good adhesion between fibre and matrix. The composite samples with enzyme-treated fibres showed greater tensile modulus than those of the samples with untreated jute fibres. Enzyme treatment removed the disordered and amorphous lignin macromolecules increasing the fibre-matrix contact surface and creating more sites for resin impregnation. Therefore, fibre-matrix interface quality was improved resulting in increased mechanical properties. Enzymes removed impurities, pectin, hemicelluloses and lignin from the fibre creating a rougher fibre surface which facilitates resin bonding onto fibres. As a result, the fibre-matrix interface was improved. Furthermore, with the removal of amorphous and disordered polymers like hemicelluloses and pectin, the mechanical properties of the composites improved. Therefore, if these different products can be bio-polished at a low cost and standardized manner, then these can earn foreign currency and overcome the issue of plastic bag usage which is hazardous for the environment. Moreover, if these jute-cotton union fabrics are antimicrobial, then this will encourage foreign buyers too. The expectation from the present work may indicate that enzyme treatment can be used as a cheap, effective and environment-friendly fibre modification method for natural jute-cotton union fabrics.

Conclusion

Bio-polishing enzymes have great influences on cotton knit goods such as improvement in pill resistance, cooler fill, brightness and softness. In our research work, the major aim was to increase the utilization of jute fiber in the commercial apparel sector by modifying its properties. In present research, evaluation of the effectiveness of the enzyme on bio-polishing was studied by treating the jute-cotton union fabrics with the enzyme where it was found that the appearance and handle of the jute-cotton union fabric have been significantly improved by treatment with a commercial enzyme xylanase. The treatment leads to the removal of surface hairs from the fabric and induces improvement in soft feeling. These fabrics can be used extensively in the manufacturing of different types of traditional packing fabrics like Hessian, carpet backing, mats, bags, tarpaulins, ropes, etc. As jute possesses aromatic ring group and cotton does not, the effect of sizing on the properties of union fabric needs to be analyzed. Moreover, in order to determine the physio-mechanical properties of these union fabrics, tensile strength, shrinkage, absorbency and Fourier Transform Infra-Red (FTIR) tests need to be investigated.

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Author Contributions

ZA and KS conceived the concept, wrote and approved the manuscript.

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Availability of data and materials
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Competing interest
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Ethics approval
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