BIOTREATMENT JUTA FIBER USING AN ENZYMATIC COMPLEX TO IMPROVE QUALITY AND APPLICABILITY IN THE TEXTILE INDUSTRY

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ABSTRACT

Extracted from the plant *Corchorus capsularis,* jute fiber is readily available at a low cost due to its ease of cultivation. It consists of a bundle of long chains of cellulose molecules with lignin and hemicellulose, which act as binding agents and make it a rather coarse fiber, limiting its application in textile products. Chemical products are used for refining jute as a form of treatment; however, these cause damage to the cellulosic material and impose serious environmental harm by releasing toxic pollutants. In an attempt to find an alternative treatment for jute fiber, the enzymes laccase and the enzymatic complex Powercell® were used. The results obtained, through capillarity testing and scanning electron microscopy (SEM) image analysis, confirmed the effectiveness of biotechnology in removing pectin, lignin, and other impurities. This parameter influences the application of future treatments, such as dyeing and functionalization, enhancing its aesthetic appearance and application value in the textile industry.

Keywords: Jute fiber. Biotechnology. Enzymes. Biopreparation. Textile Industry.

1 INTRODUCTION

Jute fiber, extracted from the plant *Corchorus capsularis*, exhibits excellent technical properties such as high tensile strength and abrasion resistance, moisture recovery, good acoustic and thermal insulation properties, and dimensional stability[1]. Currently, it is processed to produce low-cost products such as bags and ropes[2]. A single jute fiber consists of a bundle of long chains of cellulose molecules with lignin and hemicellulose, which act as binding agents to provide toughness and flexibility to the fiber. These characteristics make it a coarse fiber, limiting its application in higher-end textile products.

Jute needs to be refined to improve its appearance and reliability, thereby increasing the added value of the final product. Traditionally, chemical agents such as bleaching agents and sodium hypochlorite are used, which damage the cellulosic material and cause significant environmental harm by releasing toxic pollutants[3].

The growing awareness and concern for the environment have driven research aimed at applying enzymes at different stages of textile processing. Enzymatic processes remove pectin, lignin, and hemicellulose from jute fiber, increasing its hydrophilicity without degrading the cellulosic components and with minimal environmental impact[4]. The use of enzymes such as cellulase, xylanase, and pectinase has proven advantageous in the biotreatment of vegetable fibers and can be used to alter the properties of textile fibers[5].

This article aims to evaluate the use of laccase enzymes and a lignocellulolytic enzymatic complex in the pre-treatment of jute fiber, with the objective of reducing lignin content and improving its appearance and other properties for application in the textile industry.

2 MATERIAL & METHODS

The enzymatic treatment was carried out on single twisted yarn, 100% raw jute, donated by Castanhal Companhia Têxtil. Samples were separated into 2 g hanks and immersed in the buffer solution, which contained laccase and an enzymatic complex composed of xylanase, cellulase, and pectinase (Powercell® - provided by Prozyn BioSolutions) and fatty alcohol ethoxylate surfactant (Berol 175 - Macler), with and without the mediator ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt) – Sigma Aldrich). The process lasted 5 hours in the orbital shaker (New Lab NL-343-01), and in treatment D, an ultrasound bath was added. For comparative purposes, a conventional alkaline scouring was performed in an HT IR Dyer TC 2200 dyeing machine. The treatments carried out are described in Table 1.

Table 1 Treatments carried out on jute fibers.

Tratamento	Processo
A. Chemical	NaOH 1M + Berol 1,5 g/L (100 °C; for 2 horas)
B. Enzymatic	Powercell M 3g/L + Lacase 3g/L + Berol 1g/L (pH 5; 55°C; for 5h)
C. Enzymatic with ABTS	Powercell M 3g/L + Lacase 3g/L + ABTS 0,6 mM + Berol 1g/L (pH 5; 55°C; for 5h
D. Enzymatica with ABTS and ultrasound	Powercell M 3g/L + Lacase 3g/L + ABTS 0,6 mM + Berol 1g/L (pH 5; 55°C; for 5h) + ultrasound (55°C; for 15 min)

The treated jute fibers were analyzed for capillarity and through scanning electron microscopy (SEM).

Capillarity is an indicator for assessing vertical absorbency in textile articles. The method was adapted from A. B. Nyoni[6], where the lower part of the yarn sample (approximately 20 cm in length) was immersed (≤ 4 cm) vertically in a container with a solution of distilled water and direct blue dye. The height of absorption in the samples was measured after 15, 30, 45, and 60 minutes. The greater the height, the better the capillarity or vertical absorption of the yarn. The data were statistically analyzed using analysis of variance (ANOVA) with a significance level of 5%.

Based on the results of the capillarity test, SEM analysis was conducted on the raw substrate samples and those that showed the best results. The analyses were performed using a JEOL JSM-6390LV scanning electron microscope (SEM), with an acceleration voltage of 8 kV and magnifications of up to 1000 times.

3 RESULTS & DISCUSSION

The primary factor for evaluating the efficiency of cleaning vegetable fibers is the gain in hydrophilicity. This parameter influences the application of future treatments, such as dyeing and functionalization[7]. Among the enzymes used, pectinase provides the greatest increase in capillarity because it destabilizes the first layer of the fiber formed by pectin. Pectin acts as an adhesive material in the primary wall, and its removal facilitates the access of other enzymes, allowing them to perform their action[8]. Furthermore, the removal of pectin enables the action of the other enzymes in the complex and laccase, as these compounds are present in deeper layers of the fiber.

At different times of the enzymatic treatments, it was found that the total treatment time (60 minutes) was necessary to achieve maximum capillarity, representing maximum absorption, as described in Figure 1.

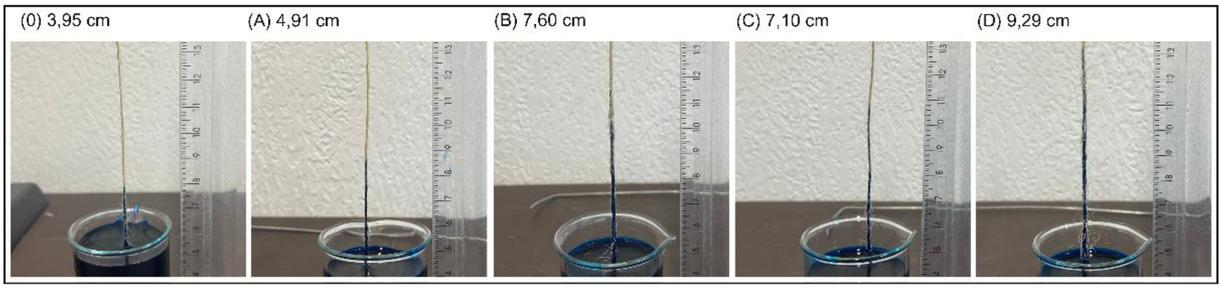

Figure 1 Maximum absorption values for (0) raw jute; (A) chemical treatment; (B) enzymatic treatment; (C) enzymatic treatment with mediator; (D) enzymatic treatment with mediator and ultrasound after 60 minutes of testing.

The chemically treated jute yarn (A) showed lower absorption compared to the other treatments, but there was an approximately 24% gain compared to raw jute. Treatments B and C had similar results, highlighting the action of pectinase. The percentage gain for these treatments was 92.4% and 79.7%, respectively, compared to the raw yarn (0). Finally, capillarity in treatment D improved significantly compared to the others (percentage increase of 135%, 89%, 22%, and 30% compared to treatments 0, A, B, and C, respectively). Variance analysis (ANOVA) was performed considering the factors of time and treatment. Comparison of means by ANOVA with 5% significance ($p<0.05$) revealed significant statistical differences between both times and treatments.

The chemical treatment (A) of jute, occurring under alkaline conditions due to the use of sodium hydroxide ($NaOH$), is commonly associated with measurable loss of hemicellulose and some marginal loss of lignin fractions, which makes the fiber finer, wavy, and considerably less rigid[1]. However, the lack of pectin degradation meant that the substrate did not show a considerable increase in absorption. In the enzymatic treatments (B, C, and D), the pectinase presents in Powercell® disrupted the pectin structure, performing its primary action of removing the outer cuticle. The removal of this adhesive material also resulted in defibrillation of the yarn, which further aids in increasing capillarity. Knowing that jute is a fiber composed of multicellular bundles, the observed defibrillation is related to the decomposition of the middle lamella and, consequently, the dissociation of the fibrillar bundles.

In the case of treatment C, the use of a mediator in the analysis did not show a gain, as the function of the mediator is to amplify the oxidation potential of the substrate, producing high laccase efficiency[8] without interfering with the action of pectinase. However, in the ultrasound-assisted treatment (D), better cleaning efficiency and consequently greater capillarity gain were achieved. Ultrasound results in acoustic cavitation in liquid media, forming bubbles that collapse in less than a microsecond and release a lot of heat. This process, called ultrasonic irradiation, increases the removal of materials/impurities from the fiber surface[9] and provides access to the bath solution to the interstices by increasing the energy/vibration of the system, resulting in greater enzyme access to the fiber and better migration of compounds present in the fiber to the liquid medium.

Raw jute yarn has a rough and irregular surface, covered with various lamellar impurities, and without noticeable separation between the fibers, as observed in Figure 2a. Bulbous lignins are also notably present on the surface of jute. After treatment

(Figure 2b), it can be seen that due to the action of pectinase, waxes, ashes, and other impurities intertwined and adhered to each other were eliminated. Laccase acted synergistically with other enzymes by polymerizing and redistributing the lignin on the substrate surface, as also observed by Dong et al[10]. This revealed a cleaner, smoother, shinier main body of jute with a high degree of fiber separation

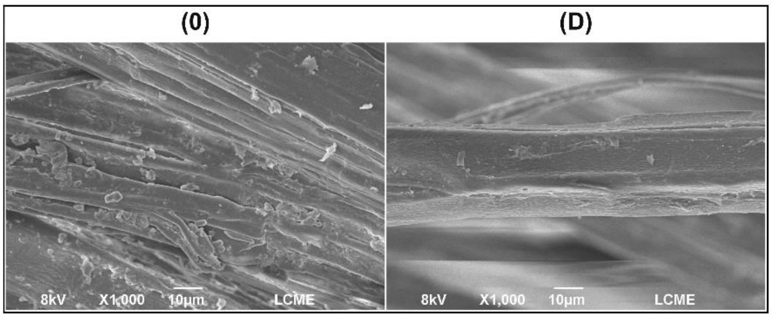

Figura 2 – SEM Images of the Surface of (0) Raw Jute Yarn and (D) Yarn Treated with enzymes, mediator, and ultrasound.

4 CONCLUSION

In this study, the enzymatic treatment of jute yarn with laccase and the enzymatic complex Powercell® was evaluated in comparison to chemical treatment, aiming to find an interesting alternative from both a technical and environmental perspective. Using capillarity and SEM analyses, the action of the enzymes in removing pectin and lignin was confirmed, especially when a mediator and ultrasound were added to the process. The enzymatically treated yarn, with the aid of the mediator and ultrasound, resulted in a cleaner yarn with a high degree of fiber separation due to the removal of waxes that provide adhesion between the yarn filaments, as well as resulting in a greater gain in hydrophilicity. By advancing the understanding of the potential of biotechnology in the enzymatic treatment of jute fiber, this study contributes to the development of more sustainable and efficient production processes in the textile industry. The results obtained may have significant implications for the creation of high-quality textile products with lower environmental impact and greater market acceptance.

REFERENCES

[1] SAMANTA, Ashis Kumar; MUKHOPADHYAY, Asis; GHOSH, Swapan Kumar. Processing of jute fibres and its applications. In: **Handbook of natural fibres**. Woodhead Publishing, 2020. p. 49-120.

[2] LIFANG, Liu et al. Mechanical modification of degummed jute fibre for high value textile end uses. **Industrial crops and products**, v. 31, n. 1, p. 43-47, 2010.

[3] MOUSUMI, Nath et al. Value addition to jute: assessing the effect of artificial reduction of lignin on jute diversification. **Heliyon**, v. 7, n. 3, 2021.

[4] Pan NC, Chattopadhyay SN, Roy AK, Patra K, Khan A. Bios-couring of jute fabric: a step towards bioprocessing.MelliandInt. 2009;15(3):100-101.

[5] Patil H, Mudaliar S, Athalye A. Ultrasound-assisted enzymatic scouring of jute optimised by response surface methodology and its natural dyeing. Coloration Technology. 2023; 139(1): 97-108.

[6] A. B. Nyoni; BROOK, D. Wicking mechanisms in yarns—the key to fabric wicking performance. **Journal of the textile institute**, v. 97, n. 2, p. 119-128, 2006.

[7] KALANTZI, S.; KEKOS, D.; MAMMA, D. Bioscouring of cotton fabrics by multienzyme combinations: application of Box–Behnken design and desirability function. Cellulose, v. 26, n. 4, p. 2771–2790, 2019.

[8] MARROQUES, Julia Cruz. Aplicações de enzimas na indústria têxtil. 2020. 47 f. Trabalho de Conclusão de Curso (Graduação em Engenharia Química) – Universidade Federal de Uberlândia, Uberlândia, 2020.

[9] PATIL, Harshal; MUDALIAR, Sahil; ASHOK, Athalye. Ultrasound-assisted enzymatic scouring of jute optimised by response surface methodology and its natural dyeing. **Coloration Technology**, v. 139, n. 1, p. 97-108, 2023.

[10] DONG, Aixue et al. Changes on content, structure and surface distribution of lignin in jute fibers after laccase treatment. **Journal of natural fibers**, v. 15, n. 3, p. 384-395, 2018.

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