ENZYMATIC TREATMENT FOR SUSTAINABLE COTTON TEXTILE PROCESSING: A GREEN APROACH

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ABSTRACT

The textile industry, despite its economic relevance, is responsible for significant environmental challenges, including the generation of pollutants and the intensive use of natural resources. On the other hand, biotechnology emerges as a promising alternative, enabling the development of sustainable and less polluting processes both in the treatment of effluents and in the production of fibers. This study proposes a new process flow aligned with the use of enzymes, aiming to meet quality standards equivalent to conventional methods while achieving resource savings. The results obtained in this study are promising, indicating that a pool of enzymes can be used in fiber preparation processes. The integration of processes and the use of milder temperature and pH conditions result in lower consumption of water, energy, and inputs.

Keywords: Enzymes. Bioscouring. Biobleaching. Dyeing. Sustainability.

1 INTRODUCTION

The textile industry, despite its economic importance, faces significant environmental challenges, including the generation of pollutants and the high consumption of water and energy, especially in fiber processing. Traditional methods result in the significant generation of toxic effluents, highlighting the urgent need for more sustainable practices.[1,2] In this context, enzymes emerge as an alternative, offering support and innovation to the textile industry while fully complying with environmental regulations.[3] Enzymatic processes offer milder operating conditions, with moderate temperatures, pH close to neutrality, and lower water and energy consumption due to reduced need for rinsing and cooling.[4,5] Specifically, pectinases and cellulases, which are studied in the scouring process of cellulosic fibers, act in removing impurities from the outer layers, providing hydrophilicity and absorption to the cotton, thus allowing the fibers to proceed to subsequent wet processes.[6]

The bioscouring using pectinases, either alone or in combination with other enzymes, has been applied, resulting in minimal damage to the cellulosic structure.[7] The combination of pectinase and cellulase has shown significant gains in hydrophilicity during cotton bioscouring.[8] In the bleaching process of cotton, the use of enzymes such as peroxidases and glucose oxidases as replacements for H_2O_2 in traditional methods has shown relevant whiteness indices.[9]

Therefore, this study proposes a new sequence of processes—bioscouring, biobleaching, and dyeing—aligned with the "green line" concept, using a single integrated solution. The objective was to achieve quality standards comparable to conventional methods while investigating the feasibility of reusing the bioscouring solution and integrating it with other process steps, aiming for savings in water, energy, and materials.

2 MATERIAL & METHODS

Three processes were evaluated in this study, as presented in Figure 1: (a) simultaneous bioscouring and biobleaching in a single bath; (b) conventional bleaching for comparison purposes; and (c) bioscouring, biobleaching, and dyeing in a single bath. 100% raw knits were treated by exhaustion at a ratio of 1:20. The effects of pH on bioscouring (7.0, 7.5, and 8.5), surfactant concentration (0-1 g/L), and cellulase enzyme concentration (0-5 g/L) (provided by Akmey company) were evaluated. The pectinase concentration (provided by Akmey company) was maintained at 1.0 g/L, according to Colombi.[6] Biobleaching was performed with glucose oxidase (Sigma-Aldrich). All experiments and analyses were performed in triplicate.

For conventional bleaching, 2.0 g/L NaOH (50%), 3.0 g/L H_2O_2 (50%), and 1.0 g/L Berol (donated by Macler) were used. Knits were treated by exhaustion at a ratio of 1:20 at 80°C for 30 minutes, followed by an additional 60 minutes at 90°C. After washing and neutralization, samples were dried in an oven at 45°C. Dyeing was performed using Red 195 dye (donated by Color Química).

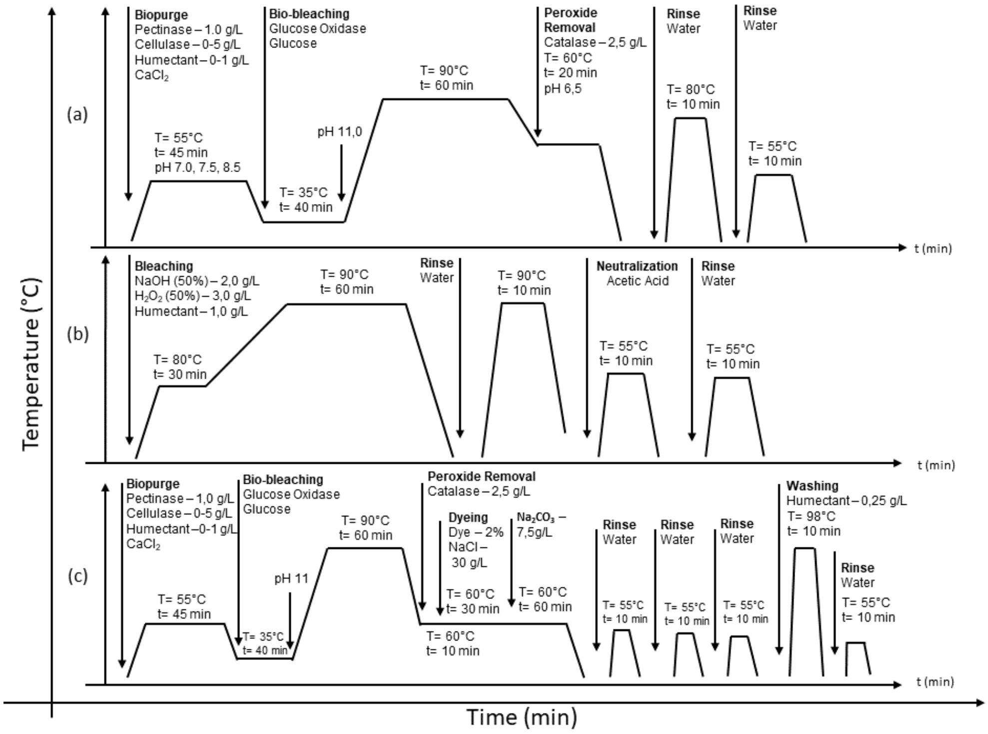

Figure 1 Processes used: (a) simultaneous bioscouring and biobleaching, (b) conventional bleaching, (c) simultaneous bioscouring, biobleaching, and dyeing.

The physicochemical characteristics of the samples were evaluated through tests for hydrophilicity, capillarity, pectin removal content, and degree of whiteness, according to Defalco. To quantify the whiteness index, measured in Berger degrees, in the pre-treated samples, and the color intensity of the dyed fabrics determined by K/S, a benchtop spectrophotometer, model Datacolor 500® Series, was employed. The determination of the degree of whiteness was based on a relationship between the coordinates of the CIELab system. For the determination of color intensity (K/S), the method followed by Defalco was used.[10]

3 RESULTS & DISCUSSION

The enzymatic pool (cellulase and pectinase) showed its best catalytic activity at pH 7.5. The mass loss in the pH 7.5 tests was about 5% higher than in the tests with pH 7.0 and 8.5, indicating greater efficiency in removing the cuticle and ensuring better dyeing. Hydrophilicity tests showed no significant differences between treatments. However, in capillarity tests, the best result was 58.3±1.5 mm at pH 7.5.

The combination of pectinase and cellulase at pH 7.5 showed a lower percentage of residual pectin (48±1.20%), indicating an enzymatic synergistic effect and favoring the removal of non-cellulosic impurities from the fiber. According to Freitas[11], the action of pectinase opens spaces in the primary layer of the fiber for cellulase entry, while cellulase creates more available positions for pectinase, generating a more effective bioscouring and facilitating the removal of non-cellulosic impurities.[12]

The initial whiteness degree of raw knit was 8.02±0.01°Berger, and treated samples showed gains of 263-295% in Berger degree. The highest degree was obtained using 1.0 g/L pectinase and 2.0 g/L cellulase at pH 8.5 (optimal enzyme pH), resulting in a whiteness degree only 5.5% lower at pH 7.5 in subsequent tests. Different surfactant concentrations did not significantly influence capillarity tests; 0.5 g/L Berol was sufficient to favor wettability, providing enzyme accessibility to the hydrophobic surface of cotton fiber and removing oils and greases. Results ranged from 37.0±2.2 to 45.0±1.8 mm. Mass loss was influenced by the concentration of surfactant and cellulase, which may explain the increased impurity removal. Finally, hydrophilicity below 1 s, a whiteness degree of 30°Berger, and 52% pectin removal were obtained.

Comparison between biobleaching and traditional bleaching methods revealed that conventional treatment achieved superior whitening, with a whiteness index of 80.48±0.49°Berger, while biobleaching recorded an index of 54.00±0.10°Berger. These results reflect the more stringent conditions of conventional bleaching. Hydrogen peroxide acts on removing natural pigments present in cotton fibers, and its concentration affects the resulting whiteness. The use of enzymatic treatment depends on the end use of the fabrics and the intensity of coloration.[13,14]

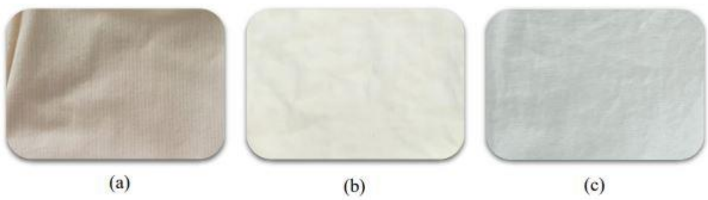

Figure 2 Comparisons between (a) raw knit, (b) knits after biobleaching, and (c) knits after traditional bleaching.

The bioscouring and biobleaching procedure in the same solution proved satisfactory for preparing cotton knit fabrics. The addition of glucose oxidase to form hydrogen peroxide and catalase to remove the remainder was adequate, proving to be environmentally friendly, with less fiber damage and a 50% reduction in water, input, and effluent consumption compared to the conventional process (Figure 2). In dyeing, an increase in residual dye was observed due to the compounds removed from cotton. Discarding the solution before dyeing improved dye efficiency, with K/S values of 3.00±0.02 in the single solution and 5.28±0.02 after discarding. Although K/S values in the single solution were lower than the traditional method (K/S 8.10±0.02), only 60% of the total solution was consumed, resulting in significant water savings, as only six solutions were needed (Figure 1c).

4 CONCLUSION

The results of this study highlight the importance of adjusting pH to maximize the efficiency of pectinase and cellulase enzymes, with pH 7.5 being ideal for their catalytic activity. The combined use of these enzymes significantly reduced residual pectin, improving the removal of impurities from cotton fibers. The bioscouring and biobleaching process proved to be environmentally sustainable, resulting in satisfactory whiteness levels and reducing water and input consumption. Discarding the biobleaching solution before dyeing intensified the color of the samples, indicating additional potential of the method for processing cotton fibers with lower environmental impact. Dyeing resulted in vibrant colors, especially in dark tones such as black and navy blue.

REFERENCES

1. MELO, C. G. et al. 2022. Toxicidade do efluente têxtil com corante reactive blue 21 submetido à irradiação por feixe de elétrons / Toxicity of reactive blue 21 dye textile effluent subjected to electron beam irradiation. Brazilian Journal of Development, v. 8, n. 4, p. 31191–31199.
2. ANDREAUS, J.; COLOMBI, B.L.; GONÇALVES, J.A.; SANTOS, K. A. Processing of Cotton and Man-made Cellulosic Fibers. In: Advances in Textile Biotechnology (Second Edition). [s.l: s.n.]. p. 185–238.
3. ALY, A.S; MOUSTAFA, A.B; A HEBEISH, 2004. Bio-technological treatment of cellulosic textiles. Journal Of Cleaner Production, [S.L.], v. 12, n. 7, p. 697-705.
4. HASANBEIGI, A.; PRICE, L. 2015. A technical review of emerging technologies for energy and water ef fi ciency and pollution reduction in the textile industry. Journal of Cleaner Production, v. 95, p. 30–44.
5. UDHAYAMARTHANDAN, S.; SRINIVASAN, J. 2019. Integrated enzymatic and chemical treatment for single-stage preparation of cotton fabrics. Textile Research Journal, v. 89, n. 19–20, p. 3937–3948.
6. COLOMBI, B. L.; PALOZI, M. D.; VALLE, R. C. S. C.; ANDREAUS, J.; ARIAS, M. J. L.; VALLE, J. A. B. 2022. A sustainable approach for cotton bioscouring: reuse of the pectate lyase containing treatment bath. Bioprocess And Biosystems Engineering, [S.L.], v. 45, n. 8, p. 1391-1405. Springer Science and Business Media LLC.
7. CHOE, E. K.; NAM, C. W.; KOOK, S. R.; CHUNG, C.; CAVACO-PAULO, A. 2004. Implementation of batchwise bioscouring of cotton knits. Biocatalysis And Biotransformation, [S.L.], v. 22, n. 5-6, p. 375-382. Informa UK Limited.
8. SILVA, L. G. DE M. DA; OLIVEIRA, D. DE; SOUZA, A. A. U. DE; SOUZA, S. M. G. U. de. 2017. Study and application of an enzymatic pool in bioscouring of cotton knit fabric. The Canadian Journal Of Chemical Engineering, [S.L.], v. 95, n. 7, p. 1253-1260.
9. OPWIS, K.; KNITTEL, D.; SCHOLLMEYER, E.; HOFERICHTER, P.; CORDES, A. 2008. Simultaneous Application of Glucose Oxidases and Peroxidases in Bleaching Processes. Engineering In Life Sciences, [S.L.], v. 8, n. 2, p. 175-178.
10. DEFALCO, S. DE L. 2023. Substituição dos Processos Tradicionais de Purga, Alvejamento e Tingimento por Processos Enzimáticos na Indústria Têxtil. 2023. 124 f. Dissertação (Mestrado) - Curso de Engenharia Têxtil, Universidade Federal de Santa Catarina, Blumenau.
11. FREITAS, K. R. DE. Estabilização enzimática para aplicação em biopurga de tecidos de malhas de algodão. [s.l: s.n.].
12. RAJA, A. S. M. et al. Single bath enzymatic scouring and bleaching process for preparation of absorbent cottonIndian Journal of Fibre & Textile Research. [s.l: s.n.].
13. TZANOV, T. et al. Hydrogen peroxide generation with immobilized glucose oxidase for textile bleaching. Journal of Biotechnology, v. 93, n. 1, p. 87–94, 2002.
14. SILVA, L. G. DE M. Biopurga de Malha de Algodão Utilizando Processo Enzimático com Associação de Enzimas. [s.l: s.n.].

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