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Enzymes at Work: Eco-Friendly Solutions for Modern Textile Finishing

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ABSTRACT

The application of enzymes in textile and leather processing has revolutionized these industries by providing eco-friendly alternatives to conventional chemical methods. Enzymes are biocatalysts that offer sustainable solutions, reducing water and energy consumption, minimizing environmental pollutants, and enhancing product quality. In the textile industry, enzymes such as amylase, cellulase, pectinase, and laccase are widely used in desizing, scouring, bleaching, bio-polishing, and denim finishing. These processes improve fabric smoothness, dye penetration, and overall aesthetics while reducing chemical use. Similarly, in leather manufacturing, enzymes like protease, lipase, and pectinase play a critical role in soaking, unhairing, bating, and degreasing, enhancing leather softness, strength, and dye uniformity. Despite their potential, enzymatic methods in the textile and leather industries have developed at a slower pace compared to their use in food and pharmaceuticals. However, increasing environmental awareness and demand for sustainable practices have driven advancements in enzyme-based processes, positioning them as vital tools for eco-friendly manufacturing.

Keywords: Enzymes, Textile processing, Eco-friendly solutions, Sustainability

INTRODUCTION

The textile industry plays a crucial role in meeting one of humanity's fundamental needs by transforming fibers into yarn, which is then woven into fabrics and other related products. This process also involves dyeing and finishing these materials through various techniques (Madhav *et al.,* 2018). Despite significant advancements in textile processing, the industry has emerged as a major contributor to environmental pollution. It is estimated that the textile sector is responsible for approximately 20% of global water pollution, releasing hazardous substances such as toxic chemicals, heavy metals, dyes, and detergents used in conventional textile manufacturing methods (Scott, 2015). As biotechnology, often described by experts as the application of living organisms to create cleaner, more cost-effective, and sustainable manufacturing processes, is set to revolutionize the textile industry in the coming years. It is making remarkable strides into innovative and sometimes surprising areas within the textile sector. This advancement holds the promise of lowering production costs, safeguarding the environment, enhancing health and safety standards, and boosting both the quality and functionality of textile products (Aly *et al.,*2004; Liisa-Auterinen, 2006 and Aly *et al.,* 2010). Consequently, it is essential to find eco-friendly and sustainable alternatives to replace these toxic chemicals. Enzymes hold significant promise for detoxifying the entire supply chain by substituting harmful substances commonly used in the textile and apparel industry, particularly during wet processing. As biocatalysts, enzymes are indispensable to life and represent a valuable gift from nature that supports sustainability (Jajpura, 2018).

Enzymes play a significant role in the bio-processing of textiles. While enzymes have existed since the 19th

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century, their application in textile processing became prominent only in the last two decades. They improve functionality by reducing the energy and effort required in textile production, replacing traditional chemical methods that harm the environment. Enzymatic processes are non-toxic, reduce water consumption, and minimize pollution, aligning with sustainable manufacturing goals. Common enzymes used in textile processing include cellulase, amylase, pectinase, catalase, and laccase, which play crucial roles in transforming knitted fabrics into functional materials during the finishing process (Sarkar, 2020).

The application of enzymatic textile processing has roots in the mid-19th century (Aly *et al.*, 2004). Enzymes were first used for de-sizing wet textiles in 1857, but their adoption was limited due to lower efficiency compared to acid-based methods. Progress came in the early 1900s with the introduction of malt extract, which further established enzymatic wet processing. By 1912, enzymatic de-sizing was successfully implemented in numerous textile factories (Cavaco-Paulo and Gubitz, 2003; Aly *et al.,* 2004;Chatha*et al.,* 2017). For nearly 70 years, amylases dominated as the primary enzyme in wet textile processing globally. The late 1980s marked a turning point with the successful introduction of cellulases for de-pilling and de-fuzzing cellulose-based fabrics. By the early 1990s, catalases were used in bleaching, and pectin-degrading enzymes began replacing traditional alkaline scouring methods, reflecting the growing shift toward enzymatic solutions in textile processing (Cavaco-Paulo and Gubitz, 2003; Chatha *et al.,* 2017).

Enzymes in Various Textile Processes:

Enzymes are large molecular weight proteins that accelerate chemical reactions without undergoing any permanent change themselves. Often referred to as biocatalysts or biological catalysts, they are synthesized by all living cells, including those of plants, animals, and microorganisms. Enzymes exhibit a high degree of specificity in their actions. Their activity is affected by various factors, including pH, temperature, reaction time, enzyme concentration, and the presence of activators or inhibitors (Kalaiarasi, 2012). These natural proteins that specifically interact with and modify textile fibers like cotton, silk, and wool. By targeting certain substances within the fibers, they induce favorable alterations, improving the fibers' characteristics and functionality (Infinitabiotech, 2024). The primary classes of enzymes utilized in the pre-treatment and finishing processes of cotton are hydrolases and oxidoreductases. The hydrolase group includes enzymes such as amylase, cellulase, cutinase, protease, pectinase, and lipase/esterase. These enzymes play crucial roles in various applications, including biopolishing and bioscouring of fabrics, antifelting of wool, softening of cotton, denim finishing, desizing, and modifying synthetic fibers (Araujo *et al.,* 2008; Chen *et al.,* 2013). On the other hand, the oxidoreductase group comprises enzymes like catalase, laccase, peroxidase, and ligninase, which are involved in processes such as bio-bleaching, bleach termination, dye decolorization, and finishing of fabrics and wool (Mojsov, 2011) (Table 1; Fig. 1 and 2).

Table 1: Leading enzyme manufacturers specializing in textile processing

Enzyme	Use	Microorganisms
Amylase	Desizing	*Bacillus* sp., *B. licheniformis*
Cellulose	Cotton softening, denim finishing	*Aspergillus niger*, *Penicillium funiculosum*
Catalase	Bleach termination	*Aspergillus* sp.
Laccase	Non-chlorine Bleaching, fabric dyeing	*Bacillus subtilis*
Pectate lyase	Bioscouring	*Bacillus* sp., *Pseudomonas* sp.
Amylase	Desizing	*Bacillus* sp., *B. licheniformis*
Cellulose	Cotton softening, denim finishing	*Aspergillus niger*, *Penicillium funiculosum*
Protease	Removal of wool fiber scales, degumming of silk, tanning of leather	*Aspergillus niger*, *B. subtilis*
Lipase	Removal of size lubricants, denim finishing,	*Candida antarctica*
Ligninase	Wool finishing	*Trametes versicolor*, *Phlebia radiata*
Collagenase	Wool finishing	*Clostridium histolyticum*
Cutinase	Cotton scouring, synthetic fiber modification	*Pseudomonas mendocina*, *Fusarium solanipisi*, *Thermomonospora fusca*

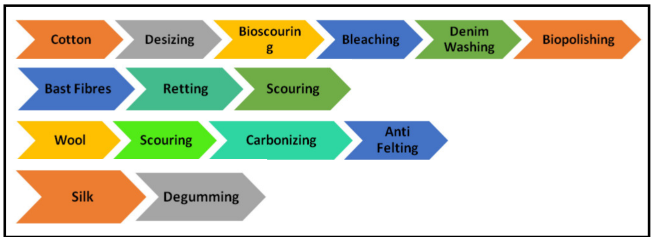


Fig. 1 : Enzymatic processing of natural fibres (Shahid *et al.*, 2016)

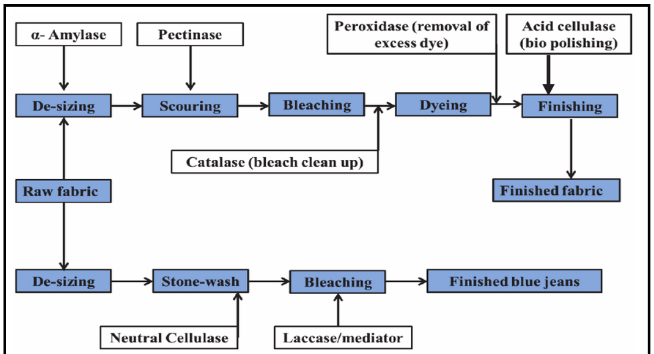


Fig. 2 : Enzymes used in various operations in textile wet processing (Kabir and Koh, 2021)

Enzymatic desizing:

Desizing, one of the key pretreatment processes in textiles, involves removing the adhesive sizing materials, such as starch and waxes, which protect fabrics from abrasion during weaving. This step is essential to make the fabric more receptive to subsequent processing stages. Traditionally, desizing is performed at elevated temperatures using acidic solutions or with strong oxidizing agents in alkaline solutions. Following this process, fabrics are typically scoured to eliminate residual materials, ensuring effective finishing, wetting, and dyeing. However, starch-degrading enzymes like amylases are increasingly favored due to their high efficiency and targeted action. Amylases effectively remove sizing without damaging the fabric and offer a more environmentally friendly alternative to harsh chemical methods (Aly *et al.,* 2010). Amylase enzymes are classified into two main types: α-amylase and β-amylase. These enzymes can be obtained

Table 2 : Enzymes and their optimal conditions for the desizing process

Sr. No.	Amylase Enzyme	Conc. (gpl)	Temp (°C)	pH
1.	Malt	5 – 20	50-60	6-7.5
2.	Pancreatic	1 – 3	50-60	6.5-7.5
3	Bacterial	0.5 - 1	60-70	5.5-7.5

from various sources, including animal origins like the pancreas, as well as plant-based sources such as malt, and microbial sources like bacteria (Vidyamitra, 2024) (Table 2, Fig. 3).

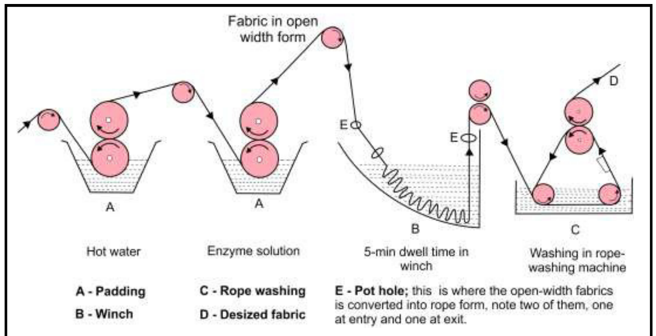


Fig. 3 : Enzymatic desizing process on fabric (Landage, 2022)

Enzymatic scouring:

Scouring removes non-cellulosic impurities from cotton to enhance wettability for bleaching and dyeing. Traditional scouring uses harsh alkaline chemicals, like caustic soda, which can weaken the fabric and generate environmentally harmful waste with high COD, BOD, and TDS levels (Aly *et al.*, 2010). To address these environmental concerns, bioscouring has emerged as a more eco-friendly alternative that employs specific enzymes to target and release noncellulosic impurities without compromising the cellulose structure. This enzymatic approach preserves the tensile strength of the fabric while improving its wettability and dye uptake, aligning with the increasing demand for sustainable textile processing practices (Agrawal, 2004; Rajulapati, 2020) (Table 3 and Fig. 4).

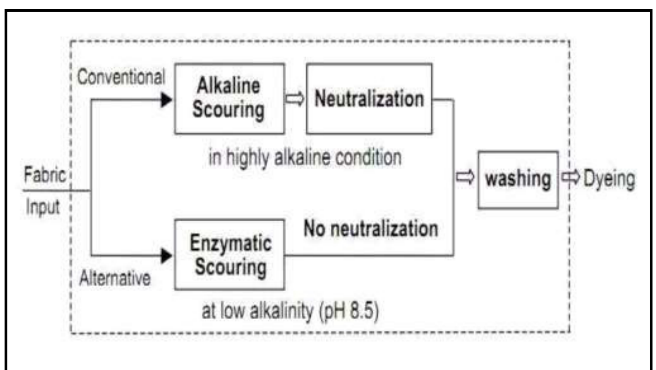


Fig. 4 : Flow chart of bioscouring (https://www.slideshare.net/slideshow/bio-scouring-85239891/85239891)

Table 3 : Enzymes and their optimal conditions for the scouring process

Enzyme	Source	Designation'	pH	Temperature (C)
Mutifect cellulase GC	*Trichoderma longibrachiatum* (formerly T. reesi)	C1	4.0	50
Cellulase cl184	*Aspergillus niger*	C2	5.0	50
Cellulase c8546	*Trichoderma reesi*	C3	4.0	50
Multifect pectinase PL	*Aspergillus niger*	P1	4.0	50
Pectinase p3026	*Aspergillus japonicus*	P2	5.5	50
Pectinase p9179	*Aspergillus niger*	P3	4-.0	50

Enzymatic bleaching:

Bleaching is a chemical process that removes color and whitens fabrics, often through oxidation. Conventional bleaching agents include sodium chlorite, hypochlorite, formic acid, sodium nitrate, and peroxides; however, these chemicals pose several disadvantages, including toxic fume production, high energy consumption, reduction in fabric strength, and environmental contamination. Hydrogen peroxide is the most commonly used oxidative bleaching agent for cotton and its blends due to its ability to provide stable whiteness without yellowing over time. It is cost-effective and allows for a one-bath scour/bleach procedure. Nevertheless, high-temperature bleaching under alkaline conditions can lead to significant fiber damage (Farooq *et al.*, 2013). Enzymatic bleaching is an innovative and eco-friendly approach to treating textiles, particularly cotton, by utilizing specific enzymes to enhance the bleaching process while minimizing environmental impact. Enzymes like peroxidase, laccase, glucose oxidase, hydrogen peroxide can also be produced through the oxidation of glucose catalyzed by glucose oxidase. This method effectively removes impurities such as greases, oils, and colored matter without the harsh effects associated with traditional chemical bleaching agents (Donze *et al.,* 2012; Mojsov, 2019) (Fig. 5).

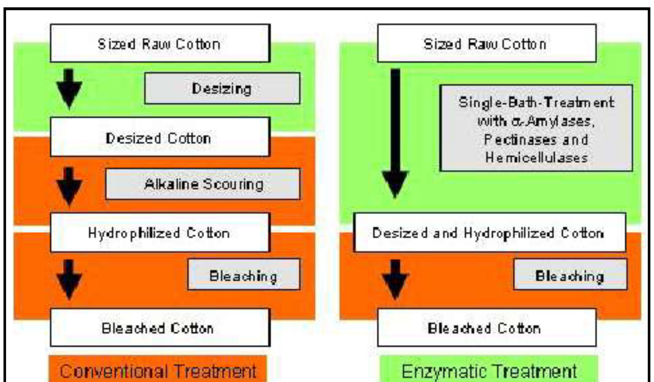


Fig. 5 : Processing steps for the conventional and enzymatic pre-treatment of cotton (Opwis *et al.*, 2013)

Bio-polishing:

Bio-polishing is a finishing process applied to textiles that enhances fabric quality by reducing pilling and fuzziness. This is achieved by eliminating microfibrils from the surface of the fabric. Among the various enzymes used in this process, cellulase stands out as the most effective option for achieving optimal results (Sen *et al.*, 2021). Bio-polishing is an eco-friendly and biodegradable wet processing technique commonly used in the textile industry to enhance fabric quality. This process involves treating cellulosic fabrics with cellulase enzymes, which hydrolyze β 1-4 glycosidic bonds to remove protruding fiber ends, resulting in a smoother, clearer surface that significantly reduces pilling and fuzziness. The typical procedure includes enzyme treatment at 50ºC for about one hour, followed by a temperature increase to 80ºC for enzyme deactivation. While bio-polishing improves dyeability, drapeability, and provides a softer feel, it may slightly reduce fabric weight and strength, necessitating careful control of processing conditions to avoid negative impacts. Overall, bio-polishing promotes sustainable practices in textile processing while enhancing the aesthetic and functional properties of fabrics (Kushwaha and Kesarwani, 2023; Reja, 2021 and Stewart, 2005) (Fig. 6).

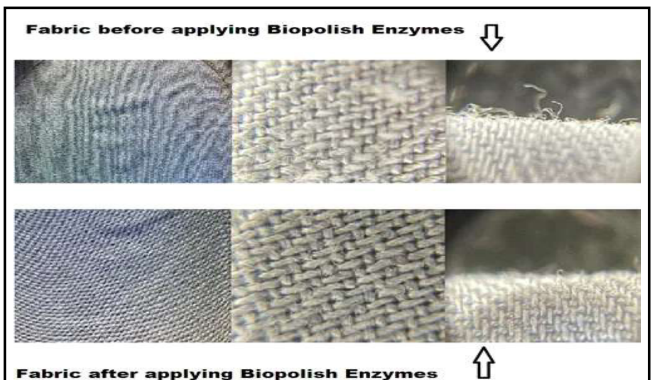


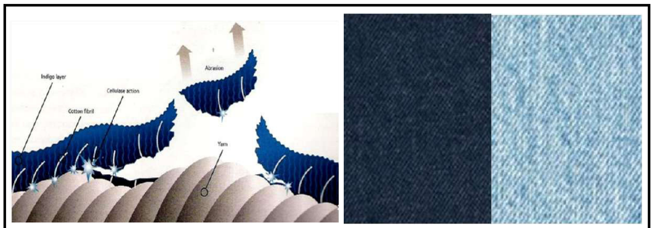
Fig. 6 : Before and after the fiberlife biopolishing treatment (https://www.innovationintextiles.com/giving-fabrics-a-boost-with-biopolishing/)

Enzymatic Treatment to Denim:

A fading effect is applied to denim during its finishing process. Traditionally, this effect was achieved using sodium hypochlorite or potassium permanganate in combination with pumice stones (Pedersen and Schneider, 1998). Denim, being a heavy-grade cotton fabric, allows for surface dye adsorption, enabling fading without significant strength loss. However, the use of pumice stones comes with several drawbacks:

- Pumice stones result in substantial back-staining.
- A large quantity of pumice stones is needed
- They contribute to significant wear and tear of machinery (Kushwaha *et al.,* 2024; Shrimali and Dedhia, 2016).

A method for achieving localized color variations on dyed denim involves treating the fabric with an aqueous solution containing pectolytic enzymes, such as pectin lyases, galactanases, arabinanases, and polygalacturonases, at a pH of 3–11 and temperatures up to 90°C. Denim garments, highly popular among youth, were studied for the impact of enzyme washing with cellulase to create innovative designs. Indigo-dyed cotton denim trousers were treated with enzyme concentrations of 0.5%–3.5%, temperatures of 40°C–70°C, and washing times of 20–60 minutes at pH 5.5 to achieve a worn look. Key properties like tensile strength, elongation, weight loss, stiffness, water absorption, shrinkage, color fading, and surface morphology (via SEM) were analyzed. Optimal washing conditions were determined to be 2% enzyme concentration at 55°C for 40 minutes (Khan *et al.,* 2012; Kalum and Andersen,1999) (Fig. 7).



(a) (b)

Fig. 7 : (a) Bio-washing/bio-stoning of denim with cellulase enzymes. (b). (a) Original (Raw) Indigo dyed denim (b) Bio-stone washed denim (Agrawal, 2017)

Enzymatic treatment of leather:

Leather manufacturing involves three key stages: pre-tanning, tanning, and post-tanning, each serving a distinct role. Traditional chemical-based methods generate significant environmental pollution, including high COD, BOD, TDS, and TSS levels. Enzymatic processes have been part of leather production since the early 20th century, starting with their use in bating. Transitioning to enzyme-based bioprocessing is essential for reducing these environmental impacts and achieving sustainable leather production (Hasan *et al*., 2022). Enzymes are now utilized in various leather production stages:

- **Soaking**: Loosen scud, open fibers, reduce soaking time, improve softness and elasticity, and increase area yield. Enzymes for fiber opening and loosening scud, such as *amylases* and *proteases*.
- **Unhairing**: Reduce toxic chemicals, lower pollution, enable milder processing, and recover valuable hair while enhancing leather smoothness and strength. *Proteases* to partially replace lime and sulfide for reducing toxic chemicals.
- **Bating**: Remove proteinaceous materials, improve chemical penetration, and produce smooth, supple leather using proteolytic enzymes. *Proteases* (e.g., trypsin and bacterial proteases) to remove non-leather-forming proteins like albumins and globulins.
- **Degreasing**: Replace chemicals, ensure even tanning material penetration, and produce soft leather. *Lipases* to break down fats and oils, replacing solvents and surfactants.
- **Tanning and post-tanning**: Enhance softness, dye affinity, color uniformity, and absorption. *Proteolytic enzymes* to improve softness, dye penetration, and uniformity.

Despite these applications, enzymatic leather processing continues to develop slower than in other industries (Lasoñ-Rydel *et al.,*2024) (Fig. 8).

Fig. 8 : Dehairing effect by conventional chemical treatment versus enzymatic method (Zhou *et al.,* 2022)

Conclusion:

Enzyme-based solutions have emerged as a sustainable and efficient alternative to traditional chemical processes in the textile finishing industry. With their ability to perform specific tasks at lower temperatures, reduce water and energy consumption, and minimize the use of harmful chemicals, enzymes offer a promising path toward eco-friendly textile processing. The application of enzymes, such as cellulases, laccases, and amylases, in processes like bio-polishing, bleaching, and denim finishing, has demonstrated substantial improvements in both the quality of textiles and the environmental impact of the industry. In conclusion, enzyme-based processes hold great promise for reducing the environmental footprint of the textile industry, contributing to a circular economy, and promoting greener manufacturing practices. With continued innovation and adoption, enzymes have the potential to become a cornerstone of eco-friendly solutions in the textile finishing sector, helping the industry move towards a more sustainable and responsible future.

REFERENCES

Agrawal, B.J. (2017). Bio-Stoning of Denim- An Environmental-Friendly Approach.

Agrawal, P. B., Nierstrasz, V. A. and Warmoeskerken, M.M.C.G. (2004). Enhanced bioscouring performance. In Proceedings of the 4th Autex Conference, 165–173. Roubaix, France.

Aly, A.S., Moustafa, A.B. and Hebeish, A. (2004). Bio-technological treatment of cellulosic textiles. *J. Cleaner Production*, **12**(7) : 697-705.

Aly, A.S., Sayed, S.M. and Zahran, M.K. (2010). One-step process for enzymatic desizing and bioscouring of cotton fabrics. *J. Natural Fibers*, **7**(2) : 71-92.

Araujo, R., Casal, M. and Cavaco-Paulo, A. (2008). Application of enzymes for textile fibres processing. *Biocatalysis & Biotransformation*, **26**(5) : 332-349.

Cavaco-Paulo, A. (2003). *Textile processing with enzymes*. Woodhead publishing limited.

Chatha, S.A.S., Asgher, M. and Iqbal, H.M. (2017). Enzyme-based solutions for textile processing and dye contaminant biodegradation—a review. *Environmental Sci. & Pollution Res.*, **24** : 14005-14018.

Chen, S., Su, L., Chen, J. and Wu, J. (2013). Cutinase: characteristics, preparation, and application. *Biotechnology Advances*, **31**(8) : 1754-1767.

Donze, J.J., Redling, E., Pflueger, A., Gysin, B. and Schmidlin, A. (2012). *Enzymatic textile bleach-whitening methods* (EP2403990A2). European Patent Office.

Farooq, A., Ali, S., Abbas, N., Fatima, G.A. and Ashraf, M.A. (2013). Comparative performance evaluation of conventional bleaching and enzymatic bleaching with glucose oxidase on knitted cotton fabric. *J. Cleaner Production*, **42** : 167-171.

Hasan, M.J., Haque, P. and Rahman, M.M. (2022). Protease enzyme based cleaner leather processing: a review. *J. Cleaner Production*, **365**, 132826.

Infinita423biotech (2024, May 31). *The role of textile enzymes in eco-friendly fabric production*.

Jajpura, L. (2018). Enzyme: a bio catalyst for cleaning up textile and apparel sector. *Detox Fashion: Sustainable Chemistry and Wet Processing*, 95-137.

Kabir, S.M.M. and Koh, J. (2021). Sustainable textile processing by enzyme applications. *Biodegradation Technology of Organic and Inorganic Pollutants*, 339-366.

Kalaiarasi, K. (2012). Ecofriendly finishing with enzymes. In *Textile colouration and finishes* (Chapter 33). Prakash. Copyright © by Prakash. All rights reserved.

Kalum, L., and Andersen, B. K. (1999). *Enzymatic treatment of denim* (U.S. Patent Application No. 09/283,176). Novo Nordisk A/S.

Khan, M.M.R., Mondal, M.I.H. and Uddin, M.Z. (2012). Sustainable washing for denim garments by enzymatic treatment. *J. Chemical Engineering*, **27** : 27-31.

Kushwaha, A. and Kesarwani, P.(2023) Bio-polishing-Environment Friendly Sustainable Approach in Textile Processing Industry.

Kushwaha, R., Kesarwani, P. and Kushwaha, A (2024). Bio-stoning: Heighten the Appearance of Denim Garment through Application of Cellulase Enzyme.

Landage, S. M. (2022). Biotechnological approaches in desizing of textile materials. In *Applications of Biotechnology for Sustainable Textile Production* (pp. 47-73). Woodhead Publishing.

Lasoñ-Rydel, M., Sieczyñska, K., Gendaszewska, D., Lawiñska, K. and Olejnik, T. (2024). Use of enzymatic processes in the tanning of leather materials. *AUTEX Research Journal*, **24**(1), 20230012.

Li, Y. and Hardin, Z. R. (1997). Enzymatic scouring of cotton: effects on structure and properties. *Cellulose*, **94**(88), 96.

Liisa-Auterinen, A. (2006). White biotechnology and modern textile processing. *Textile World,* **156**(3): 40–44.

Madhav, S., Ahamad, A., Singh, P. and Mishra, P.K. (2018) A review of textile industry: wet processing, environmental impacts and effluent treatment methods. *Environ. Qual Manag.,* **27**:31–41.

Mojsov, K. (2011). Application of enzymes in the textile industry: a review.

Mojsov, K. (2019). Enzymatic desizing, bioscouring and enzymatic bleaching of cotton fabric with glucose oxidase. *The Journal of the Textile Institute*, **110**(7) : 1032-1041.

Opwis, K., Knittel, D., Schollmeyer, E. and Nord-West eV, D. T. (2013). Use of enzymes in the pre-treatment of cotton. *Nord-West eV DT*.

Pedersen, A.H. and Schneider, P.N.N. (1998). US Pat. 5795855 A. US-Patent.

Rajulapati, V., Dhillon, A., kumarGali, K., Katiyar, V. and Goyal, A. (2020). Green bioprocess of degumming of jute fibers and bioscouring of cotton fabric by recombinant pectin methylesterase and pectate lyases from Clostridium thermocellum. *Process Biochemistry*, **92** : 93-104.

Reja, M. (2021). Effect of Bio-polishing inCotton Fabric.

Sarkar, S., Soren, K., Chakraborty, P., and Bandopadhyay, R. (2020). Application of enzymes in textile functional finishing. *Advances in Functional Finishing of Textiles*, 115-127.

Scott A (2015) Cutting out textile pollution. Chem Eng News.

Sen, A., Kapila, R., Chaudhary, S. and Nigam, A.(2021). Biotechnological applications ofmicrobial enzymes to replace chemicals inthe textile industry-a review.*TEXTILE Association*, **82**(2) : 68-73.

Shahid, M., Mohammad, F., Chen, G., Tang, R.C. and Xing, T. (2016). Enzymatic processing of natural fibres: white biotechnology for sustainable development. *Green Chemistry*, **18**(8) : 2256-2281.

Shrimali, K. and Dedhia, E. (2016). Enzymatic finishing of textiles. *Internat. J. Scientific Research*, **5** : 674-677.

Stewart, M.A. (2005).Biopolishing cellulosic non wovens. North Carolina StateUniversity

Vidyamitra (2024). *Fabric preparatory process for dyeing and printing* (Unit 2: Dyeing and Printing). INFLIBNET. Retrieved December 2, 2024, from https://vidyamitra.inflibnet.ac.in

Zhou, C., Qin, H., Chen, X., Zhang, Y., Xue, Y. and Ma, Y. (2018). A novel alkaline protease from alkaliphilic Idiomarina sp. C9-1 with potential application for eco-friendly enzymatic dehairing in the leather industry. *Scientific Reports*, **8**(1), 16467.

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