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Enzymatic Treatment of Cotton Fabric for Desizing

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ABSTRACT

The possibility of softening the conditions of biochemical treatment to remove the sizing agent from the surface of the fibers in the preparation of cotton fabric for dyeing has been studied. The efficiency of the α-amylase enzyme was evaluated by the amount of sugars reduced in the modifying solution, as well as by the capillarity of the samples of the treated fabrics. The enzyme used is active towards starch starting from a low concentration (0.02 g/l) and low temperature (32°C). The effect of enzyme concentration from 0.02 to 6.0 g/l, solution pH from 4.5 to 8.5, temperature from 32 to 60°C on the amount of sugars in the solution after enzymatic treatment, and fabric capillarity was determined. Almost complete removal of sizing from the surface of fibers of the original fabric was achieved under moderate and mild processing conditions: α-amylase concentration 1.0÷5.0 g/l, pH=6.0÷7.0, temperature 50-55°C. Based on the dependence of the logarithm of the reaction rate on the reciprocal temperature, the activation energy of the desizing reaction was calculated, which turned out to be equal to E = 17.5 kJ/mol. The low activation energy shows that the desizing process is carried out under energetically favorable conditions with moderate heating. The surface morphology of treated and untreated samples of cotton fabric was studied by scanning electron microscopy. The removal of the adhesive substance from the surface of the fibers, the separation of individual fibers, and the smoothing of the fabric surface after treatment with an amylase solution were recorded.

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1. Introduction

Cellulose has received a lot of attention due to its rich and renewable resource and biodegradability benefits. Modification of natural plant cellulose has become a topical and widely studied topic all over the world [1]. Traditionally, physical or chemical modification of cellulose is carried out [2]. It is not always possible to impart new functional properties to molecules by the method of ordinary physical modification (exposure to heat, light, mechanical stress, etc.), at the same time, their composition and structure do not change significantly in a positive direction [3, 4]. Chemical modification methods usually cause great damage to the environment. Currently, the methods of innovative, environmentally friendly, and sustainable biochemical modification technologies that affect the structure and properties of cellulose are recognized as the most promising [5, 6]. The advantages of biochemical modification with the use of various enzymes are due to the improvement of the functional properties of cellulose, reduction of energy costs and environmental pollution, as well as high specificity and selectivity [5]. Functional materials made from modified cellulose will have a wider application [7].

Enzymes have been well-known for several centuries, including in the processing of textile raw materials. In the second half of the last century and the beginning of this century, the use of enzymatic processing increased significantly, especially for the processing of natural fibers during production stages [8]. Enzymatic processing has gained acceptance in the textile industry because it is a specific, non-toxic, environmentally friendly, and energy-saving alternative. Enzymes are practically applicable to all production stages of chemical processing of textiles: amylases - for desizing fabrics, cellulase - for biopolishing and washing denim, proteases - for modifying wool, catalase - for removing oxidizing residues, etc. [9]. Combined enzyme systems for desizing and cleaning contain amylase, lipase, and pectinase enzymes to achieve results without the addition of harmful chemicals and reduce the amount of chemicals discharged into surrounding wastewater [10].

In recent years, the textile industry has become a promising market due to the growing demand of a large number of buyers for every day, at the same time innovative products [11]. This huge industry is recognized as one of the strongest sectors of the economy of developing countries [12]. Textile production involves a sequence of different chemical processes, mainly aimed at removing impurities and coloring [13, 14]. Chemical processing, widely used in the textile industry, generates huge waste due to the desizing of fabrics, bleaching chemicals, and synthetic dyes, which contributes significantly to environmental pollution [15, 16]. In recent decades, the increase in textile consumption has brought intense pressure on the manufacturing and processing sectors to develop efficient, low-cost, and environmentally sustainable technologies to meet the needs of the population through the use of environmentally friendly and hygienic textile products [17, 18]. At the same time, it is necessary to achieve high productivity with less damage to the environment [19].

Cellulases were among the first enzyme products to be used in textile production [20]. They, being effective tools for ensuring environmentally friendly processing of textiles and reducing energy consumption, increase the efficiency of cellulose splitting [7]. The ability to change the basic properties of the fiber and make them more suitable for use in the textile industry is another feature of enzymes [6].

Microbial enzymes have advantages over enzymes from other sources, such as higher yield, faster growth of microorganisms in small media, high catalytic activity, ease of genetic manipulation, and regular supply. Due to this, these enzymes are used more often than others [9]. Also, enzymes of microbial origin are more stable, convenient, and safe to produce than enzymes obtained by other means and have a long shelf life [21, 22].

Thus, enzymes derived from microorganisms have replaced the use of harmful chemical treatments in textile production to achieve an environmentally friendly and sustainable bio-based processing system. Microbial enzymes play a critical role in the sustainable wet processing of cellulosic textile materials [23]. Processes involving enzymes are currently of great interest for reasons of time reduction [24, 25], low energy consumption, cost-effectiveness, non-toxicity, and environmental friendliness [26, 27]. Microbial enzymes in the textile industry are mainly used at three different levels: in wet preparation processes and laundry detergents, in the development of biodegradable fibers, and the treatment of textile effluents [28]. One of the textile industry's biggest challenges is reducing water and energy consumption. The use of microbial enzymes in the textile industry has significantly reduced water consumption by 19,000 L/t during the processing of textile fabrics [23, 29].

The use of enzymes in technological processes not only improves the quality of the fabric but also improves its processing [30]. Another specificity of enzymes is that they can be used in very small quantities, providing the required result [31, 32]. The use of enzymes also has an economic advantage, since they are almost not consumed during the reaction process, which allows them to be reused [9].

Yarn sizing is a temporary process in weaving, it is only needed during the weaving of the fabric and is then removed before chemical finishing of the textile material. Since sizing increases the hydrophobicity of the fabric, and subsequent finishing processes of textile material are carried out in aqueous solutions, its high-quality removal is a priority [33]. Also, in addition to starch, other contaminants and impurities must be removed from the surface of the fibers by hydrolysis. In this case, you can use a chemical or enzymatic method. In the chemical method, sodium hydroxide is usually used to remove resin [34]. This chemical harms textile fibers and makes them stiff. At the same time, with the enzymatic method, using α-amylase, hydrolysis converts starch into soluble saccharides and maltose, while retaining the properties of cellulose and fibers [33].

Desizing removes the protective coating from the surface of the yarn to provide high efficiency and improved quality for subsequent steps such as bleaching, cleaning, dyeing, and printing [35]. Desizing starch, proteins, and especially synthetic polymers requires the use of high temperatures and special reagents [36], the presence of a mixture of substances of different classes reduces the efficiency of desizing [37]. In such cases, biochemical desizing using various enzymes appears to be the most effective [38].

α-Amylase is mainly used for desizing cotton fabrics, smoothing fabrics, and wet processing textiles [39-44]. The main function of amylase is to decompose starch. Starch consists of two polymers: the linear polymer amylose and the branched polymer amylopectin. Amylase breaks down into small chain sugars such as dextrin and maltose. Various microorganisms are used to produce amylase. The most widely used in recent years are *Paecilomyces variotii*, *Aspergillus oryzae*, *Rhizopus oryzae*, and *Aspergillus terreus* [45-47]. Amylase is also produced by a large number of species of bacteria of the genus Bacillus [48]. Depending on the type of sugars and broken-down starch, amylases are classified as α-amylases and β-amylases. Both amylases hydrolyze starch at glycosidic bonds but at different points in the polysaccharide chain. In the presence of α-amylase, hydrolysis occurs along the entire polysaccharide chain, which is why this type of amylase is used in industry [24]. However, β-amylase and other types of amylase have not found industrial application because, in their presence, starch hydrolysis occurs at the terminal 1,4-glucan bonds [23]. Microbial α-amylases can potentially be used for desizing cotton fabrics sized with insoluble starches due to their selectivity, specificity, and environmental benefits [49, 50]. Desizing of textile material with amylase takes place in an acidic environment - pH 5.5-6.5 and an average temperature from 60°C to 80°C [51, 52]. The process of desizing textile material using amylase consists of three stages: impregnation, in which the fabric absorbs an enzyme solution at high temperature; aging, in which the starch dressing is broken down by an enzyme; and washing when hydrolysis products are removed from the surface of the fabric [53].

Thus, a huge number of promising results have been reported in the current literature, but textile processing conditions with high temperatures, extreme pH, and very long kinetics still limit the industrial application of enzymatic modification [9, 54, 55].

The purpose of this work is to study the possibility of softening the conditions (temperature, pH, time) of biochemical preparation for dyeing cotton fabric. Cotton fabrics produced at the enterprises of the textile industry of the Republic of Uzbekistan are subjected to sizing with starch solutions before weaving. Amylase enzymes are used to remove starch from the surface of cellulose fibers. The processing of cotton fabric was carried out with the enzyme α-amylase with different concentrations, at different temperatures, pH of the solution, and process time. The degree of desizing was determined by the amount of sugars released into the solution during processing, as well as by the capillarity of the treated fabric.

2. Materials and Methods

2.1. Materials

The object of the study was a raw cotton fabric with a density of 120 ± 5 g/m^2, which was obtained from a textile enterprise in Tashkent. The enzyme used was α-amylase, which was produced by Rouyangmoer (China).

The pH of the medium was controlled using a buffer solution consisting of a mixture of potassium dihydro orthophosphate (KH_2PO_4) and sodium hydrogen orthophosphate (Na_2HPO_4). First, two solutions were prepared with a concentration of KH_2PO_4 13.6 g/l and Na_2HPO_4 31.2 g/l. Then these solutions were mixed in certain volume ratios depending on the set pH value of the medium (Table **1**).

Table 1: Dependence of the pH of the medium and the volume ratio of solutions.

pH	5.5	6.0	6.5	7.0	7.5	8.0
Solution volume KH_2PO_4, ml	80,58	87,9	68,7	48,8	18,44	3,1
Solution volume Na_2HPO_4, ml	19.15	12.1	31.3	51.2	82.9	96.9

To obtain a medium with pH<5.5, an acetate buffer was used from a mixture of sodium acetate and acetic acid; to obtain a medium with pH>8.0, an ammonia buffer was used from a mixture of ammonium chloride and ammonia water.

2.2. Processing of Cotton Fabric

The mass of the original raw fabric sample was preliminarily weighed. A solution of the buffer mixture and the required amount of amylase was prepared. A sample of the original fabric was added to the solution at a bath modulus of 1:10 and kept for 0.5-4.0 hours at a certain temperature in a thermostat. After this, the fabric sample was removed from the solution, washed first in running water, then with distilled water, and dried to a constant weight (Fig. **1**). The remaining solution was saved to determine the amount of sugars.

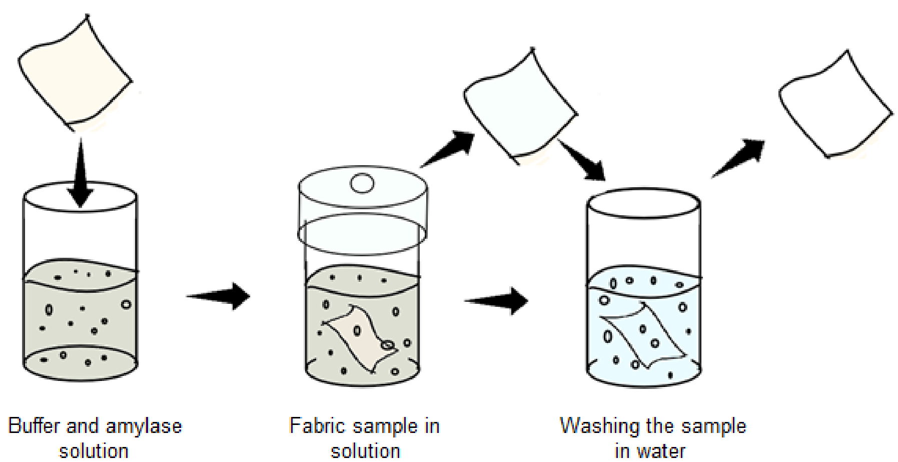


Figure 1: Scheme of enzymatic treatment of textile material.

2.3. Methods of Analysis

To determine the capillarity of the material, a solution of potassium dichromate with a concentration of 3 g/l was prepared. Strips 5 cm wide and 30 cm long were cut from a sample of the treated cotton fabric. The samples were dipped vertically into a potassium dichromate solution to a depth of 1 cm and kept for 60 minutes. The capillarity was evaluated by the average height (mm) of the rise of the dye along the length of the material sample.

The total amount of reduced sugars in the solution after the enzymatic treatment of the fabric sample was determined by the Dubois phenol-sulfur method [13]. Distilled water was added to a sample (20-30 mg) in a ratio of 1:10 (W/V). The sample was then homogenized with an Ultra-Turrax T10 (Ika®) mechanical homogenizer for 60 seconds and then with an ultrasonic homogenizer for a further 30 seconds. Next, 0.4 ml of the homogenate was taken and 7.6 ml of distilled water was added. From the resulting solution, 0.06 ml of homogenate was taken and 0.06 ml of phenol (5%) and 0.32 ml of concentrated sulfuric acid containing hydrazine sulfate were added. Then the optical density of the solution was measured using a photoelectrocolorimeter at a wavelength of 490 nm. The optical density value was substituted into the calibration curve of the standard solution and the concentration of sugars in the sample was determined. A starch solution was used as a standard.

The surface morphology of fabric samples was studied using a JSM-IT200 InTouchScope™ scanning electron microscope (Japan).

3. Results and Discussion

3.1. Processing Conditions

Even a minimal amount of enzyme, starting with a concentration of 0.02 g/l, allows one to obtain satisfactory results in desizing cotton fabric. The first experimental studies were carried out to reveal the effect of amylase concentration on the degree of fabric preparation for chemical finishing. The dependence of fabric capillarity and the amount of reduced sugars in solution after enzymatic treatment on amylase concentration was determined (Fig. **2**).

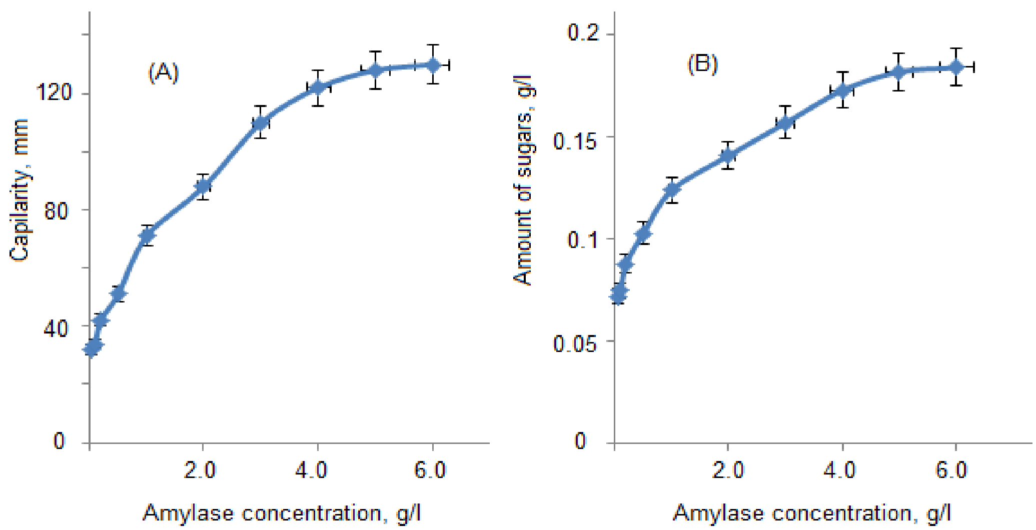


Figure 2: Dependence of fabric capillarity (**A**) and the amount of reduced sugars in solution (**B**) after enzymatic treatment on amylase concentration. Temperature: T=32°C, medium: pH=6, treatment time: τ=4 hours.

As can be seen from Fig. (**2**), there are three sections on the dependency curves. The first almost rectilinear section was found in the range of amylase concentrations of 0.02÷1.0 g/l, in which there is a sharp increase in capillarity and the amount of reduced sugars. The second section was found in the range of amylase concentrations of 1.0÷5.0 g/l, in which the growth of the parameters of the studied properties slows down. And the third site was found at amylase concentrations of more than 5.0 g/l, in which the indicators hardly change. At an amylase concentration of 5.0-6.0 g/l, almost complete removal of starch from the surface of the cotton fibers occurs, therefore, a further increase in the concentration of the enzyme does not lead to an increase in indicators.

Further studies were carried out to determine the influence of the pH of the medium on the process of enzymatic desizing of fabric. The dependence of fabric capillarity and the amount of reduced sugars in solution on the pH of the medium was determined (Fig. **3**).

As can be seen from Fig. (**3**), the dependence curves have an extreme character. As expected, amylase is most effective in weakly acidic and neutral conditions. The highest tissue capillarity and the highest concentration of reduced sugars are observed at pH=6.0-7.0. With the transition to an alkaline environment, the efficiency of the cutting enzyme decreases. As is known, polysaccharides undergo hydrolysis in an acidic environment. The enzyme is a protein, so it is stable in a neutral environment. At the same time, both in an acidic and alkaline environment, the protein itself undergoes hydrolysis. Apparently, in a neutral environment, a stable, relatively high-molecular protein forms an intermediate complex with starch, which decomposes in a slightly acidic environment.

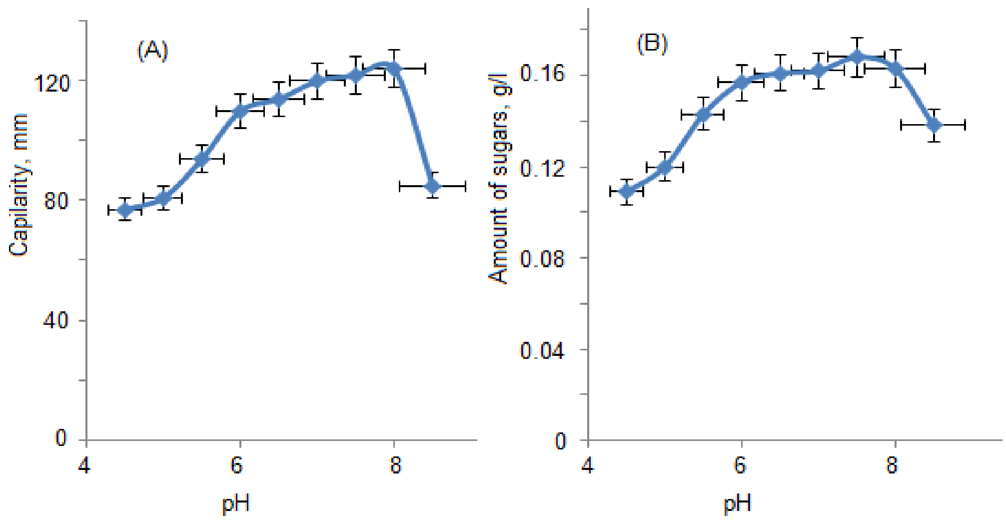


Figure 3: Dependence of fabric capillarity (**A**) and the amount of reduced sugars in solution (**B**) after enzymatic treatment on the pH of the medium. T=32°C, amylase concentration C=3.0 g/l, τ=4 hours.

Later, the effect of temperature on the efficiency of the enzymatic treatment of cotton fabric was revealed. As is known from the literature, the processing of textile materials with enzymes is carried out with moderate heating of the solution. The dependence of fabric capillarity and the amount of reduced sugars in solution on temperature in the range of 32÷60°C was determined (Fig. **4**).

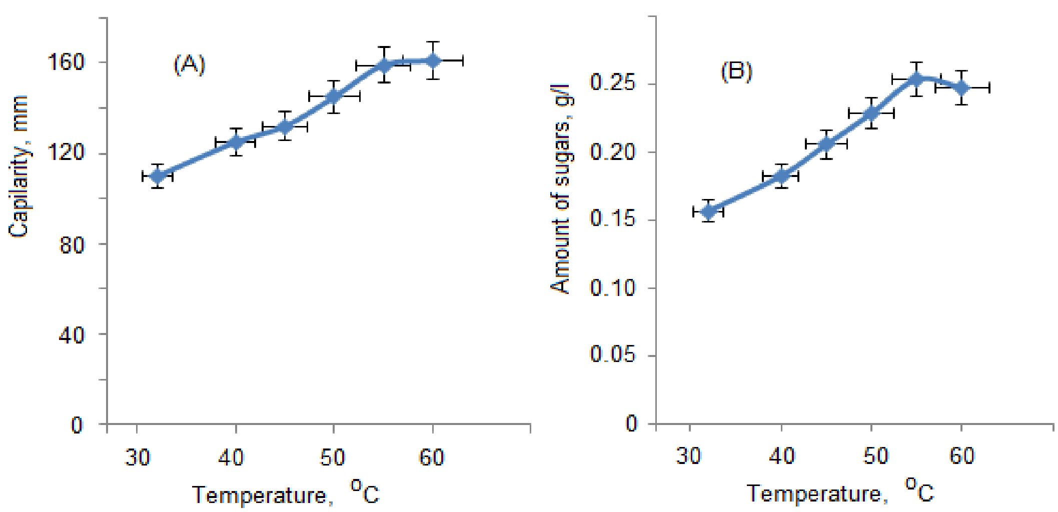


Figure 4: Dependence of fabric capillarity (**A**) and the amount of reduced sugars in solution (**B**) after enzymatic treatment on temperature. pH=6.0, C(amylase)=3.0 g/l, τ=4 hours.

As can be seen from Fig. (**4**), as the temperature rises to 55°C, an increase in capillarity and the amount of sugars in the solution is observed. In a neutral environment, the enzyme molecule is thermally stable even at higher temperatures. Complexation of the enzyme with starch is a reversible process. At a temperature of 55-60°C, the maximum amount of the intermediate complex is formed; at higher temperatures, the reverse process predominates - decomposition of the complex. Therefore, a further increase in temperature does not lead to a significant increase in indicators. The temperature-time dependence of the process of extracting starch from the fibers of the material was studied (Fig. **5**).

The growth rate of the process rate with increasing temperature turned out to be not quite significant. At the beginning of the process, up to 40-60 minutes, the rate of sugar release increases linearly, and then the process naturally slows down. The dependence of the logarithm of the reaction rate on the reciprocal of the temperature was constructed from the data of the rectilinear section. The activation energy of the desizing reaction was calculated from the slope of the obtained straight line, which turned out to be equal to E=17±2 kJ/mol. The low activation energy shows that the desizing process is carried out under energetically favorable conditions even with moderate heating.

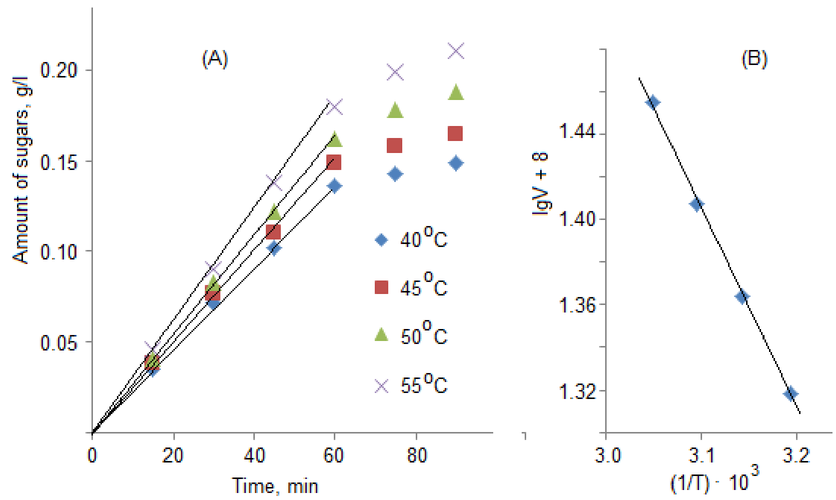
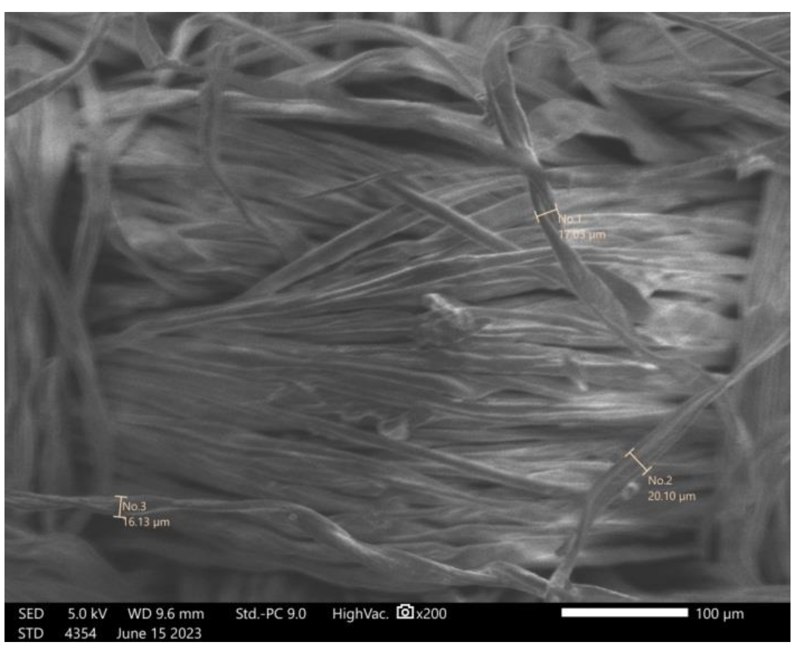


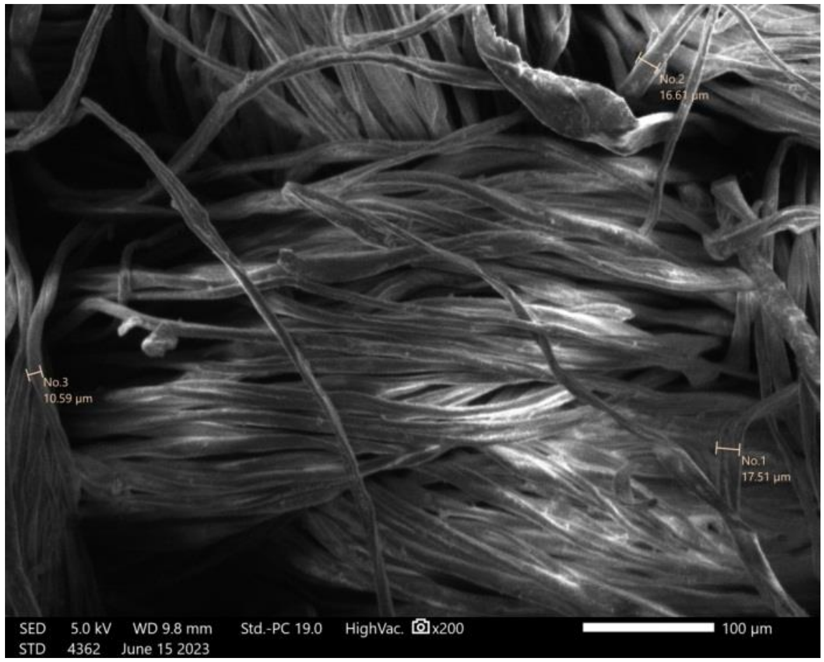
Figure 5: Dependence of the amount of sugars released over time on temperature (**A**) and the logarithm of the rate of desizing on the reciprocal of temperature (**B**). pH=6.0, C(amylase)=3.0 g/l.

3.2. Surface Morphology

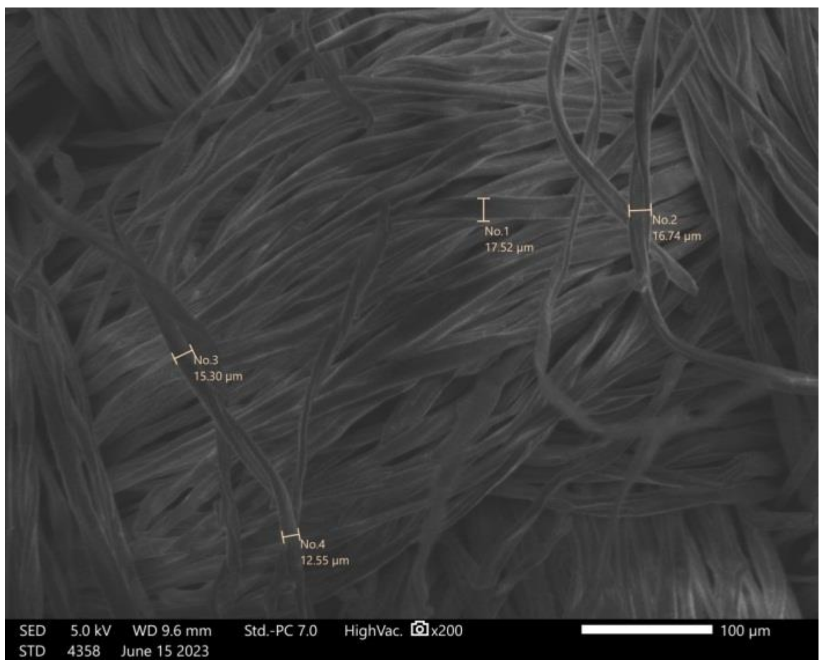
In connection with the dependences obtained, it is of particular interest to compare the morphology of the fabric surface. Enlarged images of the surface of fabrics not treated, treated with amylase, and also treated in the traditional way in a soap-soda solution were taken (Fig. **6**).

(**A**)





(**B**)



(**C**)

Figure 6: SEM images of the surface of cotton fabrics: (**A**) untreated sample, (**B**) traditionally treated sample, (**C**) amylase-treated sample.

As can be seen from Fig. (**6**), on the surface of the fibers of an untreated tissue sample, one can notice the presence of an adhesive layer, glued bundles, lumps, etc. The transverse dimensions of the fibers are in the range of 16÷20 microns. In a sample of fabric treated traditionally by boiling in a soap-soda solution, there is a removed adhesive layer, the appearance of voids, and pores. But glued bundles and lumps remain on the surface of the fibers, and the transverse dimensions of the fibers decrease by 11÷18 microns. In the tissue sample treated with amylase, the adhesive layer is almost completely removed from the surface of individual fibers, and glued bundles and lumps are not noticeable. The transverse dimensions of the fibers are in the range of 13÷18 microns, while there are almost no voids and pores. Thus, samples treated with an amylase enzyme solution have a smoother and better surface morphology.

4. Conclusion

Biochemical modification of cellulose with the help of enzymes opens up new technical, environmental, and economic opportunities in textile production. The use of α-amylase for desizing cotton fabric before chemical finishing has several advantages:

- achieving a high treatment effect with a minimum reagent consumption - 0.2-3.0 g/l;
- carrying out the process in a neutral environment, which helps to prevent the destruction of cellulose;
- reduction of processing temperature to 50-55°C compared to traditional preparation at 90-95°C, which contributes to energy savings;
- the low activation energy of the reaction 17±2 kJ/mol, which contributes to the process in energetically favorable conditions;
- almost complete removal of the adhesive from the surface of the fibers of the material;
- improving the surface morphology of cotton fabric.

Conflict of Interest

The authors declare no conflict of interest.

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References

[1] Bao X, Dong F, Yu Y, Wang Q, Wang P, Fan X, *et al*. Green modification of cellulose-based natural materials by HRP-initiated controlled “graft from” polymerization. Int J Biol Macromol. 2020; 164: 1237-45. https://doi.org/10.1016/j.ijbiomac.2020.07.248

[2] Gandini A, Pasquini D. The impact of cellulose fiber surface modification on some physico-chemical properties of the ensuing papers. Ind Crops Prod. 2012; 35: 15-21. https://doi.org/10.1016/j.indcrop.2011.06.015

[3] Repetto E, Ramirez CR, Manzano VE, García NL, D’Accorso NB. Cellulose and starch nanoparticles: function and surface modifications for biomedical application. In: Venkatesan J, Kim S-K, Anil S, Rekha PD, Eds., Polysaccharide Nanoparticles, Elsevier; 2022, p. 615–64. https://doi.org/10.1016/B978-0-12-822351-2.00023-1

[4] Han Z, Zhu H, Cheng J-H. Structure modification and property improvement of plant cellulose: Based on emerging and sustainable nonthermal processing technologies. Food Res Int. 2022; 156: 111300. https://doi.org/10.1016/j.foodres.2022.111300

[5] Shokri Z, Seidi F, Saeb MR, Jin Y, Li C, Xiao H. Elucidation of the influence of enzymatic modifications on the structure, properties and application of cellulose, chitosan, starch and their derivatives: a review. Mater Today Chem. 2022; 24: 100780. https://doi.org/10.1016/j.mtchem.2022.100780

[6] Bahtiyari Mİ, Ekmekçi Körlü A, Bilisik K. Bioprocessing of natural textile fibres and clothes. In: Mondal MIH, Ed., Fundamentals of Natural Fibres and Textiles, Elsevier; 2021, p. 221-62. https://doi.org/10.1016/B978-0-12-821483-1.00007-3

[7] de Souza Moreira LR, Lo Sciuto D, Filho EXF. An overview of cellulose-degrading enzymes and their applications in textile industry. In: Gupta VK., Ed., New and Future Developments in Microbial Biotechnology and Bioengineering, Elsevier; 2016, p. 165-75. https://doi.org/10.1016/B978-0-444-63507-5.00014-9

[8] Gautam RL, Bharadwaj AK, Kumar S, Naraian R. Microbial enzymes for the variable applications of textile industry processing. In: Gupta VK., Ed., Valorization of Biomass to Bioproducts, Elsevier; 2023, p. 297–321. https://doi.org/10.1016/B978-0-12-822887-6.00003-6

[9] Madhu A, Chakraborty JN. Developments in application of enzymes for textile processing. J Clean Prod. 2017; 145: 114–33. https://doi.org/10.1016/j.jclepro.2017.01.013

[10] Karnwal A, Singh S, Kumar V, Sidhu GK, Dhanjal DS, Datta S, *et al*. Fungal enzymes for the textile industry. In: Yadav AN, Mishra S, SinghS, Gupta A, Eds., Recent Advancement in White Biotechnology Through Fungi, vol. 1, Springer; 2019, p. 459-82. https://doi.org/10.1007/978-3-030-10480-1_14

[11] Amoozegar MA, Mehrshad M, Akhoondi H. Application of extremophilic microorganisms in decolorization and biodegradation of textile wastewater. In: Singh SN, ERd., Microbial Degradation of Synthetic Dyes in Wastewaters, 2015, p. 267-95. https://doi.org/10.1007/978-3-319-10942-8_12

[12] Sarkar S, Soren K, Chakraborty P, Bandopadhyay R. Application of enzymes in textile functional finishing. In: Shahid M, Adivarekar R, Eds., Advances in Functional Finishing of Textiles, Textile Science and Clothing Technology, Singapore: Springer; 2020, p. 115-27. https://doi.org/10.1007/978-981-15-3669-4_5

[13] Periyasamy AP, Rwahwire S, Zhao Y. Environmental friendly textile processing. In: Martínez LMT, Kharissova OV, Kharisov BI, Eds., Handbook of Ecomaterials, Cham: Springer; 2019, p. 1521-58. https://doi.org/10.1007/978-3-319-68255-6_176

[14] Nimkar U. Sustainable chemistry: A solution to the textile industry in a developing world. Curr Opin Green Sustain Chem. 2018; 9: 13-7. https://doi.org/10.1016/j.cogsc.2017.11.002

[15] Ahuja SK, Ferreira GM, Moreira AR. Utilization of enzymes for environmental applications. Crit Rev Biotechnol. 2004; 24: 125-54. https://doi.org/10.1080/07388550490493726

[16] Tochetto GA, da Silva TC, Bampi J, de FPM Moreira J, da Luz C, Pasquali GDL, *et al*. Dervanoskiy, Conversion of Syagrus romanzoffiana into a highly effective biosorbent for dye removal from synthetic and real textile effluents. Water Air Soil Pollut. 2022; 233: Article number: 252. https://doi.org/10.1007/s11270-022-05737-z

[17] Hasanbeigi A, Price L. A technical review of emerging technologies for energy and water efficiency and pollution reduction in the textile industry. J Clean Prod. 2015; 95: 30-44. https://doi.org/10.1016/j.jclepro.2015.02.079

[18] Mazotto AM, de Ramos Silva J, de Brito LAA, Rocha NU, de Souza Soares A. How can microbiology help to improve sustainability in the fashion industry? Environ Technol Innov. 2021; 23: 101760. https://doi.org/10.1016/j.eti.2021.101760

[19] Luo Y, Song K, Ding X, Wu X. Environmental sustainability of textiles and apparel: A review of evaluation methods. Environ Impact Assess Rev. 2021; 86: 106497. https://doi.org/10.1016/j.eiar.2020.106497

[20] Puranen T, Alapuranen M, Vehmaanperä J. Trichoderma enzymes for textile industries. In: Gupta VK, Schmoll M, Herrera-Estrella A, Upadhyay RS, Druzhinina I, Tuohy MG, Eds., Biotechnology and Biology of Trichoderma, Elsevier; 2014, p. 351-62. https://doi.org/10.1016/B978-0-444-59576-8.00026-6

[21] Cavaco-Paulo A, Gübitz G. Textile processing with enzymes. Woodhead Publishing; 2003. https://doi.org/10.1533/9781855738669

[22] Wavhal SD, Balasubramanya RH. Role of biotechnology in the treatment of polyester fabric. Indian J Microbiol. 2011; 51: 117-23. https://doi.org/10.1007/s12088-011-0163-9

[23] Jajpura L. Enzyme: a bio catalyst for cleaning up textile and apparel sector. In: Muthu SS, Ed. Detox Fashion Textile Science and Clothing Technology, Singapore: Springer; 2018, p. 95-137. https://doi.org/10.1007/978-981-10-4876-0_5

[24] Ramesh A, Harani Devi P, Chattopadhyay S, Kavitha M. Commercial applications of microbial enzymes. In: Arora NK, Mishra J, Mishra. V, Eds., Microbial Enzymes: Roles and Applications in Industries, Microorganisms for Sustainability, vol. 11, Springer, Singapore; 2020, p. 137-84. https://doi.org/10.1007/978-981-15-1710-5_6

[25] Niyonzima FN, Veena SM, More SS. Industrial production and optimization of microbial enzymes. In: Arora NK, Mishra J, Mishra V, Eds. Microbial Enzymes: Roles and Applications in Industries, Microorganisms for Sustainability, vol. 11, Springer; 2020, p. 115–35. https://doi.org/10.1007/978-981-15-1710-5_5

[26] Li S, Yang X, Yang S, Zhu M, Wang X. Technology prospecting on enzymes: application, marketing and engineering. Comput Struct Biotechnol J. 2012; 2: 1–11. https://doi.org/10.5936/csbj.201209017

[27] Choi J-M, Han S-S, Kim H-S. Industrial applications of enzyme biocatalysis: Current status and future aspects. Biotechnol Adv. 2015; 33: 1443–54. https://doi.org/10.1016/j.biotechadv.2015.02.014

[28] Roy Choudhury AK. Sustainable textile wet processing: applications of enzymes. In: Muthu SS, Ed. Roadmap to Sustainable Textiles and Clothing, Springer; 2014, p. 203-38. https://doi.org/10.1007/978-981-287-065-0_7

[29] Samanta KK, Pandit P, Samanta P, Basak S. Water consumption in textile processing and sustainable approaches for its conservation. In: Muthu SS, Ed., Water in Textiles and Fashion, Elsevier; 2019, p. 41-59. https://doi.org/10.1016/B978-0-08-102633-5.00003-8

[30] Adeel S, Kamal S, Ahmad T, Bibi I, Rehman S, Kamal A, *et al*. Biotechnology: an eco-friendly tool of nature for textile industries. In: Shahid M, Adivarekar R, Eds., Advances in Functional Finishing of Textiles, Textile Science and Clothing Technology, 2020, p. 85-114. https://doi.org/10.1007/978-981-15-3669-4_4

[31] Vankar PS, Shanker R. Ecofriendly ultrasonic natural dyeing of cotton fabric with enzyme pretreatments. Desalination. 2008; 230: 62-9. https://doi.org/10.1016/j.desal.2007.11.016

[32] Sarkar S, Banerjee A, Halder U, Biswas R, Bandopadhyay R. Degradation of synthetic azo dyes of textile industry: a sustainable approach using microbial enzymes. Water Conser Sci Eng. 2017; 2: 121-31. https://doi.org/10.1007/s41101-017-0031-5

[33] Aggarwal R, Dutta T, Sheikh J. Extraction of pectinase from candida isolated from textile mill effluent and its application in bio-scouring of cotton. Sustain Chem Pharm. 2020; 17: 100291. https://doi.org/10.1016/j.scp.2020.100291

[34] Au CK, Holme I. The alkali desizing of woven cotton fabrics. Res J Text Appar. 1999; 3: 16-30. https://doi.org/10.1108/RJTA-03-01-1999-B003

[35] Sarkodie B, Feng Q, Xu C, Xu Z. Desizability and biodegradability of textile warp sizing materials and their mechanism: a review. J Pol Environ. 2023; 31: 3317-37. https://doi.org/10.1007/s10924-023-02801-5

[36] Zhang X, Baek N, Lou J, Xu J, Yuan J, Fan X. Effects of exogenous proteins on enzyme desizing of starch and its mechanism. Int J of Bio Macromol. 2022; 218: 375-83. https://doi.org/10.1016/j.ijbiomac.2022.07.164

[37] Zhang X, Baek N, Fan X. Differences in the desizability of starches and the mechanism of inhibiting desizing. Tex Res J. 2022; 92: 4789-98. https://doi.org/10.1177/00405175221110110

[38] Rehman A, Raza ZA, Masood R, Hussain MT, Ahmad N. Multi-response optimization in enzymatic desizing of cotton fabric under various chemo-physical conditions using a Taguchi approach. Cellulose 2015; 22: 2107-16. https://doi.org/10.1007/s10570-015-0598-y

[39] Aggarwal R, Dutta T, Sheikh J. Extraction of amylase from the microorganism isolated from textile mill effluent vis a vis desizing of cotton. Sustain Chem Pharm. 2019; 14: 100178. https://doi.org/10.1016/j.scp.2019.100178

[40] Elmansy EA, Asker MS, El-Kady EM, Hassanein SM, El-Beih FM. Production and optimization of α-amylase from thermo-halophilic bacteria isolated from different local marine environments. Bull Natl Res Cent. 2018; 42: Article number: 31. https://doi.org/10.1186/s42269-018-0033-2

[41] Khalid-Bin-Ferdaus KM, Hossain MF, Mansur SA, Sajib SA, Miah MM, Hoque KMF, *et al*. Commercial production of alpha amylase enzyme for potential use in the textile industries in Bangladesh. Int J Biosci. 2018; 13: 149-57. https://doi.org/10.12692/ijb/13.4.149-157

[42] Indriati G, Megahati R. Optimization medium of amylase production by Bacillus licheniformis strain Mgi Originated from Pariangan hot spring, west sumatera, Indonesia. Int J Adv Res. 2017; 5: 660-4. https://doi.org/10.21474/IJAR01/5816

[43] Saravanan D, Sivasaravanan S, Sudharshan Prabhu M, Vasanthi NS, Senthil Raja K, Das A, *et al*. One-step process for desizing and bleaching of cotton fabrics using the combination of amylase and glucose oxidase enzymes. J Appl Polym Sci. 2012; 123: 2445-50. https://doi.org/10.1002/app.34838

[44] Singh S, Singh S, Bali V, Sharma L, Mangla J. Production of fungal amylases using cheap, readily available agriresidues, for potential application in textile industry. Biomed Res Int. 2014; 2014: 1-9. https://doi.org/10.1155/2014/215748

[45] Chen B, Wu Q, Xu Y. Filamentous fungal diversity and community structure associated with the solid state fermentation of Chinese Maotai-flavor liquor. Int J Food Microbiol. 2014; 179: 80-4. https://doi.org/10.1016/j.ijfoodmicro.2014.03.011

[46] Kaur H. Optimization of α-amylase and glucoamylase production in solid state fermentation of deoiled rice bran (DRB) by Rhizopus oryzae. Int J Pure Appl Biosci. 2015; 3: 249-56. https://doi.org/10.18782/2320-7051.2143

[47] Sahnoun M, Kriaa M, Elgharbi F, Ayadi D-Z, Bejar S, Kammoun R. Aspergillus oryzae S2 alpha-amylase production under solid state fermentation: Optimization of culture conditions. Int J Biol Macromol. 2015; 75: 73-80. https://doi.org/10.1016/j.ijbiomac.2015.01.026

[48] Benjamin S, Smitha RB, Jisha VN, Pradeep S, Sajith S, Sreedevi S, *et al*. A monograph on amylases from Bacillus spp. Adv Biosci Biotechnol. 2013; 04: 227-41. https://doi.org/10.4236/abb.2013.42032

[49] Chand N, Sajedi RH, Nateri AS, Khajeh K, Rassa M. Fermentative desizing of cotton fabric using an α-amylase-producing Bacillus strain: Optimization of simultaneous enzyme production and desizing. Process Biochem. 2014; 49: 1884-8. https://doi.org/10.1016/j.procbio.2014.07.007

[50] Sreelakshmi SN, Paul A, Vasanthi NS, Saravanan D. Low-temperature acidic amylases from Aspergillus for desizing of cotton fabrics. J Text Inst. 2014; 105: 59-66. https://doi.org/10.1080/00405000.2013.810019

[51] Chimata MK, Chetty CS, Suresh C. Fermentative production and thermostability characterization of α amylase from Aspergillus species and its application potential evaluation in desizing of cotton cloth. Biotechnol Res Int. 2011; 2011: 323-891. https://doi.org/10.4061/2011/323891

[52] Zafar A, Aftab MN, Iqbal I, Din Z ud, Saleem MA. Pilot-scale production of a highly thermostable a-amylase enzyme from Thermotoga petrophila cloned into E. coli and its application as a desizer in textile industry. RSC Adv. 2019; 9: 984-92. https://doi.org/10.1039/C8RA06554C

[53] Ahlawat S, Dhiman SS, Battan B, Mandhan RP, Sharma J. Pectinase production by Bacillus subtilis and its potential application in biopreparation of cotton and micropoly fabric. Process Biochem. 2009; 44: 521-6. https://doi.org/10.1016/j.procbio.2009.01.003

[54] Singh S. Aspergillus enzymes for textile industry. In: Gupta VK, Ed., New and Future Developments in Microbial Biotechnology and Bioengineering, Elsevier; 2016, p. 191-8. https://doi.org/10.1016/B978-0-444-63505-1.00014-2

[55] Tochetto GA, Aragão AMI, de Oliveira D, Immich APS. Can enzymatic processes transform textile processes? A critical analysis of the industrial application. Process Biochem. 2022; 123: 27–35. https://doi.org/10.1016/j.procbio.2022.10.030