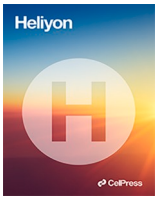
Heliyon 10 (2024) e26346

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

Eco-friendly biopolishing of cotton fabric through wasted sugarcane bagasse-derived enzymes

Md. Shah Ikbal, Fahmida Akter Tisha, Abdullah Ibn Asheque, Enamul Hasnat, Mohammad Abbas Uddin *

Department of Dyes and Chemical Engineering, Bangladesh University of Textiles, Dhaka, Bangladesh

ARTICLE INFO

Keywords:
Cellulase enzyme
Biopolishing
Sugarcane bagasse
Cotton
Knit fabric

ABSTRACT

Enzymatic processing has been a suitable bio-based sustainable application for the textile industry, mitigates the use of harsh chemicals, and minimises environmental impact. Among these enzymes, cellulase enzymes have been extensively used for biopolishing applications. This study introduces an eco-friendly biopolishing of cotton fabric that has been developed by using enzymes extracted from wasted sugarcane bagasse waste in an aqueous medium. Various extraction conditions were explored, and experiments were conducted under diverse time, pH, and temperature settings. The qualitative BUTEXDCE2022C01 testing method was used to assess the biopolishing effects, resulting in a considerable reduction in fabric weight (up to 5.26%) and strength (up to 10.54%). The optimum biopolishing condition was identified to be 1 h at pH 4.8, 55 °C from the fermented solution on day three, indicating the presence of acid cellulase enzyme. The viability of cellulase enzymes has been verified through comparative analysis with commercial samples that had undergone enzyme-biopolishing. Extracted and filtered enzymes exhibited pH stability at room temperature and proved equally effective as industrial enzymes. As textile industries pursue eco-friendly solutions, extracting cellulase from wasted sugarcane bagasse could be a sustainable and alternative option, which also can be sourced locally. Therefore, these findings have wider implications for sustainable enzyme extraction methods and contributions to environmental conservation.

1. Introduction

In the landscape of textile chemical processing, there is a compelling need for eco-friendly and sustainable solutions. Traditional methods in this industry have been water-intensive and have generated substantial effluent, posing significant environmental challenges. In response to these concerns, the textile industry is increasingly turning towards enzyme-based processes [1]. Enzymes are biodegradable, reaction-specific biocatalysts, used for particular wet-processing applications of textiles such as biopolishing, bioscouring, desizing, etc. Enzymes eliminate excess colourants from dyed fabrics and enhance colour fastness. The hydrolase group of enzymes, such as amylase, cellulase, pectinase, protease, and catalase, are commonly used in textile preparation to catalyse chemical compounds hydrolyse [2,3]. These enzymes work well in low-temperature, low-pH environments, remain unchanged during the process, and are considered a safer alternative to toxic chemicals [4,5].

There are about 4000 enzymes, which are classified into six categories by the International Union of Biochemistry and Molecular

* Corresponding author.
E-mail address: abbas.shiyak@dce.butex.edu.bd (M.A. Uddin).

https://doi.org/10.1016/j.heliyon.2024.e26346
Received 2 November 2023; Received in revised form 7 February 2024; Accepted 12 February 2024
Available online 15 February 2024

Biology (IUBMB). Among these categories, hydrolase-based enzymes are mostly used in the textile industry. Hydrolase-based enzymes are capable of catalysing the breakdown of bonds such as carbon-carbon, carbon-nitrogen, carbon-oxygen, and others. Enzymes are used in different textile processes, including desizing, bioscouring, biobleaching, biopolishing, and biostoning [4]. Different enzymes are used in these processes, such as amylase, pectinase, cellulase, cutinase, xylanase, catalase, protease, and lipase, due toles energy and water consumption and less intense process conditions [4,6]. In the desizing process of cotton woven fabric, size materials were removed using alpha-amylase enzyme, which breaks down the starch-based sizing materials [4]. In the bioscouring process of cotton fibre processing, the pectinase enzyme breaks down pectin's complex structure into simpler components, improving the dye absorbency and creating finer, softer, and brighter cotton fabric [4]. Cutinase enzymes are used in the bioscouring process to remove wax at low temperatures [7]. Laccase is also used with pectinase in bio-bleaching, resulting in less fibre damage. This process also reduces the water needed to remove residual components from the fabric [6,7]. Besides, laccases and glucose oxidases are utilised to create bleaching agents for whiteness [8]. The removal of hydrogen peroxide requires the use of a reducing agent and a huge amount of water. Catalase enzymes can be used in this process, eliminating the need for intense processing conditions and requiring less water. Peroxidase enzymes, mainly hydrogen peroxide, are used to remove peroxides in the bleaching process of textiles to remove the natural colour of textile fibre [7]. Protease enzymes break down protein into amino acids and cuticle scales of wool fibres. This is used for wool fibres to smooth out the cuticle layer, which results in improved shrink resistance [4,8]. Almost 4000 enzymes are known; of these, approximately 200 original microbial types are used commercially, and only about 20 enzymes are produced on an industrial scale [9].

Cellulase has attracted much attention over the past two decades as an enzyme with significant industrial importance and many commercial applications [10]. Cellulase has recently been ranked as the third-most significant industrial enzyme in the global retail industry [11]. Cellulases are the second largest industrial enzyme based on monetary value. Their production for commercial use started in the early 1980s with denim finishing, and their demand has been on the rise since 1995, mainly in the paper, biofuel, animal feed, detergent, and textile industries. This surge in demand is driven by a need for cost-effective and environmentally sustainable alternatives. The commercial viability of cellulases is determined by their ability to break down cellulose into its monomers efficiently [12–14].

Cellulase enzymes were also obtained from crude leaf extract. Biopolishing of cotton knitted fabric was done with chloroplast endoglucanases obtained from crude leaf extract. The application conditions were pH 5.5 and 50 °C temperature. A 50% reduction in the enzyme activity was found at the end of the biopolishing experiment [15].

Biopolishing is a process aimed at removing protruding fibres, reducing hairiness, and preventing pilling in cellulose-based fabrics, resulting in textiles with a velvety, smooth texture, vibrant colours, and softened fabric touch. Cellulase enzymes are instrumental in achieving these desired effects due to their specificity for cellulose substrates and ability to hydrolyse cellulosic micro-fibrils, which plays a central role in the process. These enzymes are ideal for biopolishing textiles because of their slow kinetics and lack of negative impact on fabric quality [1,4,16,17]. Sources of cellulase enzymes are various microbes, fungi, animals, and plants through either immersed fermentation or solid fermentation [18].

Sugarcane is a common species of herb that belongs to the grass family. The leftover material is sugarcane bagasse after cane juice is extracted from sugarcane [19]. Sugarcane bagasse is rich in cellulose (45%), hemicellulose (32%), and lignin (17%) [20]. Chemically, bagasse is composed of 2.4% ash, 30% pentosans, and approximately 50% α-cellulose. Because of its low ash concentration, bagasse has many benefits for application in microbial culture-based bioconversion processes [19]. It is the by-product of the sugarcane industry, produced in large quantities and biodegradable. Therefore, it can be used as a cost-effective and available alternative for producing microbial enzymes [21].

In Bangladesh, 15 public sugar mills produced 25,300 metric tons of sugarcane press mud and 255,162 metric tons of sugarcane bagasse as by-products from 2015 to 2016, available in the products and by-products of the Bangladesh Sugar and Food Industries Corporation (BSFIC) database [22]. 3.3 million tons of sugarcane were produced from 77,827 ha in 2021, yielding approximately 1.2 million tons of bagasse [23]. The quantities of residues have been estimated by applying a residual factor from several studies for different agricultural crops, where bagasse accounts for 36% of sugarcane production [24]. Like most agricultural wastes, bagasse biomass is rich in carbon, abundant, and useful for the generation of biofuel or biochar [25]. Several studies have explored the possibility of producing biofuel from bagasse, but little attention has been given to textile applications. Various industrially essential enzymes have been produced using bagasse from sugarcane. These materials have been used in fermentation to develop various microorganisms, such as filamentous fungi, yeasts, and bacteria [19].

Bagasse is burned to dispose of solid waste due to overproduction, which pollutes the environment. Therefore, waste recycling has become the main issue of scientific research because of environmental concerns. Utilising this waste from the sugar industry is not only vital for the environment, but it also serves as an effective substrate for the large-scale production of valuable and new products. In addition, sugarcane bagasse has been proposed as a sustainable alternative biomass for producing enzymes, sugar products, electricity, second-generation biofuels (ethanol), and other added-value products [26]. Reusing recycled sugarcane bagasse as an alternative and sustainable source for cellulase enzyme production has significant environmental and industrial implications.

Typically, the excess byproduct of the sugarcane industry, sugarcane bagasse, is incinerated to turn into solid waste used in landfills [27]. Consequently, it pollutes the air and the landfill with many toxic substances [26]. Using it as a source of raw materials for the enzyme industry will be a more practical and efficient way towards sustainable alternatives of synthetic chemicals and dyes, which are difficult to remove from the environment [28]. Therefore, the challenge is to switch to an eco-friendly system that would help to sustain the industry with fewer pollutants. The waste sugarcane bagasse-derived enzyme can meet the demands of the industry as the enzymes extracted from waste sugarcane bagasse are of natural origin and, therefore, will be environment-friendly and can be sourced locally, reducing global footprint. When the potential implications of the sugarcane industry's waste disposal and raw materials for textile enzyme industries are added, the advantages are comprehensible [14,15]. Thus, the objectives of the study are to find an

alternative and sustainable source of cellulase enzymes from wasted sugarcane bagasse to use in textile biopolishing applications and compare its performance with commercially used cellulase enzymes. To find out the optimum performance of the extracted enzymes on knitted cotton fabrics, various parameters such as extraction methods, duration, pH, and time of application were experimented with sugarcane. Therefore, this research aims to contribute significantly to environmental conservation and industrial advancement.

2. Materials and methods

2.1. Materials

100% single jersey cotton fabric of 140 gsm (grams per square meter), cut into 10 gm square shape for biopolishing, and 2 × 2-inch fabric samples for fabric weight loss test were taken. Sodium hydroxide was used for pretreatment and to maintain the pH required for biopolishing. All these were collected from the DCE lab. A reference biopolished fabric sample was collected from Knit Bazaar Pvt. Ltd., and 1 Kg sugarcane bagasse was collected from the local market, as shown in Fig. 1.

2.2. Fabric samples labeling

Table 1 describes the labels used for the experimentation of textile fabric used in this study.

2.3. Machines

A sample dyeing machine (container capacity 150 mL) for biopolishing [Fig. 2a)], a stereo microscope Euromax (up to 5.5 times magnification with 0.5 magnification gap) for microscopic tests [Fig. 2b)], and a bursting strength tester (diaphragm 30 mm) from SDL International Ltd for fabric strength test of biopolished samples [Fig. 2c)] were used.

2.4. Methods

2.4.1. Enzyme extraction

An aqueous extraction method was used at room temperature to extract enzymes from sugarcane bagasse. Fig. 3a) illustrates the initial step, where 100 g of sugarcane bagasse were measured and shredded into small fragments, screened out any undesired substances, and left to dry in the sun for three days. The next step involved a pretreatment phase using 0.18% sodium hydroxide solution at a solid to liquid ratio of 1:6 at 110 °C for 1 h to break down the lignocellulosic structure and enhance cellulose accessibility [26]. After pretreatment, washing and neutralization procedures were performed with normal water to eliminate any remaining residues.Fig. 3b) depicts the subsequent step where the treated materials were immersed in 1 L of water in a beaker for enzyme extraction. A homogeneous mixture and complete substrate immersion were ensured by stirring with a glass rod. Finally, the beaker was wrapped with aluminum foil and allowed to ferment at room temperature for up to seven days.

2.4.2. Testing of physical properties and pH

The pH and physical properties, such as colour, odour, and foam formation, were observed in raw extract on the 3rd, 5th, and 7th days. Additionally, on day 3, 10 mL of the raw extracted solution was filtered using Whatman 1001–150 filter paper and stored in a test

Fig. 1. Sugarcane bagasse.

Table 1
Labeling the required fabric samples for different conditions.

Fabric	Labeling	Description
Scoured and bleached ready for dyeing single jersey fabric (RFD S/J)	STD	Standard untreated fabric
	S1	Sample biopolished for 50 min at pH 4.8 after 3 days of sugarcane extraction
	S2	Sample biopolished for 50 min at pH 4.8 after 5 days of sugarcane extraction
	S3	Sample for biopolishing at pH 6.4, treated for 1 h after 3 days of extraction
	S4	Sample for biopolishing at pH 6.4, treated for 3 h after 3 days of extraction
	S5	Sample for biopolishing at pH 6.4, treated for 5 h after 3 days of extraction
	S6	Sample for biopolishing at pH 4.8, treated for 1 h after 3 days of extraction
	S7	Sample for biopolishing at pH 4.8, treated for 3 h after 3 days of extraction
	S8	Sample for biopolishing at pH 4.8, treated for 5 h after 3 days of extraction
Reference Fabric	Ref	Biopolished sample with a commercial acid cellulase

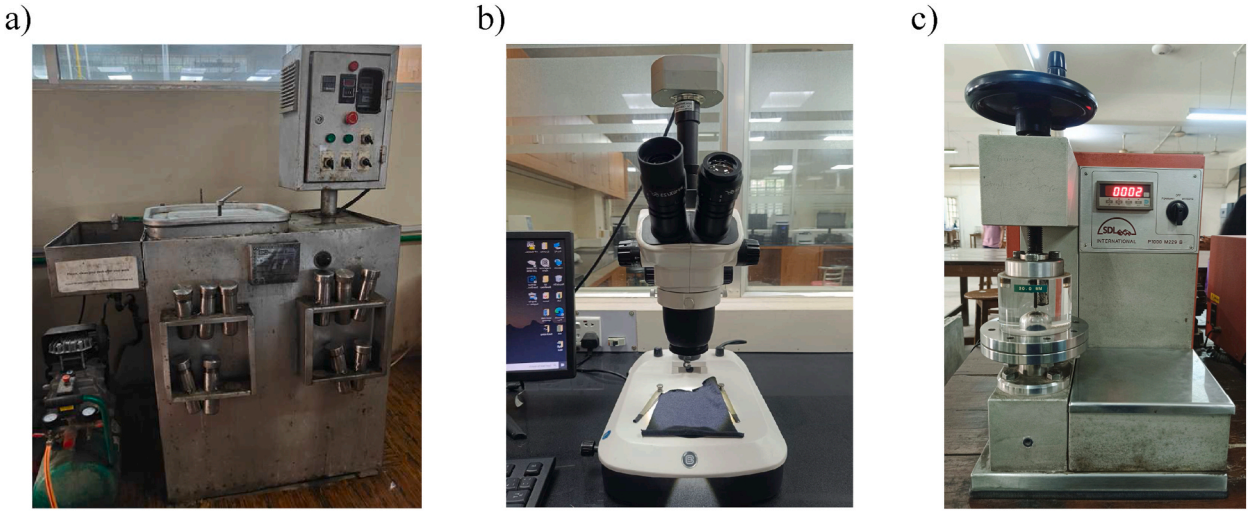


Fig. 2. Various machines used for the study - a) Sample dyeing machine, b) Stereo microscope, c) Bursting strength tester machine.

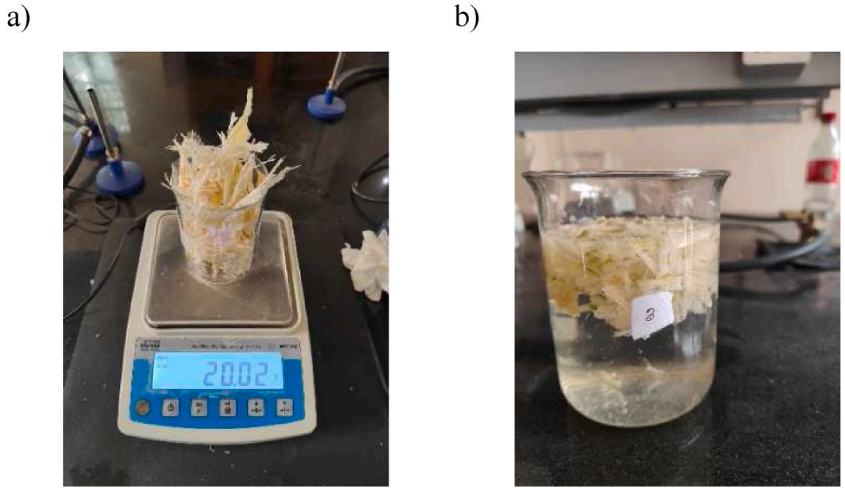


Fig. 3. Various steps of sugarcane bagasse preparation for extraction - a) Measuring sugarcane bagasse, b) Immersing sugarcane bagasse for fermentation.

tube in the refrigerator as shown in Fig. 4a) and Fig. 4b) respectively. A further 20 mL of filtered extract was placed in a beaker at room temperature. The pH of both samples was tested on the 3rd, 5th, and 7th days as a part of the stability assessment procedure as shown in Fig. 4c).

2.4.3. Test of cellulose fabric weight loss

Four separate beakers were prepared, each holding 25 mL of filtered extract solution. Four 2 × 2-inch fabric samples of pre-weighed cotton fabric were immersed in these beakers and kept at room temperature. The samples were taken out after five days, dried in an oven, and their weights were recorded.

2.4.4. Procedure of biopolishing on different days

To assess the optimal day for enzyme activity and effective biopolishing, up to 10 days of enzyme activity were observed. After 5 days, due to excessive fermentation, the colour of the extracted solution has created a foamy texture, indicating a significant reduction in enzyme stability. Therefore, for optimum performance of the enzyme, extracted solutions after day 3 and day 5 were considered. For each assessment, a fresh enzyme solution was prepared. A recipe outlining the biopolishing process on different days is provided in Table 2.

The raw extract solution was first filtered, and 120 mL of the filtered solution was kept in a container. The pH level for biopolishing was maintained at 4.8 on both days as this pH showed the most favourable outcome. A few drops of sodium hydroxide were added to the container to achieve the pH 4.8 as the initial pH values were 3.60 on day 3 and 4.10 on day 5. After the pH adjustment, the fabric sample was rolled up and added to the solution for further processing.

2.4.5. Procedure of biopolishing at different pH and times

Experiments were conducted on the 3rd day fermentation solution to investigate the optimal conditions for biopolishing the extracted enzyme, chosen for its excellent enzyme stability. The specific parameters, including pH levels, treatment times, and other details, are provided in Table 3. Six fabric samples were biopolished on the 3rd day of fermentation at various pH levels and treatment times, aiming to identify the most efficient enzyme activity. Two pH values, 4.5–6 and 6–6.5, were selected from the two different ranges to reflect the preference for acidic or neutral enzymes in the extracted solution [14,29]. 1, 3, and 5 h were chosen as the treatment times. For the procedure, fresh enzyme solutions were prepared.

Six separate baths, with two for each treatment period, were set up. One bath in each set had its pH adjusted to 4.8 and the other to 6.4 from two different ranges. These selected parameters also align with commercial practices, which normally involve acid cellulase biopolishing at pH 4.5–5.5 and neutral cellulase biopolishing at pH 6–6.5. The process was performed at a constant temperature of 55 °C, corresponding with the optimal cellulase activity range (30–60 °C) [14] and commercial biopolishing standards (50–60 °C). 120 mL of the extraction solution was placed in each container. The original pH on day 3 was 3.60, and a few drops of sodium hydroxide were added to adjust the desired pH for biopolishing. Fabric samples, arranged in roll shapes, were then introduced into the biopolishing solutions.

Biopolishing was carried out at 55 °C for six samples as labelled in Table 1. A beaker containing 150 mL of water was heated for 5 min to 80 °C to inactivate the enzymes. The fabric samples treated for 1 h were then taken out of the machine and underwent a 5-min treatment in a beaker. The samples were then rinsed and dried outside in the open air. This procedure was repeated twice for the remaining four samples that underwent treatments lasting 3 and 5 h. The process curve for biopolishing is visually represented in Fig. 5.

2.4.6. Procedure for comparison with commercial enzyme

A fabric sample was biopolished with a commercial acid cellulase enzyme and collected for reference. The biopolishing parameters

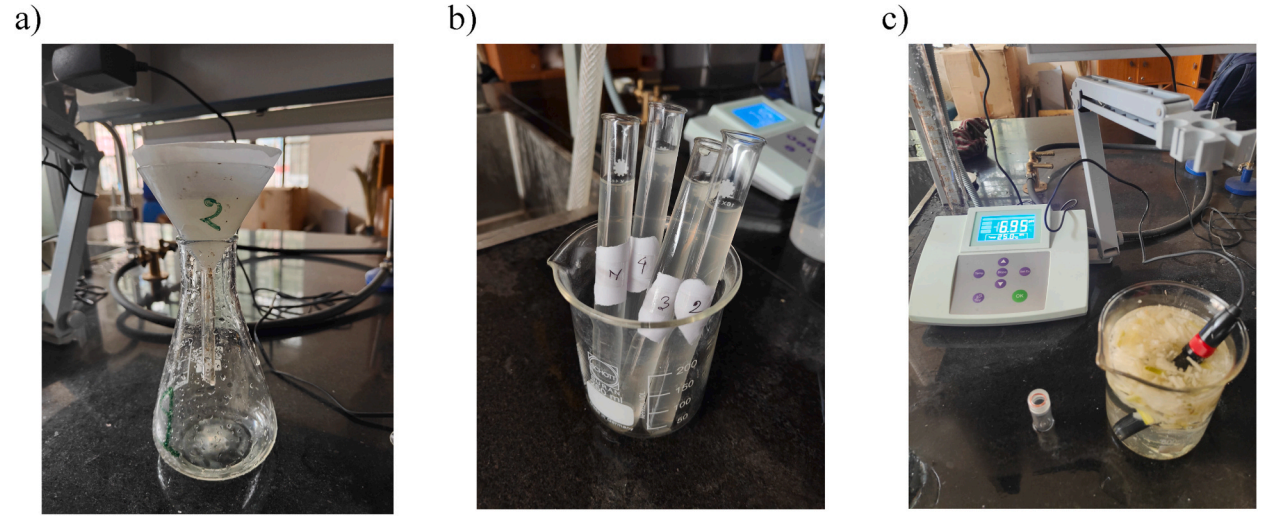


Fig. 4. Various steps of extraction of sugarcane bagasse - a) Filtering the raw sugarcane bagasse solution, b) Storing filtered extract in test tubes for refrigeration, c) Observing pH.

Table 2
Recipe for biopolishing on different days.

Biopolishing	
Extracted solution	120 mL
Fabric weight	10 gm
Sodium hydroxide	As required to maintain the pH
pH	4.8
M:L	1:12
Time	50 min
Temperature	55 °C
Enzyme Deactivation	
Time	10 min
Temperature	80 °C
Normal Wash	
Temperature	Room

On day 3 and day 5, biopolishing was carried out under the same pH circumstances. The biopolishing was carried out at a temperature of 55 °C for 50 min, followed by enzyme deactivation at 80 °C for 10 min. The samples were then cleaned with normal water and let to dry naturally.

Table 3
Recipe for biopolishing at different pH and time.

Biopolishing	
Extracted solution	120 mL
Fabric weight	10 gm
Sodium hydroxide	As required to maintain the pH
pH	4.8, 6.4
M:L	1:12
Time	1, 3, 5 h
Temperature	55 °C
Enzyme Deactivation	
Time	5 min
Temperature	80 °C
Normal Wash	
Temperature	Room

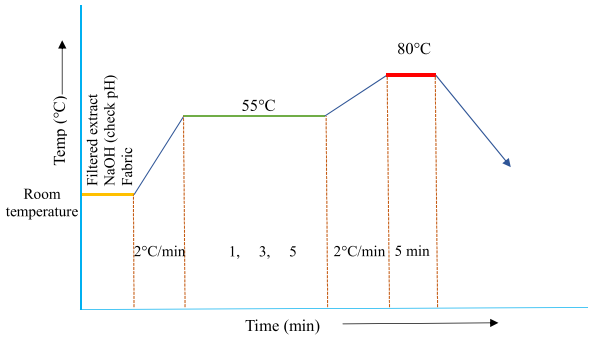


Fig. 5. Process curve for biopolishing.

Table 4
A rating scale for the evaluation of the enzyme activity according to BUTEXDCE2022C01 testing method.

Rating	In Words	Meaning	Description
α	Alpha	Not satisfactory	No loss of protruding fibres in comparison to untreated fabric
β	Beta	Satisfactory	Approximately less than 50% loss of protruding fibres in comparison to untreated fabric
γ	Gamma	Good	Approximate loss of more than 50% protruding fibres in comparison to untreated fabric
θ	Theta	Very Good	About 100% removal of protruding fibres in comparison to untreated fabric
δ	Delta	Not acceptable	Damage of the fabric structure with or without loss of protruding fibres

were maintained at 55 °C temperature, 40 min duration, and pH 5.5 at the factory. Subsequently, it was evaluated and graded by comparing it with the untreated fabric. Sample 6, the most favourable output sample, which was biopolished at pH 4.8 at 55 °C for 1 h, was compared with the reference sample to assess their similarity.

2.4.7. Evaluation of the enzyme activity

The biopolishing samples were examined under a microscope and rated using the BUTEXDCE2022C01 testing method to determine the enzyme activity [17]. The testing methodology is a qualitative grading system, outlined in Table 4, to evaluate enzymatic biopolishing effects on textile substrates more easily and potentially, classifying outcomes into five grades: α-Alpha, β-Beta, γ-Gamma, Θ-Theta, and δ-Delta, denoting Not Satisfactory, Satisfactory, Good, Very Good, and Bad, respectively, based on after treatment surface fibre removal. The method analysed the surface of folded fabric and single yarn under a stereo microscope and graded them by comparing pre and post-treatment protruding fibre amounts. The experimental samples in this study were rated on this scale by comparing treated samples with untreated fabric, treated samples, and commercial samples under microscope, Fig. 6a) and Fig. 6b).

2.4.8. Procedure for fabric strength test

The standard untreated fabric, reference, and all the biopolished fabric samples were tested by a hydraulic diaphragm bursting strength tester, and the values were compared to and analyse the samples' strength. The difference between the total pressure required to rupture the specimen and the pressure required to inflate the diaphragm was reported as the bursting strength in kPa.

3. Results and discussion

3.1. Observation of pH and physical properties

Table 5 shows the pH change of raw sugarcane bagasse solution on different days. Initially, the pH was 6.95, which decreased after the accumulation of enzymes. After the filtration of the enzymes on day 3, the pH was 3.60 and stable for the rest of the days and also at refrigeration.

The pH change of sugarcane bagasse extract is represented by time in Fig. 7, which illustrates the variation in pH values over time for three solutions: raw sugarcane bagasse solution, filtered extract at room temperature, and filtered extract under refrigeration.

The pH of the raw sugarcane bagasse solution decreased significantly from 6.95 to 3.60 after day 3, then gradually rose to 4.45 after day 7. The pH of the filtered extract at room temperature fluctuated between 3.55 and 3.70 from day 3 to day 5, then increased to 4.10 after day 7, starting at an initial pH of 3.60. The pH of the filtered extract under refrigeration remained stable, ranging from 3.55 to 3.65 over the observed days, beginning with an initial pH of 3.60.

Table 6 represents the physical transformations observed from the initial stage to day 7. Initially, the solution was transparent, with no particular odour or foaming. After day 3, a slight browning of the solution occurred, intensifying to a deeper brown shade after day 5 and remaining consistent until day 7. The smell was minimal after day 3, increased after day 5, and slightly decreased after day 7. Foaming was evident after day 3 and day 5, but after day 7, no foaming was observed.

3.2. Fabric weight loss test

Four fabric samples, each initially weighing 0.76 gm, underwent enzyme treatment, resulting in noticeable weight reduction due to enzyme activity. The specific weight changes for each sample are detailed in Table 7 where Sample 1 lost 2.63% of its weight, Sample 2 and Sample 4 both showed a 5.26% weight loss, and Sample 3 experienced a 3.94% weight reduction post-treatment.

3.3. Evaluation of biopolishing samples on different days

In Fig. 8a) and Fig. 8b), Samples S1, and S2 show the effect of cellulase enzyme on RFD S/J cotton fabric compared to standard untreated fabric (STD). S1 shows approximately 100% loss of protruding fibres compared to STD fabric, which makes it to be graded Theta (θ). The grading expresses a very good biopolishing with the extract. S2 shows more than 50 % loss of protruding fibres compared to STD fabric and graded Gamma (γ). In terms of enzyme extraction, day 3 is preferred, demonstrating the most stable enzyme activity and yielding excellent Theta (θ) grading results during biopolishing on this day.

3.4. Evaluation of biopolishing samples at different pH and time

In the comparison depicted in Fig. 9a), Sample S3 shows more than 50% of the protruding fibre removal compared to the STD, which makes it graded as Gamma (γ). Conversely, in Fig. 9b), Sample S4 exhibits less than 50% loss of protruding fibres compared to untreated fabric and is graded as Beta (β).

In the analysis presented in Fig. 10a), Sample S5 shows no loss of protruding fibres compared to untreated fabric. However, it imparts a slight yellowish tint to the fabric, resulting in an Alpha(α) grade. In contrast, as illustrated in Fig. 10b), Sample S6 displays approximately 100% removal of protruding fibres compared to untreated fabric and is graded as Theta (θ).

In Fig. 11a) and Fig. 11b), both samples S7 and S8 showcase protruding fibre removal exceeding 50% when compared with untreated fabric, justifying a Gamma (γ) grade.

Table 8 represents the performance of the treated sample at various pH and treatment time after different days of extracted

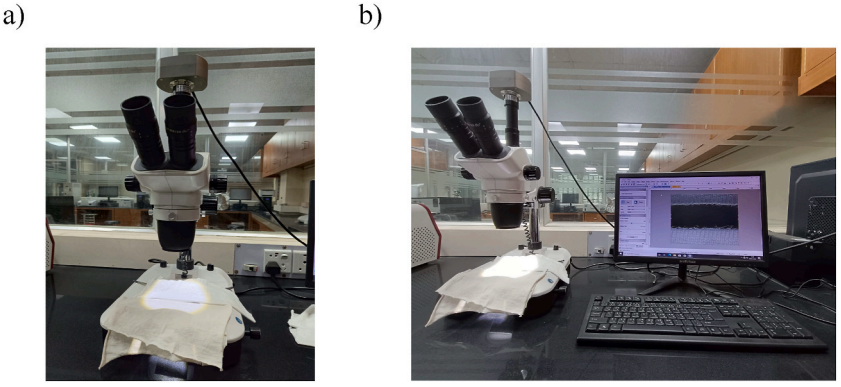


Fig. 6. Performance evaluation under microscope - a) Arrangement of fabric samples b) Assessment of biopolishing samples.

Table 5
pH observation at different conditions.

Properties	Description	Initial	After day 3	After day 5	After day 7
pH at room temperature	Raw sugarcane bagasse solution	6.95	3.60	4.10	4.45
pH at room temperature	Filtered extract	3.60	3.55	3.70	4.10
pH at refrigeration	Filtered extract	3.60	3.65	3.60	3.55

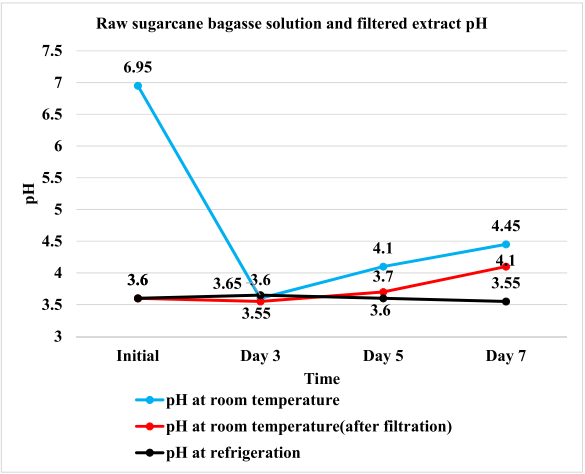


Fig. 7. Change of pH at different conditions.

Table 6
Physical properties over different days.

Days	Colour	Smell	Foam
Initial	Clear	No smell	No foam
Day 3	Slight brownish	Low	Yes
Day 5	Brownish	Increased	Increased
Day 7	No colour change	Decreased, mild	No

solution.

3.5. Fabric strength test

To evaluate the impact of biopolishing, Table 9 offers a thorough study of the fabric strength data. The bursting strength test results showed that the strength loss varied from 3% to 11%. Each sample's strength loss was measured as a percentage compared to the

Table 7
Weight changes over times.

Fabric Sample No.	Weight before treatment in gm	Weight after treatment in gm	Weight loss in percentage
1	0.76	0.74	2.63
2	0.76	0.72	5.26
3	0.76	0.73	3.94
4	0.76	0.72	5.26

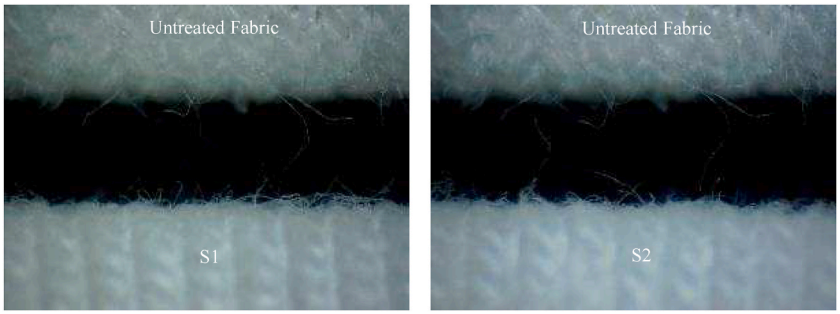


Fig. 8. Comparison of biopolishing effect with untreated fabric - a) after day 3, b) after day 5.

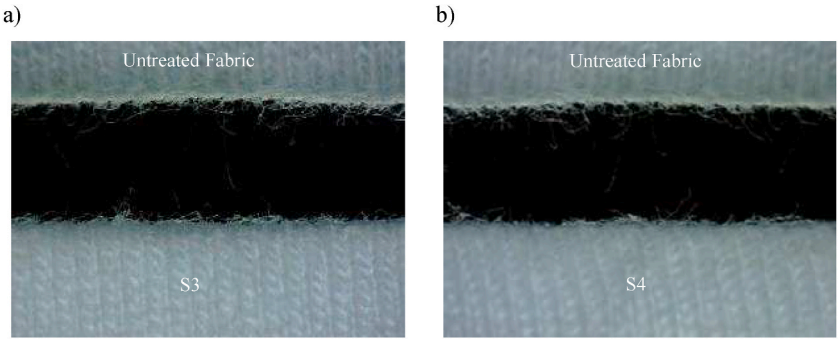


Fig. 9. Comparison of biopolishing between untreated and treated sample after day 3 at pH 6.4 - a) Sample S3, for 1 h, b) Sample S4, for 3 h.

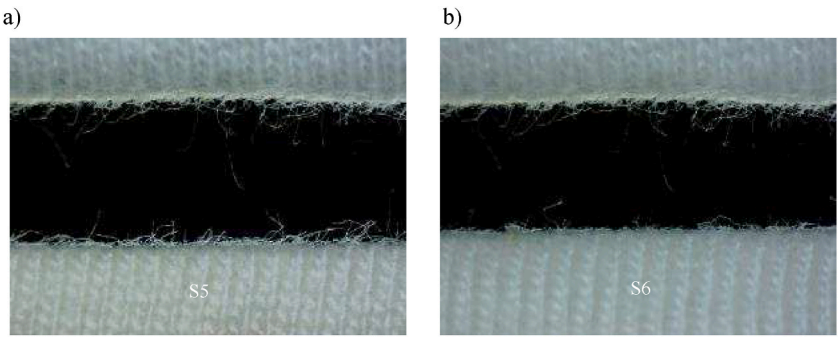


Fig. 10. Comparison of biopolishing between untreated and treated sample after day 3 - a) Sample S5, at pH 6.4 for 5 h, b) Sample S6, at pH 4.8 for 1 h.

untreated fabric.

Sample S1's bursting strength decreased by 5.44%, resulting in a strength of 278 kPa. Sample S2 lost 9.18% of its strength at 267 kPa. The strength losses for samples S3, S4, S5, S6, S7, and S8 were 6.46%, 8.50%, 10.54%, 3.06%, 7.48%, and 8.84%, respectively.

However, sample S6 had the best result, losing only 3.06% of its strength to end up at 285 kPa. This proportion showed a small weight loss compared to the STD and was much lower than the other samples. It was also nearly close to the reference sample. Sample

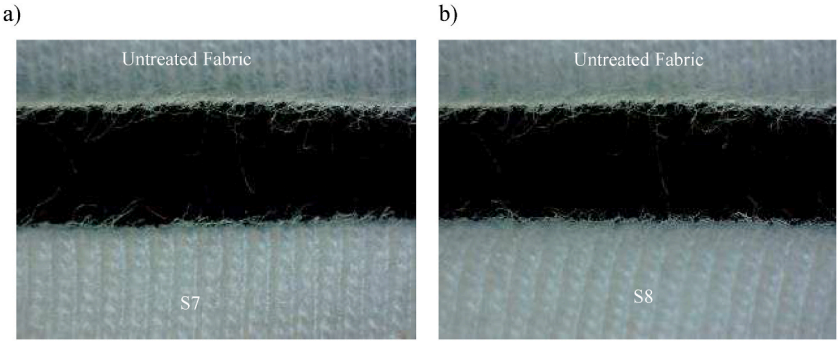


Fig. 11. Comparison of biopolishing between untreated and treated sample at pH 4.8 after day 3 - a) Sample S7, for 3 h, b) Sample S8, for 5 h.

Table 8
Rating of all tested samples with necessary interpretation.

Sample	Rating	Interpretation
STD	–	–
S1	θ	About 100% removal of protruding fibres in comparison to untreated fabric
S2	γ	Approximate loss of more than 50% protruding fibres in comparison to untreated fabric
S3	γ	Approximate loss of more than 50% protruding fibres in comparison to untreated fabric
S4	β	Approximately less than 50% loss of protruding fibres in comparison to untreated fabric
S5	α	No loss of protruding fibres in comparison to untreated fabric
S6	θ	About 100% removal of protruding fibres in comparison to untreated fabric
S7	γ	Approximate loss of more than 50% protruding fibres in comparison to untreated fabric
S8	γ	Approximate loss of more than 50% protruding fibres in comparison to untreated fabric

Table 9
Fabric strength data table.

Sample	Fabric Strength in kPa	Strength Loss in Percentage
STD	294	–
S1	278	5.44
S2	267	9.18
S3	275	6.46
S4	269	8.50
S5	263	10.54
S6	285	3.06
S7	272	7.48
S8	268	8.84
Ref	291	–

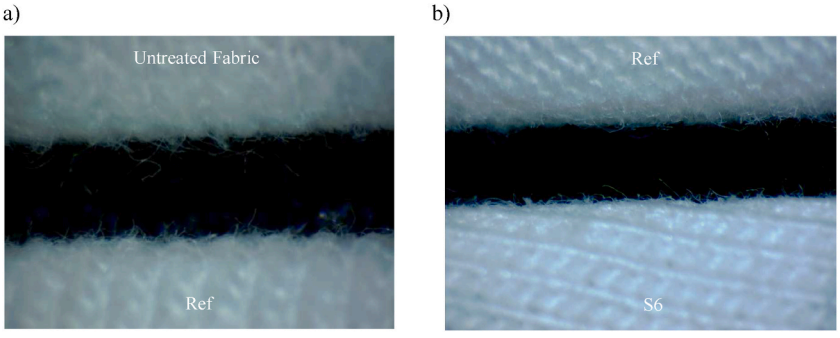


Fig. 12. Comparison of the reference sample with - a) standard untreated fabric, and b) the study's best-performing sample (S6).

S5, on the other hand, showed a massive decrease at 10.54%.

3.6. Evaluating with a reference sample

In Fig. 12a), the reference fabric shows approximately 100% removal of protruding fibres compared to untreated fabric and qualifying for a Theta (θ) grade. Again, upon comparison with the reference sample, it becomes evident in Fig. 12b) that the study's most favourable output sample (S6) exhibited a similar surface appearance as both were graded Theta (θ). This suggests the presence of cellulase enzyme in the sugarcane bagasse extraction, affirming its effectiveness as acid cellulase enzymes work best at pH 4.5–6 and temperatures 30 to 60 °C [14,29]. The commercial biopolishing with the acid cellulase enzyme is carried out at pH 4.5–5.5 and temperature 50 to 60 °C with a recommended time frame of 30–60 min. This study's biopolishing results demonstrated the most favourable effect at pH 4.8, 55 °C, and 1 h, aligning with the enzyme's optimal working conditions within the acidic range.

The optimal pH range for acid cellulase enzymes (4.5–6) and the commercial practices align with the specific biopolishing conditions in this study. The biopolishing performances obtained at pH 4.8, 55 °C, and in 1 h are indicative of the effectiveness of this method. This highlights the effective synergy between enzyme activity and the desired biopolishing effects.

4. Conclusion

This study introduces a sustainable and economical approach for textile biopolishing through extracting cellulase enzymes from wasted sugarcane bagasse. The raw extract solution, obtained through an aqueous medium, underwent biopolishing with variations in pH and time, and enzyme activity was evaluated using the BUTEXDCE2022C01 testing method. The optimal biopolishing condition, identified as 1 h at pH 4.8, 55 °C from the 3rd day fermented solution, removed nearly 100% of protruding fibres. During the processing, reductions in fabric weight (up to 5.26%) and strength (up to 10.54%) were observed, which validated the effectiveness of this enzymatic processing. Comparative analysis with commercial samples affirmed the viability of cellulase enzymes, exhibiting comparable biopolishing effectiveness. Extracted and filtered enzymes demonstrated pH stability at room temperature, proving their efficacy like industrial enzymes. The coherence between the optimal pH range for acid cellulase enzymes (4.5–6), cellulase activity range (30–60 °C), and established commercial practices at pH 4.5–5.5 and 50 to 60 °C temperature underscores the efficacy of the specific biopolishing conditions uncovered in this study. The biopolishing performances at these conditions highlight the effective synergy between enzyme activity and the desired biopolishing effects, offering a promising and scalable approach for sustainable and impactful textile processing.

Future work

The tests were conducted at a laboratory scale, leaving room for improvements. Further research could be carried out to enhance the practicality and sustainability of the whole process, as bulk-scale testing can be explored to assess the feasibility and efficiency and also to see how well the process works on a larger level. An in-depth analysis of enzyme strains extracted from sugarcane bagasse, including stability assessments, formulation studies, and how to make them more effective, can be conducted. The enzyme concentration in sugarcane bagasse extracts can be investigated to determine the exact enzyme content and optimise the concentration for enhanced biopolishing results.

Ethics declarations

This research study does not require formal ethical approval, as it does not involve human subjects, animals, or sensitive personal data.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Md. Shah Ikbal: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Fahmida Akter Tisha:** Writing – original draft, Investigation, Formal analysis, Data curation. **Abdullah Ibn Asheque:** Writing – original draft, Resources, Investigation, Formal analysis. **Enamul Hasnat:** Resources, Investigation. **Mohammad Abbas Uddin:** Writing – review & editing, Supervision, Project administration, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors acknowledge the Dyes and Chemical Engineering (DCE) laboratory for all the chemical and instrumental supports.

References

[1] M. Shabbir, J.N. Sheikh, Introduction to textiles and finishing materials, in: M. Shabbir, S. Ahmed, J.N. Sheikh (Eds.), Frontiers of Textile Materials: Polymers, Nanomaterials, Enzymes, and Advanced Modification Techniques, first ed., Wiley-Scrivener Publishing, Beverly, 2020, pp. 1–12.
[2] J. Shen, E. Smith, Enzymatic treatments for sustainable textile processing, in: Sustainable Apparel: Production, Processing and Recycling, Elsevier Inc., 2015, pp. 119–133, https://doi.org/10.1016/B978-1-78242-339-3.00004-2.
[3] R.C. Kuhad, R. Gupta, A. Singh, Microbial cellulases and their industrial applications, Enzym. Res. 2011 (1) (2011), https://doi.org/10.4061/2011/280696.
[4] M.T. Hoque, N.-U.-S. Mazumder, M.T. Islam, Enzymatic wet processing, in: L.J. Rather, M. Shabbir, A. Haji (Eds.), Sustainable Practices in the Textile Industry, first ed., Scrivener- Wiley, Beverly, 2021, pp. 87–110, https://doi.org/10.1002/9781119818915.
[5] B.J. Green, D.H. Beezhold, Industrial fungal enzymes: an occupational allergen perspective, J. Allergy 2011 (2011) 1–11, https://doi.org/10.1155/2011/682574.
[6] T. Gulzar, T. Farooq, S. Kiran, I. Ahmad, A. Hameed, Green chemistry in the wet processing of textiles, in: S. Islam, B.S. Butola (Eds.), The Impact and Prospects of Green Chemistry for Textile Technology, first ed., Elsevier, Amsterdam, 2019, pp. 1–20, https://doi.org/10.1016/B978-0-08-102491-1.00001-0.
[7] A. Sen, R. Kapila, S. Chaudhary, A. Nigam, Biotechnological applications of microbial enzymes to replace chemicals in the textile industry-A review, J. Textil. Assoc. 82 (2) (Sep. 2021) 68–73.
[8] S. Li, X. Yang, S. Yang, M. Zhu, X. Wang, Technology prospecting on enzymes: application, marketing and engineering, Comput. Struct. Biotechnol. J. 2 (3) (Sep. 2012) 1–11, https://doi.org/10.5936/csbj.201209017.
[9] R.H. Bischof, J. Ramoni, B. Seiboth, Cellulases and beyond: the first 70 years of the enzyme producer Trichoderma reesei, Microb. Cell Factories 15 (106) (2016) 1–13, https://doi.org/10.1186/s12934-016-0507-6.
[10] N. Bhardwaj, B. Kumar, K. Agrawal, P. Verma, Current perspective on production and applications of microbial cellulases: a review, Bioresources and Bioprocessing 8 (1) (2021), https://doi.org/10.1186/s40643-021-00447-6. Springer Science and Business Media Deutschland GmbH, Dec. 01.
[11] H.S. Oberoi, Y. Chavan, S. Bansal, G.S. Dhillon, Production of cellulases through solid state fermentation using kinnow pulp as a major substrate, Food Bioprocess Technol. 3 (4) (2010) 528–536, https://doi.org/10.1007/s11947-008-0092-8.
[12] H. Noreen, M. Anjum Zia, S. Ali, T. Hussain, Optimization of bio-polishing of polyester/cotton blended fabrics with cellulases prepared from Aspergillus Niger, Indian J. Biotechnol. 13 (1) (Jan. 2014) 108–113.
[13] R.R. Singhania, M. Adsul, A. Pandey, A.K. Patel, Cellulases, in: A. Pandey, S. Negi, C.R. Soccol (Eds.), Current Developments in Biotechnology and Bioengineering: Production, Isolation and Purification of Industrial Products, first ed., Elsevier Inc., Amsterdam, 2016, pp. 73–101, https://doi.org/10.1016/B978-0-444-63662-1.00004-X.
[14] R. Araújo, M. Casal, A. Cavaco-Paulo, Application of enzymes for textile fibres processing, Biocatal. Biotransform. 26 (5) (2008) 332–349, https://doi.org/10.1080/10242420802390457.
[15] U. Kumari, et al., Validation of leaf enzymes in the detergent and textile industries: launching of a new platform technology, Plant Biotechnol. J. 17 (6) (Jun. 2019) 1167–1182, https://doi.org/10.1111/pbi.13122.
[16] N.A. Ibrahim, K. El-Badry, B.M. Eid, T.M. Hassan, A new approach for biofinishing of cellulose-containing fabrics using acid cellulases, Carbohydr. Polym. 83 (1) (Jan. 2011) 116–121, https://doi.org/10.1016/j.carbpol.2010.07.025.
[17] S.C. Das, M.A. Uddin, BUTEXDCE2022C01: a Qualitative Testing method for assessing Enzymatic biopolishing effect on Textile substrate, in: 1st International Conference on Textile Science & Engineering, BUTEX, Jan. 2022, Dhaka, 2023, pp. 77–85. https://www.butex.edu.bd.
[18] X.-Z. Zhang, Y.-H.P. Zhang, Cellulases: characteristics, sources, production, and applications, in: Bioprocessing Technologies in Biorefinery for Sustainable Production of Fuels, Chemicals, and Polymers, John Wiley & Sons, Inc., 2013, pp. 131–146, https://doi.org/10.1002/9781118642047.ch8.
[19] B. Parameswaran, Sugarcane bagasse, in: P.S. nee' Nigam, A. Pandey (Eds.), Biotechnology for Agro-Industrial Residues Utilisation: Utilisation of Agro-Residues, first ed., Springer Netherlands, Dordrecht, 2009, pp. 240–248, https://doi.org/10.1007/978-1-4020-9942-7.
[20] P. Yadav, et al., Sugarcane Bagasse: an Important Lignocellulosic Substrate for Production of Enzymes and Biofuels, Biomass Convers Biorefin, 2022, pp. 1–32, https://doi.org/10.1007/s13399-022-02791-9.
[21] Y.R. Loh, D. Sujan, M.E. Rahman, C.A. Das, Sugarcane bagasse - the future composite material: a literature review, Resour. Conserv. Recycl. 75 (2013) 14–22, https://doi.org/10.1016/j.resconrec.2013.03.002.
[22] "Bangladesh Sugar & Food Industries Corporation." Accessed: Oct. 26, 2023. [Online]. Available: https://bsfic.gov.bd/.
[23] FAO," FAOSTAT Statistics Database. Accessed: Oct. 26, 2023. [Online]. Available: https://www.fao.org/faostat/en/#home.
[24] S.M.I. Hossain, M.A. Zaman, M.M. Huq, M. Abdullah, Potential of sugarcane as a renewable source of energy in Bangladesh, Journal of Agricultural Machinery & Mechanics 1 (1) (1994) 47–52.
[25] M. Inyang, B. Gao, P. Pullammanappallil, W. Ding, A.R. Zimmerman, Biochar from anaerobically digested sugarcane bagasse, Bioresour. Technol. 101 (22) (Nov. 2010) 8868–8872, https://doi.org/10.1016/j.biortech.2010.06.088.
[26] Anu Alokika, A. Kumar, V. Kumar, B. Singh, Cellulosic and hemicellulosic fractions of sugarcane bagasse: potential, challenges and future perspective, Int. J. Biol. Macromol. 169 (2021) 564–582, https://doi.org/10.1016/j.ijbiomac.2020.12.175.
[27] T.C. Mokhena, M.J. Mochane, T.E. Motaung, L.Z. Linganiso, O.M. Thekisoe, S.P. Songca, Sugarcane bagasse and cellulose polymer composites, in: A. De Oliveira (Ed.), Sugarcane - Technology and Research, first ed., IntechOpen, London, 2018, pp. 225–240, https://doi.org/10.5772/intechopen.71497.
[28] L. Alves, E. Ferreira Cruz, S.I. Lopes, P.M. Faria, A.M. Rosado da Cruz, Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: a review, Waste Manag. Res. 40 (1) (2022) 3–23, https://doi.org/10.1177/0734242X211052858.
[29] W.D. Schindler, P.J. Hauser, Finishing with enzymes: bio-finishes for cellulose, in: Chemical Finishing of Textiles, first ed., Woodhead Publishing Limited, Cambridge, 2004, pp. 181–188.