A sustainable and green process for scouring of cotton fabrics using xylano-pectinolytic synergism: switching from noxious chemicals to eco-friendly catalysts

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Abstract

The objective of this research was to develop an appropriate, eco-friendly, cost-effective bioscouring methodology for removing natural impurities from cotton fabric. Maximum bioscouring was achieved using 5.0 IU xylanase and 4.0 IU pectinase with material to liquid ratio of 1:15 in a 50 mM buffer (glycine–NaOH buffer, 1.0 mM EDTA and 1% Tween-80, pH 8.5) with a treatment time of 60 min at 50 °C and an agitation speed of 60 rpm. The bioscouring cotton fabrics showed a gain of 1.17% in whiteness, 3.23% in brightness and a reduction of 4.18% in yellowness in comparison to fabric scoured with an alkaline scouring method. Further, after bleaching, the whiteness, brightness and tensile strength of the bioscouring fabrics were increased by 2.18, 2.33 and 11.74% along with a decrease of 4.61% in yellowness of bioscouring plus bleached fabrics in comparison to chemically scoured plus bleached fabrics. From the results, it is clear that bioscouring is more efficient, energy saving and an eco-friendly process and has the potential to replace the environment-damaging scouring process with the xylano-pectinolytic bioscouring process.

Keywords Cotton fabric · Alkaline scouring · Bioscouring · Bleaching · Eco-friendly

Introduction

Cotton is the top-grade raw material for the textile industries. The raw cotton fibers are composed mainly of cellulose and are surrounded by hydrophobic layers of natural impurities such as hemicellulose, pectin, lignin, fats, waxes, proteins and mineral compounds. These natural hydrophobic impurities must be removed to make cotton fibers hydrophilic and suitable for industrial applications (Ahlawat et al. 2009; Battan et al. 2012; Ledakowicz et al. 2007). Textile industries are using traditional scouring processes in which high temperature, high pH and environment-damaging chemicals are

being used to remove these impurities. Such harsh chemical processes not only remove the impurities from the raw cotton fabrics, but also attack the cellulosic component of cotton, thus affecting the quality of the fabric by causing decrease in weight and strength (Battan et al. 2012; Mojsov 2016; Nalankilli et al. 2008). Also, the effluents from such processes are highly alkaline and are also high in BOD, COD and TDS values, which are harmful for the environment (Ledakowicz et al. 2007). Furthermore, after alkaline scouring, extensive washing of the fabrics is required, which also leads to wastage of water resources.

Alternatively cost-effective, energy saving and eco-friendly processes are required for textile industries (Singh et al. 2012). It is thus desirable that processes should operate at lower temperature so as to conserve the energy and also at low pH to avoid unacceptable damage to textile fibers. The use of microbial enzymes for textile fiber processing has increased significantly, as they cause less damage to fibers, improve fabric quality, require less energy and use less environment-damaging chemicals. (Chiliveri and Linga 2014; Dhiman et al. 2008; Joshi et al. 2013; Mojsov 2016; Shanthi and Krishnabai 2013). Bioscouring produces good quality fibers with more softness and better strength.

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In this study, bioscouring process using xylano-pectinolytic enzymes produced by a microbial isolate have been reported. Concurrent production of these xylano-pectinolytic enzymes in the same production medium by a microbial isolate utilizing agricultural wastes decreases the manufacturing cost in comparison to the production of these two enzymes in different production media and thus makes the strategy cost-efficient. There are only few reports on fungi such as *Aspergillus awamori*, thermophilic fungi belonging to *Deuteromyces*, *Aspergillus flavus*, *Thermomyces lanuginosus* and *Aspergillus niger* (Botella et al. 2007; Gomes et al. 1992; Mellon 2015; Mendoza 2006; Rodriguez-Fernandez et al. 2011) and also very few on bacteria such as *Streptomyces* sp. (Beg et al. 2000) and *Bacillus pumilus* (Kaur et al. 2011), which have also been shown to produce xylanases and pectinases concurrently by the same microbial isolate.

Materials and methods

Materials

Bacillus pumilus strain AJK (MTCC culture collection accession number 10,414), capable of producing industrially important xylanase and pectinase in the same production medium concurrently, was used in this study. The strain was routinely subcultured and maintained on nutrient agar (pH 7.0) containing (g/l) peptone 5.0, beef extract 3.0, NaCl 5.0 and agar 15.0. The substrates, such as xylan and polygalacturonic acid, used for the estimation of xylanase and pectinase activity were purchased from Sigma-Aldrich, USA, while all other chemicals were purchased from HiMedia Laboratories, India. However, sodium silicate and hydrogen peroxide were purchased from SDFCL, India, and RANKEM, India. Undegummed cotton fabric, utilized for scouring purpose, was specially fabricated using handlooms from Textile City, Panipat, Haryana, India.

Production and estimation of xylanase and pectinase

Xylanase and pectinase were produced under submerged fermentation in 250 ml Erlenmeyer flasks containing 50 ml basal medium with 0.5% peptone and 10 mM MgSO₄ (pH 7.0), supplemented with 2% wheat bran and 2% citrus peel (Kaur et al. 2017). The medium was inoculated with a 2% inoculum of a 21-h-old bacterial culture and incubated at 37 °C for 60 h in an orbital incubator shaker at 200 rpm. After 60 h growth, the cells were harvested by centrifugation and the clear supernatant obtained was used for enzymes activity assay according to the method given by Miller (1959). Enzyme aliquots were added to 490 µl of substrates prepared in 0.1 M glycine–NaOH buffer (1% birchwood

xylan, pH 8.5, for determining xylanase activity and 0.5% polygalacturonic acid, pH 9.0, for determining pectinase activity) and the total volume of the reaction was made to 500 µl. It was incubated at 55 °C for 10 min and the release of sugars was measured using 3, 5-dinitrosalicylic acid reagent. One unit of xylanase or pectinase is the amount of enzyme that catalyzes the release of 1 µmole of reducing sugar equivalent of xylose or galacturonic acid, respectively, per minute.

Scouring and bleaching of cotton fabric

In this section, bioscouring of cotton fabric was carried out with xylanase and pectinase enzymes and compared with alkaline scouring. Further, the effect of bleaching on bioscoured and alkaline-scoured fabric was also checked.

Bioscouring using xylanase and pectinase

Different conditions were optimized by employing one variable at a time approach to study the optical and physical properties of the cotton fabric. For each treatment, 1 g of cotton fabric was used. The enzymatic treatment was carried out at different pH values (7.0–9.5) and buffer molarity (10–100 mM) to get the most effective bioscouring condition. Sodium phosphate buffer and glycine–NaOH buffer was used for the pH range of 7.0–8.0 and 8.5–9.5, respectively. The processing material to liquid ratio (ratio of cotton fabric to liquid medium containing enzymes and other ingredients) in the range of 1:10–1:30 was also optimized so as to obtain the best scouring conditions. Different enzyme doses (1.0–10.0 IU of xylanase and 0.8–8.0 IU of pectinase) per gram cotton fabric were used for different treatment time periods (15–150 min) at temperatures varying from 40 to 60 °C. The treatment was carried out in flasks using water bath incubator shaker with agitation speed ranging from 50 to 75 rpm. Different concentrations (0.1–5.0 mM) of EDTA were also tried to enhance different optical properties of the cotton fabrics. To improve the water absorbancy, different wetting agents were used such as lissapol-D, Tween-20, Tween-80, Triton X-100 and Brij-35. The concentration of the most effective wetting agent was also optimized in a range of 0.1–2.0% for getting the most effective scouring condition. To ensure the uniform distribution of xylano-pectinolytic enzymes on to the cotton fabric, the enzyme preparation was first added to the liquid reaction medium and mixed properly, followed by the addition of the fabric into the liquid reaction medium. This step facilitated the maximum removal of non-cellulosic impurities from the raw cotton fabric. Similarly, for control experiments, treatments were carried out under the same reaction conditions, but using inactivated enzymes. After each enzymatic treatment, the treated fabrics were washed in warm water followed by

drying in an oven at 45 °C. All the experiments were carried out in triplicate.

Alkaline scouring

A slightly modified method of Joshi et al. (2013) was used for alkaline scouring of cotton fabric. The treatment was carried out using a solution containing sodium hydroxide (10 g/l), soda ash (5 g/l) and non-ionic wetting agent Tween 80 (2 g/l) at 90 °C for 60 min. The material to liquid ratio was adjusted similarly to that optimized for the bioscouring treatment. After scouring, the treated fabrics were washed several times in water and after that oven dried at 45 °C. Control samples (fabrics in the deionised water) were subjected to the same treatment conditions, but without addition of chemicals. All the experiments were carried out in triplicate.

Bleaching

A slightly modified method of Joshi et al. (2013) was used for bleaching of bioscoured and scoured fabrics. A solution containing hydrogen peroxide (5 g/l, 30%), sodium carbonate (3 g/l), sodium silicate (2 g/l) and non-ionic wetting agent (Tween 80, 2 g/l) was used for bleaching at 85 °C for 60 min. After each treatment of bleaching, the treated fabrics were washed with water, followed by drying in an oven at 45 °C. All the experiments were carried out in triplicate.

Analysis of the properties of cotton fabric and fabric-free filtrates

- Reducing sugars released after each scouring treatment were measured using 3, 5-dinitrosalicylic acid method (Miller 1959).
- After treatment, the weight loss of each fabric sample was determined by drying the sample in an oven at 45 °C. To calculate the %weight loss of each fabric sample, the following formula was used:

$$\% \text{Weight loss} = (W1 - W2) \times 100 / W1,$$

where W1 and W2 are the dry weights of the cotton fabric before and after a particular treatment, respectively (Aly et al. 2004).

- The whiteness index on the Hunter scale (Hunter 1975), brightness on the ISO 2470 scale (ISO 2470 1977) and yellowness on the ASTM-E-313 scale (ASTM-E-313 1974) were measured using a Macbeth Color-Eye® spectrophotometer.
- Water absorbancy of the samples was tested using AATCC Test methods 39-1980 (AATCC Technical Manual 1980) by water drop test, counting the elapsed time between the contact of the water drop with the fabric

and the disappearance of the drop into the fabrics. Three readings were taken from different locations of the cotton fabric sample and the average was reported. A wetting time of under 1 s was considered as a sign of sufficient water absorbancy of the fabrics (Li and Hardin 1998).

- A digital tensile strength tester 'Paramount' was used for measurement of the tensile strength of the fabric samples.
- A light microscope with magnification at 1000× was used for examination of raw, bioscoured and scoured fibers.

Results and discussion

Optimization of bioscouring parameters

Different reaction conditions were optimized to make the cotton fabric suitable for the textile industries. Bioscouring was more effective at pH 8.5 and 50 mM buffer ionic strength (Table 1). The removal of non-cellulosic impurities was maximum at a material to liquid ratio (MLR) of 1:15 using an optimal enzyme dose of 5.0 IU of xylanase and 4.0 IU of pectinase per gram of cotton fabrics (Table 2). Various properties of cotton fabrics were improved after a treatment time of 60 min at a temperature of 50 °C (Table 3). An agitation speed of 60 rpm and EDTA at a concentration of 1.0 mM were also optimized for effective removal of impurities from the cotton fabrics (Table 4). Several researchers have reported that the removal of impurities can be increased with addition of EDTA during bioscouring (Adamsen et al. 2002; Ahlawat et al. 2009; Akin et al. 2004; Battan et al. 2012; Csiszar et al. 2004; Foulk et al. 2008; Henriksson et al. 1997; Sharma 1986). EDTA appears to help in the formation of free and open regions for the enzymes (Losonczi et al. 2005). Among the different wetting agents used, Tween-80 was optimized at a concentration of 1% to increase the efficiency of these enzymes for scouring of cotton fabrics (Table 5). Wetting agents reduced the surface tension on to the fibers, which ultimately improved the penetration of the enzymes into the fibers (Losonczi et al. 2005). Ahlawat et al. (2009) and Dhiman et al. (2008) have studied the synergistic impact of EDTA and wetting agent in bioscouring of cotton fabrics using xylanase enzyme. Li and Hardin (1998) investigated the impact of enzymes, surfactants and agitation during scouring of cotton fibers and concluded that the effect of agitation and surfactants depends on the nature of fiber and type of enzymes used in the process. Kalantzi et al. (2008) carried out bioscouring of cotton fabric utilizing pectinase in the presence of a non-ionic wetting agent (0.1%) at pH 8.0 of 50 mM buffer, temperature 50 °C and agitation speed 50 rpm, using a material to liquid ratio (MLR) of 1:40. Enzymatic scouring of cotton fibers using pectinase was performed at pH 8.0 and temperature 55 °C

Table 1 Effect of buffer pH and buffer molarity on bioscouring of cotton fabrics

Buffer pH	Buffer molarity (mM)	Sugar (mg/g fabric)	Weight loss (%)	Whiteness	Yellowness	Brightness
Buffer pH						
7.0 C	100	0.53±0.02	0.97±0.03	74.81±0.05	17.44±0.02	52.11±0.03
7.0 T	100	0.94±0.03	1.25±0.02	75.77±0.02	16.76±0.03	53.48±0.04
7.5 C	100	0.55±0.04	1.03±0.04	74.86±0.04	17.42±0.05	52.14±0.02
7.5 T	100	1.01±0.05	1.31±0.02	76.02±0.03	16.63±0.04	53.73±0.05
8.0 C	100	0.57±0.02	1.06±0.01	74.90±0.02	17.41±0.06	52.17±0.01
8.0 T	100	1.08±0.03	1.37±0.03	76.20±0.04	16.53±0.07	53.90±0.07
8.5 C	100	0.58±0.04	1.07±0.05	74.92±0.02	17.40±0.08	52.18±0.06
8.5 T	100	1.11±0.05	1.43±0.03	76.35±0.03	16.42±0.02	54.15±0.01
9.0 C	100	0.57±0.04	1.07±0.04	74.90±0.05	17.41±0.05	52.16±0.02
9.0 T	100	1.07±0.03	1.40±0.07	76.14±0.06	16.56±0.04	53.87±0.03
9.5 C	100	0.55±0.02	1.05±0.06	74.87±0.03	17.43±0.06	52.13±0.04
9.5 T	100	0.98±0.01	1.33±0.04	75.90±0.07	16.68±0.08	53.65±0.09
Buffer molarity (mM)						
8.5	10	0.93±0.02	1.23±0.03	75.72±0.02	16.82±0.02	53.44±0.03
8.5	25	1.05±0.01	1.36±0.02	76.08±0.04	16.61±0.05	53.82±0.02
8.5	50	1.11±0.03	1.43±0.04	76.35±0.05	16.42±0.04	54.15±0.04
8.5	75	1.10±0.04	1.43±0.05	76.35±0.03	16.42±0.06	54.15±0.05
8.5	100	1.11±0.02	1.43±0.02	76.35±0.02	16.42±0.03	54.15±0.02

C control, T test

These experiments were performed at MLR of 1:25, enzyme dose of 7.5 IU of xylanase and 6.0 IU of pectinase, treatment time of 90 min, temperature of 50 °C and agitation speed of 60 rpm

Table 2 Effect of material to liquor ratio (MLR) and enzyme dose on bioscouring of cotton fabrics

MLR	Enzyme dose (IU) (X:P)	Sugar (mg/g fabric)	Weight loss (%)	Whiteness	Yellowness	Brightness
MLR						
1:10	7.5:6.0	1.14±0.02	1.45±0.01	76.62±0.03	16.10±0.02	54.35±0.04
1:15	7.5:6.0	1.19±0.03	1.53±0.03	76.95±0.05	15.94±0.03	54.71±0.02
1:20	7.5:6.0	1.15±0.04	1.49±0.02	76.68±0.02	16.15±0.04	54.42±0.03
1:25	7.5:6.0	1.11±0.02	1.43±0.01	76.35±0.04	16.42±0.05	54.15±0.01
1:30	7.5:6.0	1.04±0.03	1.32±0.05	76.12±0.01	16.58±0.03	53.76±0.05
Enzyme dose						
1:15	—	0.67±0.02	1.14±0.03	74.97±0.02	17.38±0.03	52.20±0.02
1:15	1.0:0.8	0.84±0.01	1.23±0.02	75.42±0.02	16.91±0.02	53.27±0.03
1:15	2.5:2.0	0.97±0.02	1.31±0.01	76.24±0.04	16.57±0.05	54.18±0.04
1:15	5.0:4.0	1.19±0.03	1.53±0.02	76.95±0.01	15.94±0.04	54.71±0.05
1:15	7.5:6.0	1.19±0.01	1.53±0.03	76.95±0.03	15.94±0.06	54.71±0.02
1:15	10.0:8.0	1.19±0.04	1.53±0.04	76.95±0.05	15.94±0.05	54.71±0.01

These experiments were performed at pH 8.5, 50 mM buffer molarity, treatment time of 90 min, temperature of 50 °C and agitation speed of 60 rpm

for 1 h treatment time (Nalankilli et al. 2008). Dhiman et al. (2008) demonstrated that bioscouring of cotton fabrics was more efficient at pH 9.5, temperature 70 °C and after a treatment period of 180 min using a xylanase dose of 5 g/l, while bioscouring of cotton fabric was most effective at pH 9.5 and temperature 65 °C, using an enzyme dose of 5 IU of

pectinase per gram fabric after a treatment time of 180 min (Ahlawat et al. 2009). Similarly, Battan et al. (2012) also reported that xylanase dose of 5 U/g fabric is sufficient for bioscouring of cotton fabrics at pH 7.0 after a treatment time of 60 min. Joshi et al. (2013) have reported maximum bioscouring efficiency, when carried out using pectinase at

Table 3 Effect of time period and temperature on bioscouring of cotton fabrics

Time (min)	Temp (°C)	Sugar (mg/g fabric)	Weight loss (%)	Whiteness	Yellowness	Brightness
Time						
15	50	0.93±0.02	1.23±0.02	75.72±0.02	16.65±0.03	53.65±0.02
30	50	1.04±0.01	1.35±0.03	76.25±0.01	16.31±0.02	53.96±0.03
45	50	1.13±0.03	1.44±0.05	76.63±0.03	16.18±0.05	54.32±0.04
60	50	1.19±0.04	1.53±0.02	76.95±0.04	15.94±0.04	54.71±0.05
75	50	1.19±0.01	1.53±0.01	76.92±0.02	15.95±0.01	54.70±0.04
90	50	1.19±0.02	1.54±0.02	76.90±0.05	15.95±0.02	54.68±0.05
120	50	1.19±0.03	1.53±0.03	76.85±0.01	15.98±0.03	54.63±0.01
150	50	1.19±0.01	1.53±0.01	76.81±0.02	16.02±0.01	54.56±0.02
Temperature						
60	40 C	0.57±0.03	1.08±0.02	74.85±0.02	17.43±0.05	52.15±0.02
60	40 T	1.03±0.02	1.31±0.03	76.23±0.03	16.32±0.02	54.83±0.03
60	45 C	0.63±0.04	1.11±0.05	74.92±0.04	17.41±0.04	52.18±0.04
60	45 T	1.12±0.05	1.46±0.04	76.60±0.05	16.20±0.02	54.32±0.02
60	50 C	0.67±0.01	1.14±0.06	74.97±0.02	17.38±0.01	52.20±0.01
60	50 T	1.19±0.02	1.53±0.04	76.95±0.01	15.94±0.04	54.71±0.03
60	55 C	0.67±0.03	1.13±0.02	75.01±0.02	17.36±0.05	52.21±0.01
60	55 T	1.11±0.02	1.48±0.05	76.52±0.01	16.23±0.02	54.27±0.03
60	60 C	0.65±0.04	1.12±0.04	75.03±0.02	17.32±0.01	52.24±0.02
60	60 T	1.02±0.03	1.43±0.02	76.20±0.04	16.36±0.03	53.80±0.01

These experiments were performed at pH 8.5, 50 mM buffer molarity, MLR of 1:15, enzyme dose of 5.0 IU of xylanase and 4.0 IU of pectinase, and agitation speed of 60 rpm

Table 4 Effect of agitation speed and EDTA on bioscouring of cotton fabrics

Agitation (rpm)	EDTA (mM)	Sugar (mg/g fabric)	Weight loss (%)	Whiteness	Yellowness	Brightness
Agitation						
Static	–	1.11±0.02	1.42±0.03	76.35±0.04	16.43±0.02	53.95±0.03
50	–	1.14±0.04	1.49±0.02	76.67±0.05	16.28±0.03	54.21±0.02
55	–	1.17±0.05	1.51±0.04	76.81±0.02	16.12±0.04	54.47±0.01
60	–	1.19±0.01	1.53±0.05	76.95±0.04	15.94±0.01	54.71±0.04
65	–	1.13±0.04	1.48±0.06	76.63±0.03	16.32±0.02	54.12±0.03
70	–	1.04±0.03	1.32±0.04	76.28±0.02	16.57±0.03	53.82±0.02
75	–	0.94±0.02	1.25±0.02	75.82±0.01	16.71±0.04	53.56±0.01
EDTA (mM)						
60	–	1.19±0.02	1.53±0.04	76.95±0.01	15.94±0.03	54.71±0.02
60	0.1	1.23±0.03	1.55±0.03	77.16±0.02	15.87±0.04	54.83±0.03
60	0.5	1.27±0.01	1.59±0.01	77.33±0.04	15.76±0.01	54.96±0.01
60	1.0	1.31±0.02	1.64±0.02	77.62±0.03	15.63±0.05	55.13±0.04
60	1.5	1.30±0.03	1.62±0.04	77.60±0.02	15.61±0.02	55.08±0.02
60	2.0	1.27±0.01	1.58±0.02	77.41±0.01	15.82±0.03	54.92±0.04
60	2.5	1.18±0.02	1.51±0.04	77.22±0.04	15.91±0.06	54.76±0.06
60	5.0	1.07±0.02	1.39±0.02	76.83±0.02	16.04±0.04	54.63±0.05

These experiments were performed at pH 8.5, 50 mM buffer molarity, MLR of 1:15, enzyme dose of 5.0 IU of xylanase and 4.0 IU of pectinase, treatment time of 60 min and temperature of 50 °C

a dose of 2.8 IU/g of the fabric, at pH 7.0 and temperature 60 °C for 120 min with a material to liquid ratio (MLR) of 1:30. Shanthi and Krishnabai (2013) have showed the

best scouring efficiency at pH 8.5 and temperature 55 °C, using pectate lyase after a treatment period of 30 min with a material to liquid ratio (MLR) of 1:10. Chiliveri and Linga

Table 5 Effect of wetting agents and Tween-80 on bioscouring of cotton fabrics

Wetting agents (2%)	Tween-80	Sugar (mg/g fabric)	Weight loss (%)	Whiteness	Yellowness	Brightness
Wetting agents (2%)						
Control	–	0.67 ± 0.03	1.16 ± 0.03	74.88 ± 0.02	17.34 ± 0.02	52.20 ± 0.04
Lissapol D	–	1.17 ± 0.02	1.47 ± 0.05	76.67 ± 0.01	15.95 ± 0.04	54.82 ± 0.02
Control	–	0.76 ± 0.04	1.34 ± 0.02	74.97 ± 0.03	17.29 ± 0.01	52.27 ± 0.03
Tween-20	–	1.37 ± 0.01	1.62 ± 0.01	77.25 ± 0.02	15.61 ± 0.03	55.38 ± 0.01
Control	–	0.81 ± 0.02	1.42 ± 0.03	75.28 ± 0.04	17.23 ± 0.04	52.36 ± 0.05
Tween-80	–	1.46 ± 0.03	1.71 ± 0.04	78.32 ± 0.05	15.25 ± 0.02	55.64 ± 0.02
Control	–	0.71 ± 0.05	1.29 ± 0.02	75.12 ± 0.01	17.31 ± 0.05	52.23 ± 0.01
Triton X-100	–	1.29 ± 0.04	1.56 ± 0.05	77.43 ± 0.03	15.72 ± 0.01	55.14 ± 0.03
Control	–	0.61 ± 0.02	1.37 ± 0.03	74.83 ± 0.04	17.40 ± 0.05	52.16 ± 0.02
Brij-35	–	1.13 ± 0.07	1.61 ± 0.09	76.30 ± 0.03	16.13 ± 0.07	54.56 ± 0.06
Tween-80						
Tween-80	0.10	1.35 ± 0.02	1.67 ± 0.01	77.78 ± 0.03	15.51 ± 0.04	55.20 ± 0.03
Tween-80	0.25	1.39 ± 0.01	1.69 ± 0.04	77.91 ± 0.02	15.38 ± 0.02	55.33 ± 0.02
Tween-80	0.50	1.43 ± 0.03	1.72 ± 0.03	78.18 ± 0.04	15.29 ± 0.03	55.58 ± 0.01
Tween-80	0.75	1.47 ± 0.04	1.76 ± 0.02	78.31 ± 0.01	15.18 ± 0.02	55.72 ± 0.04
Tween-80	1.0	1.55 ± 0.02	1.81 ± 0.04	78.53 ± 0.02	15.12 ± 0.01	55.87 ± 0.02
Tween-80	1.25	1.52 ± 0.05	1.77 ± 0.02	78.46 ± 0.03	15.12 ± 0.04	55.81 ± 0.05
Tween-80	1.50	1.50 ± 0.06	1.75 ± 0.03	78.40 ± 0.05	15.16 ± 0.02	55.76 ± 0.03
Tween-80	1.75	1.48 ± 0.02	1.72 ± 0.04	78.35 ± 0.01	15.21 ± 0.03	55.72 ± 0.02
Tween-80	2.0	1.46 ± 0.04	1.71 ± 0.06	78.32 ± 0.02	15.25 ± 0.05	55.64 ± 0.05

These experiments were performed at pH 8.5, 50 mM buffer molarity, MLR of 1:15, enzyme dose of 5.0 IU of xylanase and 4.0 IU of pectinase, treatment time of 60 min and temperature of 50 °C, agitation speed of 60 rpm and EDTA concentration of 1.0 mM

(2014) have reported a maximum bioscouring efficiency of pectate lyase using 100 U/g fabric at temperature 50 °C and pH 9.0 after 30 min of treatment time. Mojsov et al. (2016) found the maximum bioscouring efficiency of pectinase at pH 8.0 and temperature 55 °C after a treatment time of 60 min. After optimizing all necessary reaction conditions for bioscouring, the whiteness and brightness of bioscoured fabrics were increased by 4.31 and 6.70% as compared to the control (fabric treated with inactivated enzymes) sample. A decrease was also seen in the yellowness of the fabrics. After bioscouring, a decrease of 12.24% in yellowness was also noticed (Table 6). Besides that, the other important property of these xylano-pectinolytic enzymes is that they showed their optimal catalytic activity at 50 °C, making the process energy efficient. So, the working of these enzymes at very

low temperature, in comparison to very high temperature (nearly boiling) used in the traditional scouring method, makes this process energy efficient, eco-friendly and valuable for the textile industries.

Bioscouring/alkaline scouring

When bioscouring was compared with alkaline scouring, it was observed that bioscouring resulted in higher release of reducing sugars as compared to the scouring treatment. Alkaline-scoured fabrics showed 6.63% more weight loss as compared to bioscoured fabrics, which may be due to damage of the fabrics by the chemicals used in the alkaline scouring process. A weight loss of 1.4% has been reported for cotton fabric after a treatment time of 1 h in

Table 6 Comparison between different properties of bioscoured and scoured cotton fabrics

Treatment type	Sugar (mg/g fabric)	Weight loss (%)	Whiteness	Yellowness	Brightness	Drop test (s)
Bioscouring/scouring						
Control	0.81 ± 0.03	1.42 ± 0.02	75.28 ± 0.01	17.23 ± 0.03	52.36 ± 0.02	< 1
Bioscouring	1.55 ± 0.02	1.81 ± 0.03	78.53 ± 0.03	15.12 ± 0.02	55.87 ± 0.03	< 1
Control	0.74 ± 0.02	1.36 ± 0.01	74.80 ± 0.02	17.45 ± 0.01	52.08 ± 0.02	26
Scouring	1.43 ± 0.04	1.93 ± 0.08	77.62 ± 0.04	15.78 ± 0.04	54.12 ± 0.05	2.7

an agitated system using commercial xylanase plus chelating agent (Csiszar et al. 2001). Nalankilli et al. (2008) also recorded high weight loss of the alkali-scoured cotton fibers in comparison to bioscoured fibers treated with pectinase enzymes. A weight loss of only 0.89% has been noticed after bioscouring of cotton fabric with pectinase as compared to high weight loss of 4.9% by conventional alkaline scouring (Rajendran et al. 2011). Similarly, a weight loss of 1.5% was obtained after scouring of cotton fabric using xylanase dose of 5 IU/gat pH 7.0 after a treatment time of 1 h in an agitated system (Battan et al. 2012). Mojsov (2016) has also reported that alkaline scouring resulted in higher weight loss (1.58%) as compared to bioscouring using alkaline and acid pectinases (0.94 and 0.37%).

The present study showed that bioscoured fabrics have more whiteness and brightness and less yellowness as compared to scoured fabrics. A gain of 1.17% in whiteness, 3.23% in brightness and a reduction of 4.18% in yellowness was obtained for bioscoured cotton fabrics in comparison to the fabrics scoured with an alkaline method. Ahlawat et al. (2009) have reported an increase of 1.2% whiteness of pectinase-treated cotton fabrics over conventional alkaline-scoured fabrics. Battan et al. (2012) observed 0.9% higher whiteness in bioscoured cotton fabrics using xylanase as compared to chemically scoured fabric. Bioscouring also improved the water absorbancy of cotton fabrics. A wetting time of less than 1 s was observed for bioscoured fabrics, while chemically scoured fabrics showed a wetting time of 2.7 s, which proves that bioscoured fabrics are more hydrophilic in nature. Several workers have reported an improvement in water absorbancy of cotton fabrics using wetting agents along with enzyme xylanase (Battan et al. 2012; Dhi-man et al. 2008; Wang et al. 2007) and pectinase (Ahlawat

et al. 2009; Kalantzi et al. 2008; Mojsov 2016; Shanthi and Krishnabai 2013; Spicka et al. 2015; Vigneswaran et al. 2012).

Efficiency of xylano-pectinolytic enzymes in improving the different physical properties can also be seen from the pictures clicked after bioscouring and chemical scouring (Fig. 1). Abdel-Halim et al. (2008) also confirmed that the enzymatically scoured fabric has better optical properties than the conventionally scoured fabric. Traditionally, a high temperature, high pH and alkaline chemicals are utilized for scouring of cotton fabrics, which has several disadvantages such as loss of fiber, toxic effluent and high energy consumption, (Karmakar 1999; Lenting and Warmoeskerken 2004). In comparison to harsh alkaline conditions employed traditionally, treatment of textile fibers by xylan- and pectin-degrading enzymes might not affect the cellulosic part of the fabric and avoid fiber damage and wastewater pollution (Rouette 2001). Similarly, Chiliveri and Linga (2014) have reported that scouring using specific enzymes is the best option compared to the traditional scouring method. Singh et al. (2016) also observed that bioscouring is more efficient than alkaline scouring.

Bleaching

Bioscoured and scoured fabrics were further bleached to increase their whiteness and brightness so as to meet the industrial requirement (Fig. 1). After bleaching, an increase of 2.18 and 2.33% in whiteness and brightness of bioscoured plus bleached fabrics was obtained as compared to scoured plus bleached fabrics. Yellowness was also decreased by 4.61%. Similarly, the tensile strength of bioscoured plus bleached fabric was also improved by 11.74% as compared

Fig. 1 Effect of bioscouring, chemical scouring and bleaching treatments on cotton fabrics. **a** Bioscoured fabric obtained after treating the fabric at pH 8.5 with enzyme dose—5.0 IU of xylanase and 4.0 IU of pectinase, treatment time—60 min, temperature—50 °C, EDTA—1 mM and Tween-80—1%. **b** Chemically scoured fabric obtained after treating the fabric with sodium hydroxide—10 g/l,

soda ash—5 g/l and Tween-80—2 g/l at 90 °C for 60 min. **c** Bleaching of bioscoured fabric done with hydrogen peroxide (30%)—5 g/l, sodium carbonate—3 g/l, sodium silicate—2 g/l and Tween-80—2 g/l at 85 °C for 60 min. **d** Bleaching of chemically scoured fabric done with hydrogen peroxide (30%)—5 g/l, sodium carbonate—3 g/l, sodium silicate—2 g/l and Tween-80—2 g/l at 85 °C for 60 min

Table 7 Physical properties of cotton fabrics after bleaching

Fabric type	Whiteness	Yellowness	Brightness	Tensile strength (Kg)
Control	84.15 ± 0.02	7.88 ± 0.02	72.24 ± 0.03	–
Bioscoured fabric + bleaching	88.54 ± 0.03	3.93 ± 0.06	75.52 ± 0.03	15.42 ± 0.02
Control	83.90 ± 0.01	8.07 ± 0.02	71.68 ± 0.02	–
Scoured fabric + bleaching	86.65 ± 0.05	4.12 ± 0.04	73.80 ± 0.05	13.80 ± 0.03

Fig. 2 Microscopic images of raw, bioscoured and chemically scoured cotton fibers. **a** Raw fiber, **b** bioscoured fiber, **c** chemically scoured fiber

to scoured plus bleached fabric (Table 7). Joshi et al. (2013) also noticed almost similar brightness and whiteness values for both pectinase and alkaline-scoured cotton fabrics. However, bioscoured fabrics retained good tensile property in comparison to fabric scoured using the alkaline method.

Fiber characterization

The effectiveness of bioscouring was also supported by the microscopic images of raw, bioscoured and alkaline-scoured fabrics (Fig. 2). The enzymatic and chemical scouring removed the impurities and made the fabrics clean. Bioscouring was more efficient than chemical scouring, as the yellowness of the fabrics was increased after chemical scouring. Sreenath et al. (1996) observed the control and enzyme-treated fabric by light microscopy and observed that an enzymatic mixture of xylanase, pectinase and cellulase removed all protruding surface fibers compared to the untreated control fabric.

Conclusion

This study evaluates the bioscouring efficiency of cotton fabric using xylano-pectinolytic enzymes. Bioscouring with better fabric properties has presented itself as a sustainable and green process for cotton scouring, which requires a lower demand of energy, water, chemicals and time as compared to alkaline scouring, thus completely replacing the conventional environment-damaging process in this study. Moreover, concurrent production of these enzymes by a single microbe utilizing

agricultural wastes decreases the manufacturing cost, which makes the strategy cost efficacious and congruous for various industrial applications. So, this biocompatible approach seems to be safer, attractive, credibly reproducible, commercially feasible and environment-friendly alternative compared to conventional alkaline scouring method, and hence can be successfully adopted by the cotton fabric industries.

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Compliance with ethical standards

Conflict of interest There is no conflict of interest concerning the publication of this article.

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