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Improved Properties of Cotton Fabrics Treated with Lipase and Its Combination with Pectinase

Abstract
A commercial lipase preparation (Lipolase) was examined as a scouring agent for cotton fabrics. Application of the enzyme enabled the creation of wax-free textiles where considerable amounts of pectin and protein were removed. Compositional changes were associated with the modification of the crystallinity index and degree of polymerisation as well as improved hydrophilicity and whiteness of fabrics. Assessment of micromechanical properties by the Kawabata Evaluation System showed that lipase-mediated scouring could be as effective as conventional alkali treatment. Combining lipase with pectinase in a one-step process enabled to reduce the time required for bioscouring and forming fabrics with superior properties and excellent dyeing performance. The features desired were achieved by applying an appropriate mixture of scouring agents for suitable treatment times. The crystallinity index of fabrics could be used as a single variable for predicting their mechanical behaviour.

Key words: *bioscouring, cotton fabrics, crystallinity index, lipase, mechanical properties.*

Introduction

During the processing of cotton fabrics, hydrophobic components of the outermost layer are eliminated in a scouring step, which improves their water absorbency, bleachability and dyeability [1]. Traditionally, industrial scouring is accomplished by treatment with solutions of sodium hydroxide, surfactants and chelators at elevated temperatures [2]. Alternatively, non-cellulosic impurities of the cuticle and primary walls, such as waxes and pectin, can be removed by the action of enzymes under mild reaction conditions [3]. This approach, known as bioscouring, offers considerable advantages over conventional alkali-treatment, including lower water and energy consumption, reduced costs, lessening pollution problems, the preservation of fibre strength and structure, and compatibility with other processes, machinery and materials [3 - 5].

Based on the composition of the fibre surface, several enzymes, such as pectinases, lipases, cutinases, cellulases, hemicellulases and proteases, have been screened as bioscouring agents [6 - 10]. Alkaline pectinase is considered by many researchers as the most suitable enzyme for cotton scouring, presumably because the degradation and elimination of pectin facilitates the removal of loosened waxes [1, 10, 11]. However, enzymatic scouring has not yet been widely employed on an industrial scale due to the partial removal of waxes and extended treatment times [6]. A number of investigators have attempted to boost the effectiveness of bioscouring by applying multi-enzyme schemes. Improved results were achieved by mixtures of pectinase and another enzyme [1, 6, 12 - 14], or multi-step combinations where enzymes were added successively [9, 15].

The involvement of lipolytic activities in bioscouring can be easily justified since the main objective of the process is the removal of waxes, comprised of fatty alcohols, fatty acids and their esters, that form polymers such as suberin and cutin [4, 16, 17]. Examination of lipase efficiency in facilitating scouring, either separately or in combination with other hydrolases, has generated contradictory results. When applied alone, lipase from *Pseudomonas mendocina* and two unspecified lipases exhibited an inadequate performance [7, 12], while more positively porcine pancreas lipase increased the water absorbency of scoured textiles [9]. When used in combination with pectinases, an unspecified lipase had no effect on flax rove properties [18], while *Mucor meihei* lipase (Lipozyme) was quite promising in the scouring of cotton fabrics [14]. The suitability of other lipases as scouring agents remains to be further investigated [7]. The thermostable lipase from *Thermomyces lanuginosus* (TlL), which constitutes a major component of commercial detergents, is a promising candidate with desirable features. Unlike other lipases, its interfacial activation is not dependent on calcium ions [19], whose removal is essential for primary cell wall destabilisation during the scouring process [20]. In addition, both the activity and stability of TlL can be enhanced in the presence of non-ionic surfactants [21, 22]. Such additives supplement scouring agents to improve their performance [20].

The effectiveness of a scouring process can be appraised in various ways. The removal of non-cellulosic elements from textiles is estimated either by the total weight loss or resolving individual components [23]. Several specifically devised techniques, such as the standard AATCC drop test and light reflectance methods, provide a means for assessing the hydrophilicity, bleachability and dyeability of scoured fabrics [9, 24]. In addition, the mechanical behaviour of fabrics subjected to nondestructive, low-stress forces can be quantified using the Kawabata Evaluation System (KES) [25]. KES allows objective and reproducible measurement of a set of parameters including fabric bending, tensile, compression, shear, friction and surface roughness, which can be related to 'hand' aesthetic properties (e.g. smoothness, fullness,

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stiffness, softness, flexibility and crispness) [26].

The aim of the present study was to evaluate the effectiveness of Lipolase (a commercial preparation of *T. lanuginosus* lipase) as a scouring agent for cotton fabrics. The assessment was based on an inclusive set of physicochemical and mechanical properties of bioscoured fabrics and a comparison with those determined after conventional alkaline scouring. The relationship between the chemical composition and properties of cotton fabrics was investigated. Improving the overall process was attempted by combining Lipolase with Bioprep (a commercial pectinase preparation especially designed for bioscouring) in a one-step treatment.

Materials and methods

Materials

A desized, plain woven (52 and 29 yarns·cm^{-1} in the warp and weft directions, respectively) 100% cotton fabric (122 g·m^{-2}), which was kindly provided by Thomoglou Textile Industry S.A. (Greece), was used throughout the present study. Compositional analysis of the untreated material is presented in ***Table 1***. Lipolase 100L with *T. lanuginosus* lipase (TlL) and Bioprep 3000L containing endopectate lyase from genetically modified *Bacillus* sp. were kindly supplied by Novozymes A/S (Denmark). The main enzyme activities detected in these commercial preparations are given in ***Table 2***.

Determination of enzyme activities

Lipase activity was determined against p-nitrophenyl-propionate (pNPP) at pH 7.0 and 25 °C [27]. The release of p-nitrophenol was monitored (5 min) spectrophotometrically at 410 nm with the aid of a microplate reader (Molecular Devices Corporation, Sunnuvale, USA). The reaction was initiated by adding 10 μL of properly diluted enzyme to 190 μL of substrate solution (0.4 mM). Control reactions with inactivated lipase were used to correct nonenzymatic pNPP hydrolysis. One unit of activity was defined as the amount of enzyme which released 1 μmol of product per minute under the conditions described.

Pectate lyase activity was determined as described in [28]. One unit of pectate lyase activity was defined as the amount of enzyme required to produce 1 μmole of reducing sugars per minute.

Scouring of cotton fabrics

A fabric sample ravelled to a dimension of 10 cm × 5 cm (approximate weight, 3.0 g) was immersed in phosphate buffer (50 mM) at pH 7.0, where Lipolase is mostly active and Bioprep pectate lyase retains 90% of its optimal activity. A non-ionic wetting agent (Sadopane SF 0.1% w/v) and an appropriate amount of enzyme(s) supplemented the solution. The liquor-to-fabric ratio was adjusted to 40:1, and the mixture was incubated at 50 °C and 50 r.p.m for different treatment times. Inactivation of the enzyme(s) was carried out in hot distilled water, which was followed by extensive washing with distilled water and air-drying for at least 24 hours before assessing the fabric's properties [14]. The same procedure, but with the absence of an enzyme, was applied for reference fabrics, while conventional scouring was achieved by sodium hydroxide solutions (2.0%, w/v) [23]. Experiments were carried out in duplicate.

Wettability drop test

Samples were tested at room temperature using the AATCC Test Method 39-1980 [29] The wetting time was defined as the time period between the contact of a water drop with the fabric and its disappearance into the fabric. Ten readings were taken from different locations on the sample and the average reported. A wetting time of less than 1 s was considered as an indication of the adequate absorbency of the fabric [30].

Dyeing procedure

The dyeing of the fabrics was performed in an Ahiba Polimat dyeing machine (Datacolor, Luzern, Switzerland). The textiles were mixed at a 1:100 fabric to-liquor ratio with a solution containing a reactive dye (Blue Herd, Reactive Blue 160) at a concentration of 5% o.w.f, electrolyte (Na_2SO_4, 24.5 g·L^{-1}), and wetting agent (1 g·L^{-1}). The temperature of the bath was increased slowly (0.5 °C/min for approximately 30 min) and maintained at 90 °C for 50 min. After the addition of Na_2CO_3 (20 g·L^{-1}), the dyeing procedure was continued under alkaline conditions for 23 min at the same temperature. Finally, the dyed samples were washed with cold tap water until no residual colour could be observed in the effluent.

Whiteness - colour strength

The whiteness index (WI) of the scoured samples and the colour strength of the dyed fabrics were determined with the aid of Datacolor apparatus, according to methods described previously [23].

Table 1. Chemical composition of cotton fabric.

Component	wt.-% (dry basis)
Waxes	2.1 ± 0.1
Protein	1.2 ± 0.2
Pectin	0.6 ± 0.1
Hemicellulose	1.8 ± 0.3
Cellulose	93.2 ± 1.5
Other	1.2 ± 0.2

Table 2. Main specific activities (in U·mg^{-1} protein) detected in the commercial enzyme preparations used in the present study.

	Lipolase	Bioprep
Lipase	4.10	-
Pectate lyase	-	11.93
Polygalacturonase	-	2.19
Protease	-	0.14
Endoglucanase	-	0.12
Xylanase	-	0.02

Fastness test

The colour fastness to washing was measured by ISO 105-C01 (1989). The change in colour as well as the staining of cotton and other adjacent materials were assessed by means of the appropriate 5-grade grey scales [31].

Polymerisation degree (DP) and crystallinity index (CrI)

The degree of polymerisation (DP) of the fabrics was estimated after dissolution in a copper ethylene diamine solution and measurement of the viscosity, while the crystallinity index (CrI) was determined with the aid of an X-ray diffractometer [23].

Chemical analysis of cotton fabrics

Chemical analysis of cotton fabrics was conducted in triplicate according to a multi-step procedure described before [23]. The method included the drying of samples, the extraction of oils, fats and waxes, enzymatic proteolysis and the isolation of pectic polysaccharides by ammonium oxalate.

Kawabata evaluation system

The low stress mechanical and surface properties of the treated and untreated fabrics were assessed by the Kawabata Evaluation System (KES-FB) under high sensitivity conditions [23]. Three tests

Table 3. Comparison of the physical properties of cotton fabrics treated for 120 min with various levels of Lipolase and those of reference and conventionally scoured materials; CI - Crystallinity index, DP - Degree of polymerisation, WI - Whiteness index.

Type of treatment	CrI, %	DP	WI, %	Wetting time, s
No enzyme	87.0 ± 0.5	2294 ± 13	36.4 ± 0.7	12.5
Lipolase 50 U·g^{-1} fabric	87.3 ± 0.3	2274 ± 36	42.0 ± 0.3	2.5
Lipolase 100 U·g^{-1} fabric	88.2 ± 0.1	2217 ± 34	44.2 ± 0.9	1.5
Lipolase 200 U·g^{-1} fabric	90.2 ± 0.2	2194 ± 12	46.3 ± 0.6	< 1
Lipolase 300 U·g^{-1} fabric	90.1 ± 0.0	2192 ± 20	46.1 ± 0.4	< 1
Alkali-treatment	93.0 ± 0.1	1894 ± 18	54.9 ± 0.2	< 1

per direction were conducted so as to estimate average values of extensibility (EMT) at 500 (gf·cm^{-1}), shear stiffness (G) (gf·cm·degree^{-1}), bending rigidity per unit length (B) (gf·cm^2·cm^{-1}) and compressional resilience (RC) (%). The samples were conditioned at 20 ± 0.5 °C temperature, and 65 ± 5% relative humidity before measuring their properties.

Results and discussion

Chemical analysis

Following treatment with Lipolase, a significant proportion of fatty components, as well as other non-cellulosic impurities of the raw material could be eliminated. The application of various enzyme levels during the bioscouring showed that the removal of waxes and pectin was dependent on the enzyme concentration (***Figure 1***). The highest lipase activity resulted in an almost wax-free fabric. No weight loss could be detected for the control samples treated in scouring solution without enzymes but in otherwise identical conditions. It must be noted that previous attempts to remove waxes using lipases gave poor results [7, 12, 18], except for the study of Sae-be et al., [15] where the successful removal of waxy materials from a fabric prewashed in boiling water was reported.

The fraction of pectin which could be removed by Lipolase was as high as 67%, which is equivalent to the corresponding amount of pectin released when a high dose (500 U·g^{-1} fabric) of commercial pectate lyase preparation was applied to the same material under the same conditions [23]. The simultaneous release of pectin and waxes, which are located in close proximity to each other in the outer cuticle of the cell wall, was observed when either lipolytic or pectinolytic enzymes were used for bioscouring [15, 32].

In addition to waxy and pectic components, a significant amount of protein, which varied between 20% and 37% of the initial content, could be removed. The application of high doses of commercial proteases to cotton fabrics was associated with the removal of components which could be as high as 50% of the initial protein content [7]. In contrast to the removal of other non-cellulosic components, the hemicellulosic content of the fabrics was not affected by treatment with Lipolase.

The addition of surfactant in the form of a non-ionic wetting agent, probably an ingredient of a commercial detergent preparation such as Lipolase, may contribute to the outstanding performance of TlL in several ways: The presence of surfactant molecules can accelerate the wetting of fabric at the start of the process, promote enzyme adsorption by the textile, and assist in the removal of degraded pectin and hydrophobic material, which are of major importance in the bioscouring process [33]. Furthermore, non-ionic detergents, such as the one used in the present study, activate TlL through a non interfacial activation mechanism without destabilising the protein [22].

Physical properties

A broad set of physical properties for Lipolase-treated cotton fabrics is presented in ***Table 3***. The results are compared with corresponding values for reference and conventionally-treated fabrics. The CrI increased considerably after treatment with high Lipolase concentrations, which is in agreement with previous reports where the CrI of a knitted greige cotton fabric increased significantly when it was treated with porcine pancreas lipase [9]. Changes in CrI after the enzymatic treatment of fabrics have been attributed to the removal of amorphous material [23]. When higher Lipolase concentrations were implemented the DP decreased. It is possible that reduced DP values may result from the elimination of non-cellulosic materials of the fibre, which interfere with DP measurement [23]. Information concerning the DP of lipase-treated fabrics is not available in the literature.

The WI of cotton fabrics increased significantly after treatment with Lipolase, which can be attributed to the removal of colouring materials, such as gossypol and resins, which have been reported among the constituents of cotton waxes [20]. Contradictory results have been cited in literature concerning the whiteness of cotton fabrics treated with lipases. After pre-washing and treatment with porcine pancreas lipase, a knitted fabric displayed an improved WI [15], whereas a plain woven fabric scoured with the same enzyme showed a marginally increased WI [9].

As a result of the extended removal of non-cellulosic contaminants, Lipolase-treated cotton fabrics exhibited similar wetting times to those of alkali-scoured materials, indicating equally high hydrophilicity (***Table 3***). Contrary to this, Hartzell et al demonstrated that treatment with porcine pancreas lipase at high enzyme doses had practically no effect on textile absorbency [12]. Furthermore, Sae-be et al. reported that fabrics treated with the same lipase showed poor absorbency (wetting time higher than 30 s) [15]. In contrast, Sangwatanaroj et al. reported that the extent of the hydrophilicity of bioscoured fabrics depends on the type of raw material; thin plain woven fabric treated with lipase showed instantaneous water absorption [9].

Micromechanical properties

The effect of lipase-mediated scouring on the mechanical properties of textiles is a topic which deserves more attention. Previous studies reported that the bursting strength of fabrics remains unaffected following treatment with lipase [15], while the breaking load increases in both weave components [9]. Comparison of the micromechanical properties displayed by Lipolase-treated cotton fabrics, as well as those exhibited by reference and alkali-treated fabrics is presented in ***Table 4***. The treatment of fabrics with Lipolase resulted in the significant improvement of their properties, which were comparable or superior to those estimated after traditional chemical scouring. When increasing the amount of Lipolase, a positive effect on the fabric's mechanical properties could be observed. The best results were obtained at the highest enzyme concentrations examined (200 and 300 U g^{-1} fabric).

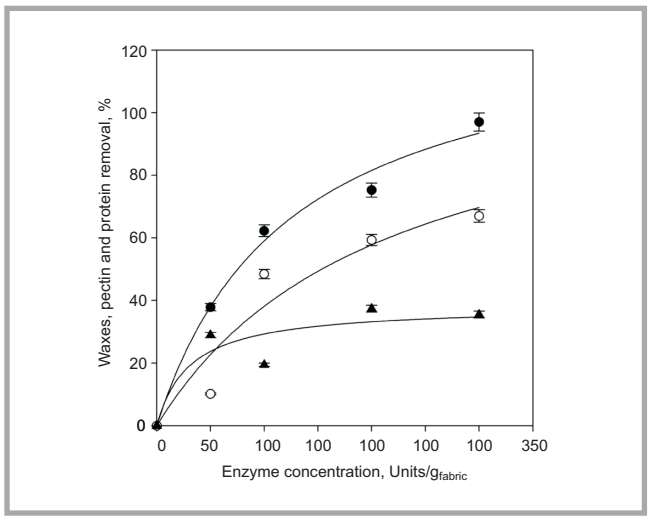

Figure 1. *Effect of Lipolase concentration on the removal of waxes (●), protein (▲) and pectin (○) from cotton fabrics treated for 120 min.*

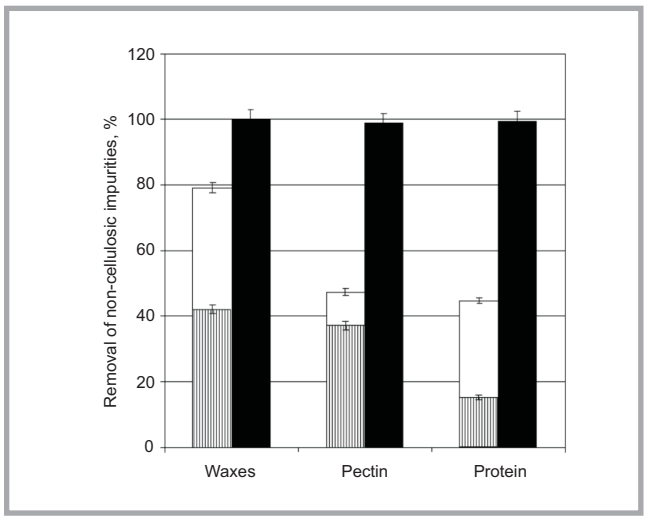

Figure 2. *Removal of non-cellulosic impurities of cotton fabrics using Lipolase, Bioprep and their combination (white, grey and black columns, respectively). The concentrations of Lipolase and Bioprep were 50 and 100 U·g^{-1} fabric, respectively.*

Table 4. *Comparison of the micromechanical properties of cotton fabrics treated for 120 min with various levels of Lipolase and those of reference and conventionally scoured materials.*

Type of treatment	Bending rigidity (B), gf cm^2 cm^{-1}			Shear stiffness (G), gf cm^{-1} degree^{-1}			Extensibility (EMT), %			Compressional resilience (RC), %
	weft	warp	Mean	weft	warp	mean	weft	warp	mean	
No enzyme	0.061 ± 0.002	0.083 ± 0.003	0.072	2.90 ± 0.1	3.20 ± 0.20	3.05	1.93 ± 0.09	3.32 ± 0.06	2.63	10.53 ± 1.33
Lipolase 50 U g^{-1}	0.081 ± 0.001	0.122 ± 0.001	0.102	3.20 ± 0.14	4.20 ± 0.10	3.70	3.30 ± 0.10	4.60 ± 0.16	3.95	17.68 ± 1.30
Lipolase 100 U g^{-1}	0.121 ± 0.002	0.150 ± 0.002	0.136	3.60 ± 0.12	4.30 ± 0.10	3.95	2.95 ± 0.10	3.73 ± 0.05	3.34	27.61 ± 1.93
Lipolase 200 U g^{-1}	0.156 ± 0.002	0.160 ± 0.001	0.158	3.75 ± 0.21	4.45 ± 0.15	4.10	2.56 ± 0.10	5.28 ± 0.24	3.92	38.65 ± 1.61
Lipolase 300 U g^{-1}	0.157 ± 0.004	0.151 ± 0.001	0.154	3.82 ± 0.10	4.52 ± 0.10	4.17	2.64 ± 0.04	5.12 ± 0.10	3.88	40.20 ± 0.97
Alkali-treatment	0.104 ± 0.005	0.121 ± 0.001	0.113	3.60 ± 0.20	4.60 ± 0.10	4.10	2.10 ± 0.08	6.05 ± 0.25	4.08	54.30 ± 1.18

Bending rigidity (B), which reflects a fabric's ability to resist bending deformation, was the most affected of the properties examined. The values of B estimated following treatment with Lipolase were much higher than corresponding values measured after alkaline scouring. Equivalent values of shear rigidity (G), which is a measure of the resistance to rotational movement of the warp and weft threads within a fabric, were observed for lipase-treated and alkali-treated fabrics. In addition, a similar level of extensibility (EMT), i.e. the ability to be stretched under tensile load, was estimated for enzymatically and chemically scoured fabrics. Treatment with Lipolase improved the ability of fabrics to recover from compressional deformation (known as compressional resilience, RC), it but was not as effective as conventional alkali-treatment.

Combined lipase – pectinase treatment

The cross-synergism of Lipolase and Bioprep during the bioscouring of cotton fabrics was observed. It is well known that the disruption and removal of the outermost waxy layer, which was accomplished in the present study using Lipolase, is a prerequisite for higher pectinase performance to achieve sufficient hydrophilicity in the enzymatic scouring process [16]. Extensive removal of waxes, pectin and protein had been completed after 30 min of treatment using a lipase and pectinase combination (50 and 100 U·g^{-1} fabric, respectively). This condition was more effective than the scouring carried out separately with each one of the enzymes at the same concentration for longer treatment times (120 min). The sum of waxes, pectin and protein removed when separate lipase and pectinase treatments were applied were 79.1%, 47.4% and 44.7%, respectively (***Figure 2***). This is in contrast to previous results, which reported no difference in the weight loss of fabrics after the addition of lipase to the pectinolytic scouring agent [14]. Comparably low treatment times have been applied successfully in batch processes where pectinase and cutinase mixtures were used [6.34]. A synergistic effect was also observed for the same combination of enzymes with regard to hydrophilicity. The wetting time of fabrics treated for 30 min with the lipase-pectinase combination was less than 1 s, which is much lower than corresponding values measured for fabrics treated for 120 min with lipase or pectinase alone (2.5 and 5 s, respectively). In accordance with these results, a four-fold enhancement in the absorbency of fabrics has been reported following combined lipase-pectinase treatment [14].

Synergy between pectinolytic and lipolytic enzyme activities could not be detected when assessing the crystallinity, polymerisation and whiteness of bioscoured cotton fabrics. The CrI of lipase-pectinase bioscoured fabrics (90.4) did not change significantly from the corresponding value of fabrics treated with pectinase alone (90.0). Similarly, the DP of bioscoured fabrics was practically unchanged no matter if the treatment was carried out using pectinase or its combination with lipase (2137 and 2188, respectively). The WI of cotton fabrics treated with the lipase and pectinase combination (42.7%) was only marginally increased when compared to the corresponding value observed for lipase-treated fabrics

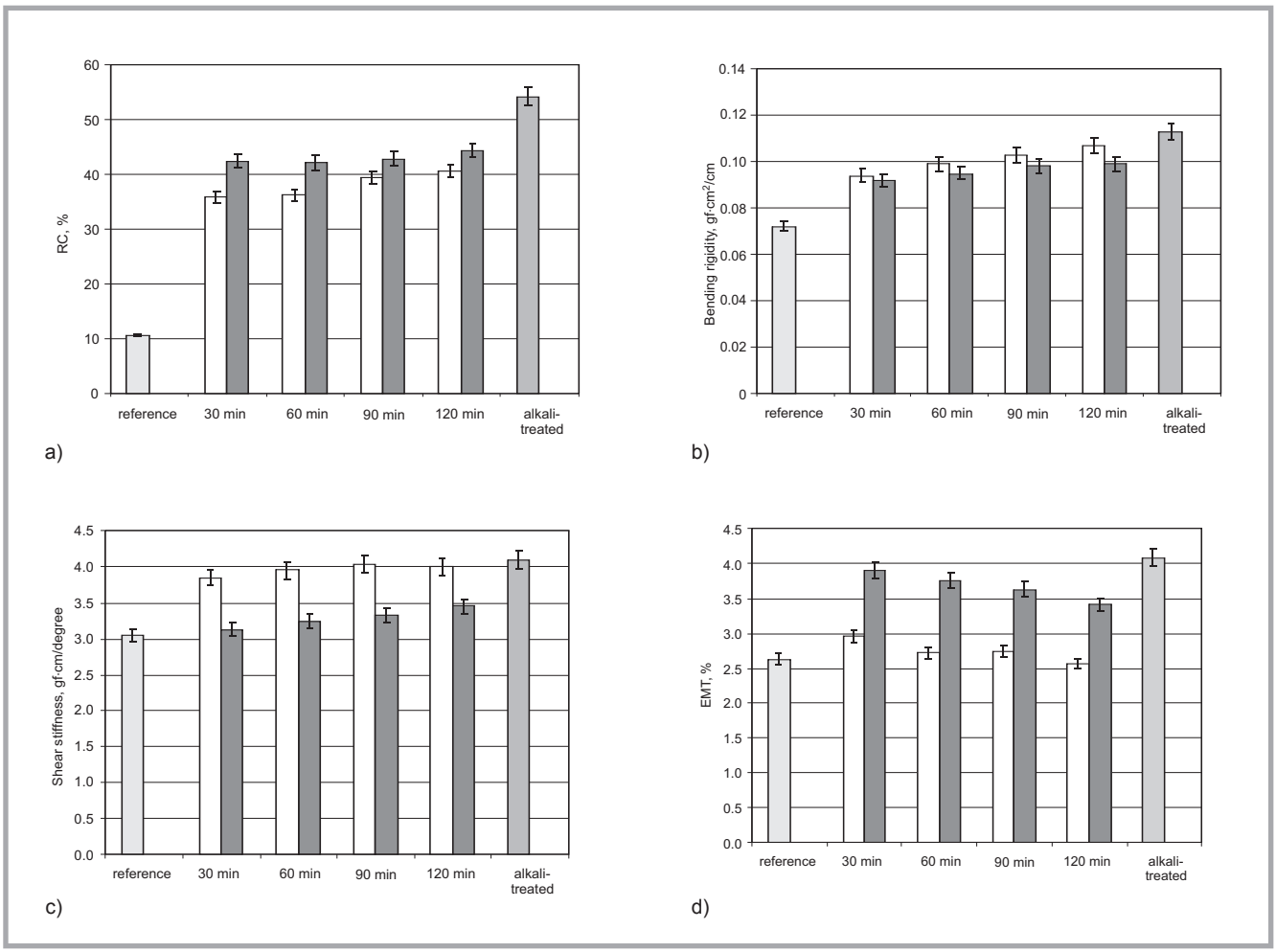

Figure 3. *Effect of combined Lipolase-Bioprep treatment on the compressional resilience of cotton fabrics. The enzyme concentrations were as follows (in U·g^{-1} fabric): Lipolase 12 and Bioprep 25 (white bars), and Lipolase 50 and Bioprep 100 (black bars).*

(42.0%). Unexpectedly, fabrics where the lipase-pectinase combination was applied showed a lower WI than those treated with pectinase alone (44.5%).

Improved micromechanical properties of cotton fabrics were achieved after scouring with lipase and pectinase combinations. The upgrading of tensile properties (3 - 7% higher breaking load) as a result of lipase-pectinase treatment has been reported before [14]. Fabrics subjected to extended treatments exhibited higher compressional resilience as well as bending and shear rigidity (***Figures 3.a - 3.c***). Maximum B and G values (0.107, and 4.03, respectively) were observed for the longest treatment examined and were equivalent to those obtained after alkali-treatment. However, satisfactory results were possible with the implementation of shorter treatment times. Cotton fabrics scoured for 30 min showed the highest extensibility, while increasing the time of treatment resulted in lower EMT values (***Figure 3.d***), which is in agreement with results reported for the extensibility of cotton fabrics treated with pectinase [23]. The level of lipolytic and pectinolytic activities had a significant effect on the mechanical properties of bioscoured textiles. A higher compressional resilience and extensibility of fabrics was observed when scouring was carried out with an increased concentration of enzymes. In contrast, the application of lower enzyme activities formed materials with greater bending and shear rigidity. The potential for selecting an appropriate combination of modifying agents to form fabrics with desired features in certain textile applications is highly advantageous [35].

Table 5. *Dyeing performance of reference, conventionally scoured and bioscoured cotton fabrics.*

Type of treatment	Treatment time, min	Colour strength	Colour change	Staining
No enzyme	120	2.70 ± 0.1	5	4 - 5
Lipolase	120	3.11 ± 0.1	5	4 - 5
Bioprep	120	4.53 ± 0.2	4 - 5	4 - 5
Lipolase - Bioprep	30	5.03 ± 0.2	4 - 5	4 - 5
Alkali-treatment	60	7.79 ± 0.1	3	3 - 4

Dyeing performance

The dyeing properties of cotton fabrics treated with lipase, pectinase or their combination were determined and compared with those obtained for reference and alkali-treated fabrics (***Table 5***). A slight improvement in colour strength was observed for fabrics treated with Lipolase for 120 min, while a corresponding treatment with pectinase was more effective. When scouring was carried out in the presence of both enzymes, a noticeably higher value of colour strength could be attained in a considerably shorter time (30 min). In a previous study, where lipase and its combination with other hydrolases were applied for

60 min, fabrics with a comparable colour strength were reported [14].

Based on the estimation of colour change, which is a measure of a material's capacity to retain dye, Lipolase-treated fabrics showed excellent dyeing performance (grade 5). It must be noted that even a short treatment (30 min) with the lipase and pectinase combination resulted in fabrics with a superior colour change quality (grade 4-5) when compared to conventionally treated fabrics (grade 3).

Similar staining behaviour was exhibited by bioscoured fabrics, regardless of the type of enzyme implemented. Based on staining grades, it can be concluded that enzymatically-treated fabrics can withstand washing much more successfully than those subjected to conventional alkali-treatment. No staining could be detected for the rest of the materials, such as wool, acrylic, polyester, nylon, or acetate, that were adjacent to the dyed cotton samples during washing (data not shown).

Correlation of fabric properties

Hyperbolic curves were applied to model the relationship between enzyme concentration and the removal of fabric components (***Figure 1***). Relevant equations as well as the standard error of estimates, correlation coefficients and P values are given below [Equation (1) - (3)]. Based on statistical analysis, the removal of waxes and pectin can be efficiently described by the model proposed.

$$\% \text{ of removed waxes} = \frac{131.9\,[E]}{123.3 + [E]} \quad (1)$$
$$R^2 = 0.989,$$
std error of estimate = 4.6,
P = 0.0005

$$\% \text{ of removed pectin} = \frac{119.0\,[E]}{212.0 + [E]} \quad (2)$$
$$R^2 = 0.923,$$
std error of estimate = 9.6,
P = 0.0091

$$\% \text{ of removed protein} = \frac{38.3\,[E]}{30.6 + [E]} \quad (3)$$
$$R^2 = 0.848,$$
std error of estimate = 6.9,
P=0.0265

Uncovering a correlation between the composition of textiles and their physical properties was also attempted. When examining the effect of minor constituents of cotton on essential fabrics variables, the pectin concentration was found to be the most important factor. The properties of Lipolase-treated materials, such as CrI, DP and WI, were dependent on a single fabric component - residual pectin (RP). The best fitting was achieved by second order polynomial equations, which are cited along with important estimates of statistical analysis [Equation (4) - (6)]. The results are in accordance with previous findings, where the WI and colour strength of enzymatically treated cotton fabrics were influenced only by RP [23].

$$CrI = 13.39 \times RP^2 - 18.29 \times RP + 93.07 \quad (4)$$
$$R^2 = 0.966,$$
std error of estimate = 0.54,
P = 0.0062

$$DP = -1785 \times RP^2 + 1671 \times RP + 1904 \quad (5)$$
$$R^2 = 0.975,$$
std error of estimate = 29.62,
P=0.0040

$$WI = 23.74 \times RP^2 - 41.57 \times RP + 54.413 \quad (6)$$
$$R^2 = 0.928,$$
std error of estimate = 2.099,
P = 0.0192

The potential use of various physicochemical features for predicting the mechanical properties of Lipolase-treated textiles was investigated. Interestingly, a linear relationship was identified between the CrI of the fabrics and the entire range of properties estimated by the Kawabata Evaluation System [Equation (7) - (10)]. Except for extensibility, a positive correlation with crystallinity was observed for all micromechanical properties examined in the present study. The results are in line with previous reports where the CrI alone was used to predict low-stress mechanical properties of chemically and enzymatically treated cotton fabrics [23, 36]. The orrelation of variables has been attributed to the increased contact area and frictional forces between fibres which are induced by the removal of amorphous materials [23].

$$RC = 9.602\,CrI - 821.4 \quad (7)$$
$$R^2 = 0.984,$$
std error of estimate = 2.14,
P = 0.0009

$$B = 0.073\,CrI - 0.565 \quad (8)$$
$$R^2 = 0.990,$$
std error of estimate = 0.001,
P = 0.0005

$$G = 0.413\,CrI - 33.910 \quad (9)$$
$$R^2 = 0.942,$$
std error of estimate = 0.04,
P = 0.029)

$$EMT = -0.650\,CrI - 62.175 \quad (10)$$
$$R^2 = 0.974,$$
std error of estimate = 0.04,
P = 0.013

Conclusion

In the present study we demonstrate that Lipolase can be used as an effective scouring agent for cotton fabrics. Application of the enzyme preparation removed substantial amounts of non-cellulosic impurities, resulting in wax-free materials. The treatment of textiles with Lipolase changed their physicochemical features and improved their micromechanical properties, which were comparable to those estimated after traditional chemical scouring. Combined treatment with Lipolase and Bioprep for reduced times in a one-step bioscouring process was sufficient for creating fabrics with the characteristics desired and excellent dyeing performance. The removal of pectin and CrI were the key variables when exploring the relationship between the chemical composition and properties of enzymatically treated cotton fabrics.

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