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Coloration of ultraviolet-C-assisted combined desizing-scouring cotton fabric

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The textile chemical processing industry is one of the most polluting industries. The water and energy consumption in textile wet processing is very high and produces vast amounts of effluent. Desizing, scouring, bleaching, and mercerising are the essential processes involved in textile pretreatment. A novel photocatalytic technique is implemented to minimise the consumption of energy, water and time in a combined desizing and scouring process. The industrial woven cotton grey fabric is treated with an oxidising agent in the padding method and irradiated under ultraviolet-C (UVC). Then, the UVC-exposed fabric is washed at a lower temperature than that used in conventional washing. Furthermore, the scoured fabric is dyed with reactive dyes to study its dyeability. This technique saves 79% of the processing time and is superior to the conventional process in terms of dyeability. The water and energy consumption of the demonstrated process is reduced by 71% and 72%, respectively. The fabric properties are analysed using weight loss, tensile strength, absorbency time, whiteness, colour value, colour fastness, FTIR, WXRD, SEM, and EDX. Life cycle analysis is also conducted.

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Sustainability spotlight

Usually, desizing, scouring, and bleaching are done before fabric colouring. These step-by-step preparation procedures use a significant amount of energy and water. Time-consuming process cycles are another issue. The primary goal of this effort is to use less time and resources, namely, water and energy, than would be required for conventional procedures. This study determines whether industrial starch-sized grey cloth may be used for industrial applications by combining desizing and scouring with UVC help. We dye and compare the UVC-assisted pretreated fabric to the fabric from the traditional two-step desizing and scouring procedure. The significance of the following UN sustainable development objectives is emphasised by this study: affordable and clean energy (SDG 7), industry, innovation, and infrastructure (SDG 9), and climate action (SDG 13).

Introduction

Sizing is one of the weaving preparatory processes where a protective coating is put on warp yarns before weaving.[1] Sizing is necessary to decrease yarn hairiness, increase yarn strength, and reduce the cyclic stress on warp yarns during weaving.[2] The most common sizing agents used are based on starch, carboxymethyl cellulose, and polyvinyl alcohol (PVA).[3]

Removal of the sizing agents from the fabric is essential before dyeing and finishing and is performed by desizing.[4] Enzymatic desizing, oxidative desizing, acid desizing, alkaline desizing, and plasma-assisted desizing are different types of desizing techniques used in textile wet processing. Desizing cotton fabric using hydrochloric acid or sulphuric acid is the oldest desizing method. However, any residual acid deteriorates the fabric upon drying. The enzymatic desizing process has been used in the textile industry since the 1950s.[5] However, the enzymatic process requires proper care for the storage of enzymes and is sensitive to pH and temperature in the process, and enzymes are expensive.[6] Other alkaline and oxidative desizing methods require excessive water and energy. Therefore, a dry process is quite preferable to replace the existing water-intensive processes. Atmospheric pressure plasma treatment (APT) on PVA-sized fabric was studied, where a simple cold wash can remove the PVA.[7] APT in the presence of oxygen was applied to starch-coated fabric for desizing.[8] Although many researchers have practised plasma-assisted desizing, these are limited to the lab stage only. Plasma reactors for bulk processing may not be affordable due to their high cost and require safety measures due to high voltage electrodes.

Natural impurities such as pectins, proteins, fats and waxes result in hydrophobicity in grey cotton fabric. The fabric must be treated to become hydrophilic before colouration.[9] An alkaline aqueous medium using sodium hydroxide is generally used for removing the hydrophobic impurities from cotton, known as scouring. Alkaline scouring makes the fabric harsh due to damage to cellulosic walls. An alternative process to alkaline scouring is enzymatic scouring.[10] The reproducibility of enzymatic scouring has been questioned due to the sensitivity of enzymes in the process.

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An alternate dry process as a substitute for plasma was demonstrated for desizing PVA-sized fabric using UVC.[11,12] UVC-assisted desizing was also carried out on starch-sized cotton fabric.[13] Many attempts have been made to combine desizing and scouring. A one-bath desizing-scouring-depilling process was carried out and compared with the conventional 2-step process. Although the combined process was attempted at a lower temperature and reduced time, the performance of the pretreated fabric was poor in terms of whiteness and hydrophilicity compared to the conventional process.[14] Ozone desizing was found to be an economical process, and when compared with conventional desizing and scouring, it was noticed that the fabric strength loss was higher in the ozone process.[15] DBD plasma treatment has the potential to reduce water and energy consumption in desizing and scouring compared to conventional processes. However, their application in bulk is in question.[16]

Generally, before colouration of the fabric, desizing, scouring, and bleaching are carried out. This study aims to combine desizing and scouring with the assistance of UVC on industrial starch-sized grey fabric and to find its suitability for industrial applications. The UVC-assisted pretreated fabric is dyed and compared with the fabric from the conventional two-step desizing and scouring process. The fabric is characterised by weight loss, tensile strength, whiteness index, yellowness index, colour value, colour fastness, SEM, EDX, WXRD, and FTIR. Life cycle analysis is also part of the study.

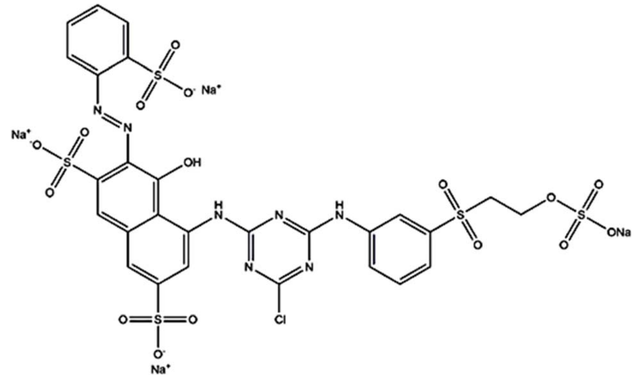

Fig. 1 Structure of C.I. Rea. Red 194 (tetrasodium 5-[[4-chloro-6-[[3-[[2-(sulphonatooxy)ethyl]sulphonyl]phenyl]amino]-1,3,5-triazin-2-yl]amino]-4-hydroxy-3-[(2-sulphonatophenyl)azo]naphthalene-2,7-disulphonate).

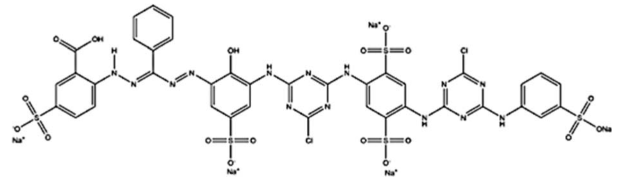

Fig. 2 Structure of C.I. Rea. Blue 160 (pentasodium; 2-[[[[3-[[4-chloro-6-[4-[[4-chloro-6-(3-sulfoanilino)-1,3,5-triazin-2-yl]amino]-2,5-disulfonatoanilino]-1,3,5-triazin-2-yl]amino]-2-hydroxy-5-sulfonatophenyl]diazenyl]-phenylmethyl]diazenyl]-5-sulfonatobenzoate).

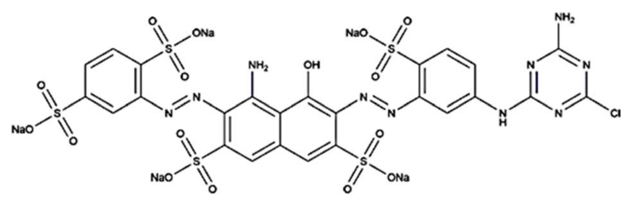

Fig. 3 Structure of C.I. Rea. Black 39 (pentasodium; 5-amino-3-[[5-[(4-amino-6-chloro-1,3,5-triazin-2-yl)amino]-2-sulfonatophenyl]diazenyl]-6-[(2,5-disulfonatophenyl)diazenyl]-4-hydroxynaphthalene-2,7-disulfonate).

Materials and methods

Materials

The specifications of the materials used for the research are tabulated below in Table 1. Three different dyes are used for dyeing, and their molecular structure is depicted in Fig. 1–3.

Experimental setup

A UVC chamber was fabricated in-house for the exposure of samples. Two sets of UVC lamps are used horizontally where the

Table 1 Materials with specifications

Materials	Specification	Supplier
Starch-sized grey cotton fabric	Ends per inch-131, picks per inch-72, warp count – 40's Ne & weft count-40's Ne, grams per square meter-117	Vardhaman Industry
Wetting agent	Nonionic and alcohol ethoxylate-based, cloud point – 25 °C, solid content – 45%	Croda
Soda ash	White powder, purity – 99.5%	Merck
Caustic soda	Pellets, purity – 97%	Merck
Sodium chloride	White powder, purity – 99%	Merck
Acetic acid	Glacial acetic acid, purity – 99%	Merck
Detergent	Nonionic and alcohol ethoxylate based, cloud point – 65 °C, solid content – 77%	Archroma
Sodium perborate	White solid tetrahydrate form, purity – 97%	Fisher Scientific
Reactive dyes with C.I. numbers	Rea. Red 194, Rea. Blue 160, Rea. Black 39, and Black mixture in powder form	Jay Chemicals

upper set is fixed and the lower set is movable to adjust the level of irradiation energy on the fabric surface. An energy meter is attached to measure the UVC energy on the fabric surface. A heating element and exhaust system control the temperature inside the chamber.

Experimental method

Fig. 4 depicts the method used in this experiment, and the following sections detail the processes being experimented with. Table 2 shows the recipe used in the pretreatment processes.

Conventional desizing

The fabric was treated with sodium hydroxide, as mentioned in Table 2, at a boil (100 °C) for 60 min. Then, the fabric was washed for 10 min each at a boil thrice separately.[17]

Conventional scouring

A scouring bath was prepared with chemicals, as shown in Table 2. The fabric was scoured for 60 min at 95 °C. Then, hot washing was performed for 10 min at 95 °C and the fabric was neutralised for 10 min at 55 °C before drying.[18]

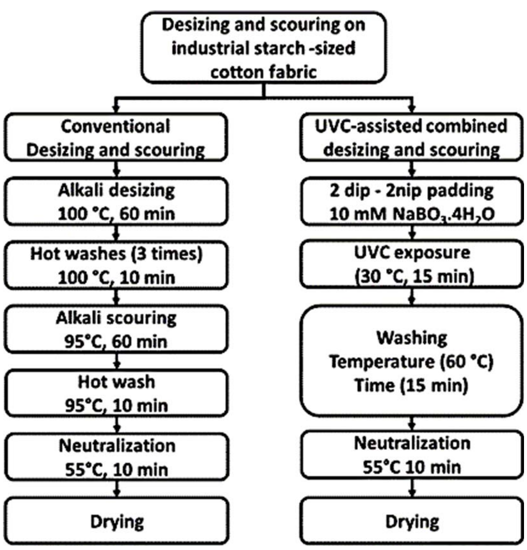

Fig. 4 Flowchart for combined desizing and scouring.

Table 2 Recipe for pretreatment processes

Name of chemicals	Desizing	Scouring	Combined process
Sodium perborate tetrahydrate (mM)	—	—	10
Wetting agent (g L^{-1})	—	2	—
Soda ash (g L^{-1})	—	3	—
Sodium hydroxide (g L^{-1})	25	5	7.5
Acetic acid (g L^{-1})	—	1	1

UVC exposure

The fabric, before combined desizing and scouring, was padded with 10 mM $NaBO_3 \cdot 4H_2O$ and exposed for 15 min under UVC at 30 °C. The irradiation energy was noted as 15 mW cm^{-2}.

Table 3 Recipe for dyeing

Sr. no.	Materials used	Sky blue	Fuchsia	Navy	Black
1	Rea. Blue 160 (%)	0.25			
2	Rea. Red 194 (%)		3.00		
3	Rea. Black 39 (%)			6.00	
4	Rea. Black mix (%)				8.00
5	Common salt (g L^{-1})	30	70	90	100
6	Soda ash (g L^{-1})	10	20	20	25
7	Acetic acid (g L^{-1})	1.0	2.0	2.0	2.0
8	Detergent (g L^{-1})	0.5	1.0	2.0	2.0

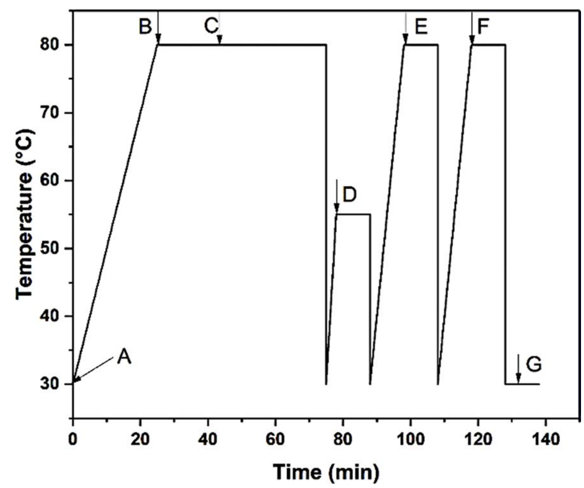

Fig. 5 Dyeing cycle for sky blue shade ((A) dye, (B) salt, (C) soda, (D) acid, (E) soap, (F) hot wash, and (G) cold wash).

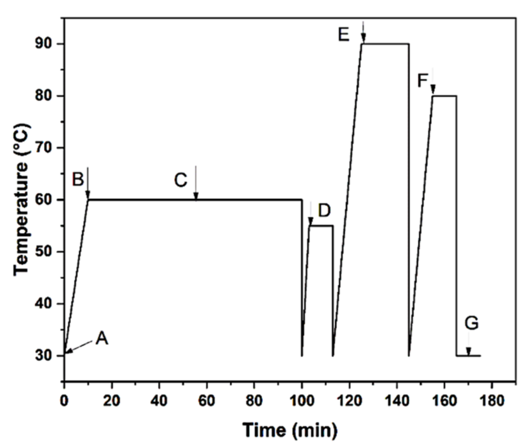

Fig. 6 Dyeing cycle for fuchsia shade ((A) dye, (B) salt, (C) soda, (D) acid, (E) soap, (F) hot wash, and (G) cold wash).

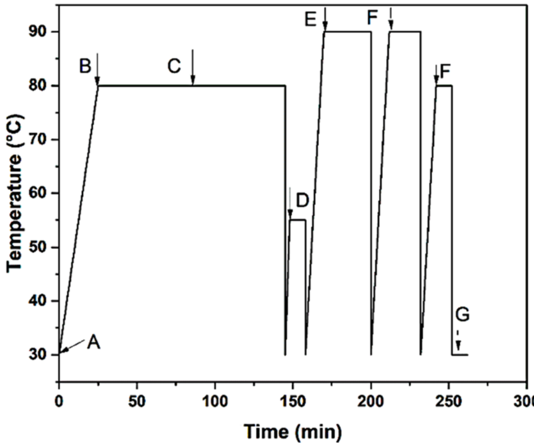

Fig. 7 Dyeing cycle for navy shade ((A) dye, (B) salt, (C) soda, (D) acid, (E) soap, (F) hot wash, and (G) cold wash).

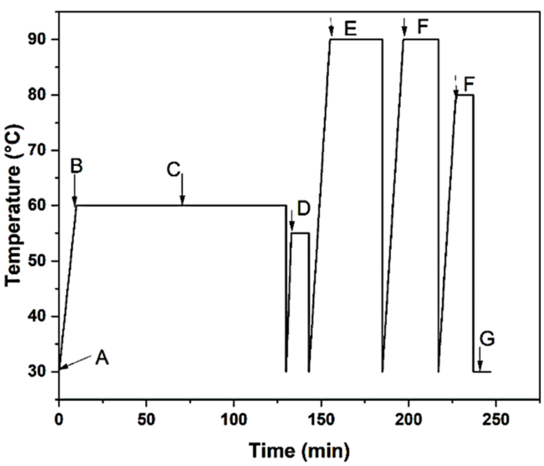

Fig. 8 Dyeing cycle for black shade ((A) dye, (B) salt, (C) soda, (D) acid, (E) soap, (F) hot wash, and (G) cold wash).

Combined desizing and scouring

The fabric was only washed with alkali for 15 min, as shown in Table 2, at 60 °C and neutralised before drying. The scoured fabric was conditioned for 24 h at 20 ± 2 °C and 65 ± 5% RH before the characterisation process.

Dyeing

Conventional and UVC-assisted scoured samples were dyed in four shades using recipes, as mentioned in Table 3.

The material-to-liquor ratio for dyeing was 1 : 20. The dyeing cycles for sky blue, fuchsia, navy, and black are given in Fig. 5–8, respectively. The addition of dye, salt, soda, acid, and soap is carried out in steps as shown in A, B, C, D, and E in Fig. 5–8. Steps F and G are shown for hot wash and cold wash.

Evaluation process energy consumption

The energy utilised in the process is determined using eqn (1).

$$(q) = (m) \times (C_p) \times (\Delta T) \tag{1}$$

where q is energy, m is mass, C_p is specific heat capacity, and ΔT denotes change in temperature.

Characterisation

Weight loss. The fabric weight loss in the process was determined from eqn (2).

$$\text{Weight loss}(\%) = \frac{(W_1 - W_2)}{W_1} \times 100 \tag{2}$$

W_1 is the oven-dry weight before the treatment and W_2 is the oven-dry weight after treatment.

Absorbency test. AATCC Test Method 79-2007 was followed to test the absorbency time.

Degree of desizing. The degree of desizing of starch-sized fabric was evaluated using the TEGEWA test. The TEGEWA standard scale was referenced to assess the rating of desizing by observing the colour formation of starch iodide in the presence of any starch residue in the fabric.

Whiteness and yellowness index. The CIE whiteness and yellowness indices were measured with an X-Rite spectrophotometer using AATCC Test Method 110-2007.[19]

Colour value. A spectrophotometer (X-Rite) was used to determine the colour value which was reported as a K/S value (eqn (3)). A D65 light source was set at 10° observer as per colour space CIE Lab 1976.

$$K/S = \frac{(1 - R)^2}{2R} \tag{3}$$

Fabric strength. The ravelled strip method was followed to test the fabric tensile strength at Instron using the ASTM D 5035 test method.[20]

Fourier transform infrared spectroscopy (FTIR). ATR-FTIR spectra were obtained in a range of 4000–500 cm^{-1} using a Thermofisher Scientific Nicolet iS50 FTIR spectrometer.

Wide angle X-ray diffraction (WXRD). The wide angle X-ray diffraction pattern was determined and analysed using OriginLab (2023).[21] Gauss fitting was used to determine the peak position and full width at half maxima from the XRD pattern. The dislocation density, crystallite size, and microstrain were also determined.

Scanning electron microscopy (SEM). Fabric samples for SEM were coated with 10 Å thickness of gold using a sputter coating instrument. For the surface image analysis, 20 kV of electron high tension was used with a 6.5 mm working distance in a high-resolution SEM (ZEISS EVO50).

Energy-dispersive X-ray microscopy (EDX). Fabric samples for EDX were prepared in a similar way as mentioned above. A high-resolution SEM (ZEISS EVO50) was used. The SEM has RONTEC's EDX system Model QuanTax 200, which is based on the SDD technology and provides an energy resolution of 127 eV at Mn K alpha.

Colourfastness. ISO 105 C06, ISO 105 C09, ISO 105 X12, ISO 105 E04, and ISO 105 B02 methods were used to evaluate the colourfastness to laundering, colourfastness to oxidative bleaching, rubbing fastness, perspiration fastness, and light-fastness of dyed samples, respectively.[22]

Life cycle analysis. Life cycle assessment (LCA) is the compilation and evaluation of input and output data and the impact on a product system's environment throughout its life cycle. According to ISO-14040, LCA methodology combines four interrelated phases: goal and scope definition, inventory analysis, impact analysis, and interpretation. The environmental impact of the new UVC-assisted preparatory process was determined through a cradle-to-gate LCA process. The life cycle impact assessment was done using the Ecoinvent database using OpenLCA 1.11 software. Recipe 2016 endpoint (H) LCIA methodology computed the life cycle impact assessment.

Results and discussion

Mechanism of combined desizing and scouring

The water molecule in the fabric as moisture breaks down to $^{\bullet}OH$ and $H^{\bullet}$ upon exposure to UVC, as shown in eqn (4). The free radicals are responsible for the chain scission of starch molecules and other impurities on the surface.

$$H_2O + UVC \rightarrow {}^{\bullet}OH + H^{\bullet} \quad (4)$$

The degradation of impurities was also facilitated by embedding $NaBO_3 \cdot 4H_2O$. In the presence of moisture, $NaBO_3 \cdot 4H_2O$ is transformed into $NaBO_2 \cdot 4H_2O$, where H_2O_2 is released. Enough $^{\bullet}OH$ are generated out of H_2O_2 upon exposure to UVC as mentioned in eqn (5).[23] Alkali hydrolysis during washing further helps breakdown starch and other impurity molecules for facilitating their easy removal.

$$NaBO_3 \cdot 4H_2O + H_2O + UV \rightarrow NaBO_2 \cdot 4H_2O + 2OH^{\bullet} \quad (5)$$

Efficiency of pretreatment

The conventional desizing and scouring of the grey fabric were done in two steps. In the UVC-assisted process, the untreated grey fabric was treated with 10 mM $NaBO_3 \cdot 4H_2O$ and exposed to UVC. Then, the fabric was washed. For comparison, control samples without UVC treatment were washed in a similar bath as the UVC-treated samples. The pretreatment parameters were evaluated and are tabulated in Table 4. By looking at the results of the control from Table 4, the role of UVC in pretreatment can be observed. Weight loss of the fabric in UVC-treated fabric is 35.8% lower than that of the conventionally processed sample with a similar absorbency time. The whiteness index of the UVC-treated fabric is 45.8% higher than that of the conventional one. The tensile strength of the UVC-treated fabric (460 ± 15 N) is 15% higher than that of the conventional sample (401 ± 7 N). The higher degradation in conventional processes is due to the harsh alkali treatment at high temperatures. After observing the pretreatment results, it may be inferred that the efficacy of the

Table 4 Pretreatment results

Sr. no.	Process	Weight loss (%)	TEGEWA rating (1–9)	Absorbency time (s)	Whiteness index	Yellowness index
1	Grey fabric untreated	0	1 to 2	>180	14 ± 0.55	19 ± 0.34
2	Conventional desizing & scouring	10.95 ± 0.14	6 to 7	<1	24 ± 0.59	15 ± 0.38
3	UVC-assisted desizing & scouring	7.03 ± 0.16	8 to 9	<1	35 ± 0.40	13 ± 0.23
4	Control	2.98 ± 0.15	1 to 2	>180	14 ± 0.76	17 ± 0.23

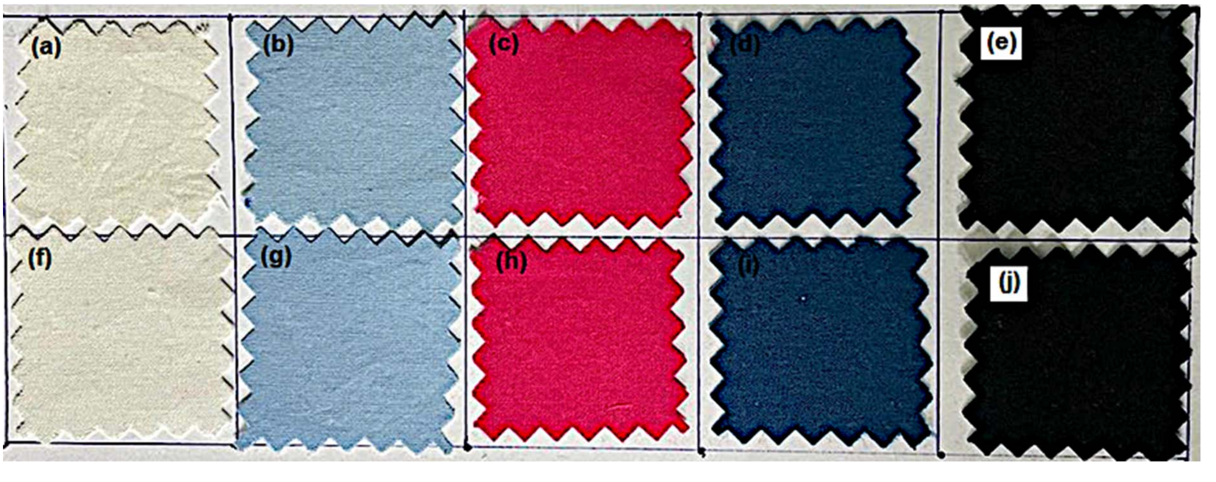

Fig. 9 Conventional (a–e), UVC-treated (f–j), scoured (a and f), sky blue (b and g), fuchsia (c and h), navy, (d and i), and (d) black (e and j).

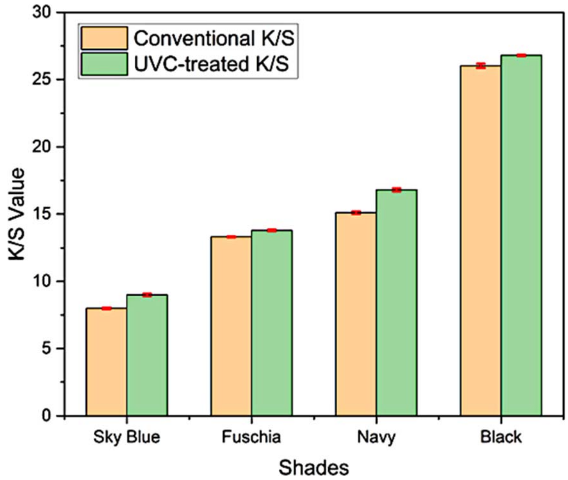

Fig. 10 *K*/*S* plot for different shades.

Table 5 Dyeing results

Shades	L^*	a^*	b^*	C^*	H^*
Fuchsia (conventional)	52.27	57.32	4.69	57.51	4.68
Fuchsia (UVC-treated)	50.31	61.01	7.06	61.41	6.60
Sky blue (conventional)	75.48	−5.09	−15.56	16.38	251.86
Sky blue (UVC-treated)	73.73	−6.59	−9.27	11.37	234.56
Navy (conventional)	27.89	−5.90	−18.02	18.96	251.83
Navy (UVC-treated)	23.42	−3.65	−16.79	17.18	257.70
Black (conventional)	27.89	−5.90	−18.02	18.96	251.83
Black (UVC-treated)	23.42	−3.65	−16.79	17.18	257.70

process for UVC-treated fabric is much better than that of the conventional process.

Dyeability

The UVC-assisted combined desizing-scouring fabric samples were dyed in four shades to study their dyeability. Images of pretreated and dyed samples are shown in Fig. 9. The comparison of the *K*/*S* of UVC-treated samples with conventional pretreated samples is shown in Fig. 10. The *K*/*S* value measured for fuchsia shade (λ_{max} = 520 nm) dyed from the UVC-treated fabric was 4% higher than that of the conventional sample. Similarly, the sky blue shade (λ_{max} = 630 nm) dyed from UVC-assisted pretreated fabric was 12% higher *K*/*S* than that of the conventional sample. The *K*/*S* value measured for navy shade (λ_{max} = 610 nm) dyed from the UVC-assisted pretreated fabric was 11% higher than that of the conventional sample. The *K*/*S* value calculated for the black shade (λ_{max} = 590 nm) dyed from the UVC-assisted pretreated fabric was 3% higher than that of the conventional sample. The colour space values in terms of L^*, a^*, b^*, C^*, and H^* are tabulated in Table 5. As mentioned above, the depth of shades in all four shades is higher than that of the conventional sample despite the higher whiteness indices. A higher *K*/*S* value (Fig. 10) and lower L^* value (Table 5) of different shades show that the dye uptake of UVC-treated fabric is better. The difference in *K*/*S* correlates with the difference in dye sorption of reactive dyes, as results are shown in the literature.[24,25] It may be inferred that using the UVC-assisted process, the fabric can be dyed in light shades without opting

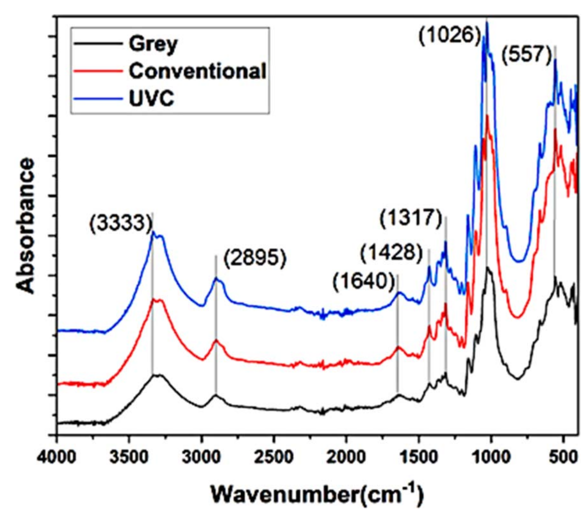

Fig. 11 FTIR of fabrics with various treatments.

Table 6 Colorfastness results[a]

	Fastness to soaping		Fastness to oxygen bleaching		Fastness to perspiration			Rubbing fastness	
Shades	CC	CS	CC	CS	CC	CS	Lightfastness	Dry	Wet
Fuchsia (conventional)	4–5	5	3–4	4–5	4–5	4–5	5–6	3–4	2–3
Fuchsia (UVC-treated)	5	5	3–4	5	5	4–5	6	3–4	2–3
Sky blue (conventional)	4	4–5	3	4–5	4–5	4	4–5	4–5	4–5
Sky blue (UVC-treated)	4–5	5	3	4–5	5	4–5	4–5	4–5	4–5
Navy (conventional)	4–5	4	4–5	5	4–5	4–5	6	3–4	2–3
Navy (UVC-treated)	5	4–5	5	5	4–5	4–5	6	3–4	2–3
Black (conventional)	4–5	3–4	4–5	5	4–5	4–5	6–7	2–3	1–2
Black (UVC-treated)	4–5	4	4–5	5	4–5	4–5	7	2–3	1–2

[a] CC (change in colour) and CS (colour staining).

for the bleaching process. The colourfastness to soaping, oxygen bleaching, perspiration, light fastness and rubbing fastness ratings are shown in Table 6. The fastness rating for all the dyed samples dyed from the UVC-assisted pretreated fabric is similar to or higher than the rating of conventional samples. So, the dyed fabrics produced with UVC treatment gave better results than the conventional samples due to their better pretreatment efficacy.

Fourier transform infrared spectroscopy (FTIR)

FTIR of untreated grey fabric, conventional two-step desizing-scouring fabric, and UVC-assisted single-step pretreated fabrics were studied to investigate their chemical structure. The absorbance spectra are depicted in Fig. 11. The associated functional groups are OH stretching at 3333 cm^{-1},[26] CH stretching at 2895 cm^{-1},[27] OH bending (for absorbed moisture) at 1640 cm^{-1},[28] CH symmetric bending (CH_2) at 1428 cm^{-1},[29] CH wagging (CH_2) at 1317 cm^{-1},[30] CO stretching at C_6 1026 cm^{-1},[31] and OH bending (out of plane) at 557 cm^{-1}.[32] It may be noted from the FTIR spectra that the chemical structure of the UVC-treated fabric has not been altered.

Wide-angle X-ray diffraction

It was pertinent to check if the photocatalytic desizing process affected the microstructure of cotton. The XRD spectra, as shown in Fig. 12, illustrate miller indices 1–10, 110, 200, and 004 for cellulose-I.[33] The crystallinity of the grey fabric was 66.89%.

The crystallinity of the conventional pretreated sample (62.76%) is 6.2% lower than that of the untreated fabric due to harsher treatment with the strong alkali used in the process. The crystallinity of the UVC-treated sample was 65.60%. The analysed data from XRD spectra of untreated and desized fabrics are recorded in Table 7. An almost similar pattern of the spectra for the treated and untreated fabric is observed from the wide-angle X-ray. The data from Table 7 also show no

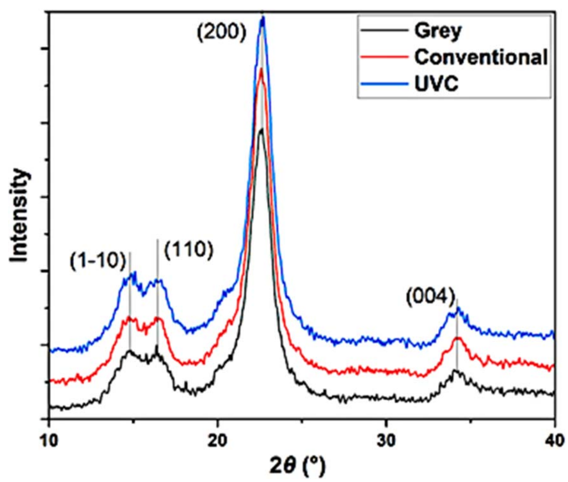

Fig. 12 XRD of fabric samples.

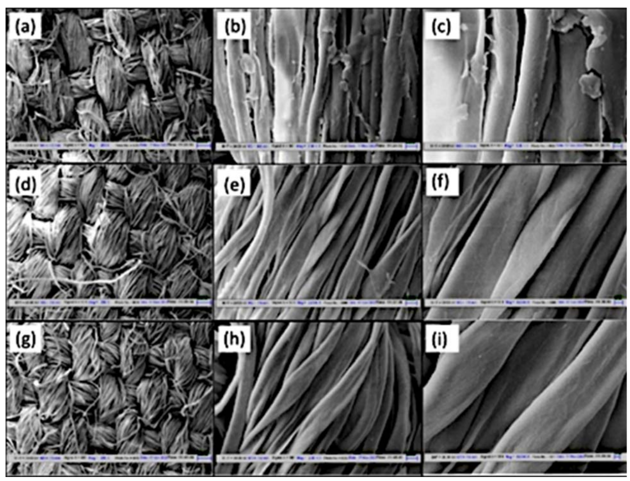

Fig. 13 SEM images [Mag (a, d and g) 250×, (b, e and h) 2000×, (c, f and i) 5000×] (a–c) grey, (d–f) conventional desizing and scouring, and (g–i) UV-C-assisted combined desizing and scouring.

Table 7 XRD analysis data for fabric samples

Sample type	Bragg angle 2θ (°)	FWHM β (°)	Crystallite size D (nm)	Dislocation density $\delta \times 10^{-3}$ (nm^{-2})	Microstrain $\varepsilon \times 10^{-3}$
Untreated	14.78	1.40	5.73	30.47	47.04
	16.41	1.40	5.72	30.52	42.42
	22.54	1.65	4.89	41.74	36.24
	34.25	1.23	6.77	21.82	17.39
Conventional	14.77	1.52	5.26	36.09	51.23
	16.45	1.30	6.15	26.42	39.38
	22.54	1.68	4.84	42.76	36.67
	34.28	1.37	6.08	27.06	19.35
UVC-treated	14.71	1.37	5.86	29.16	46.24
	16.42	1.64	4.89	41.90	49.69
	22.60	1.65	4.90	41.71	36.14
	34.22	1.29	6.46	23.96	18.24

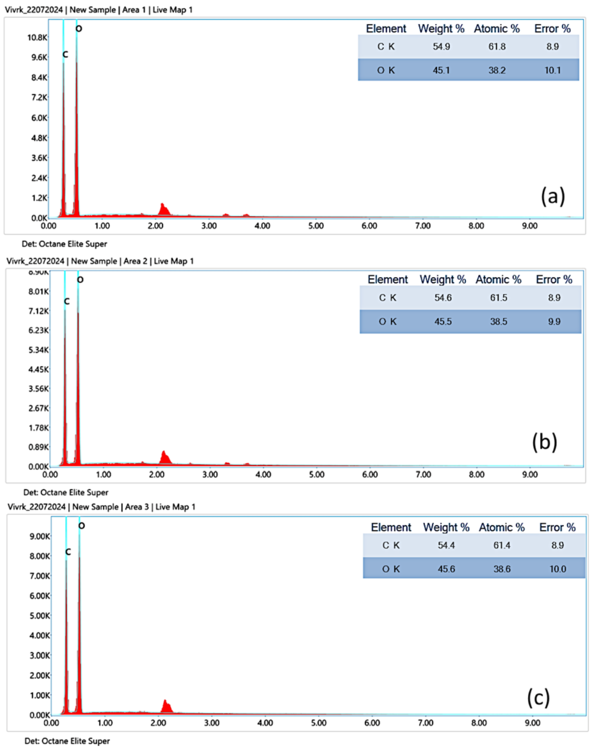

Fig. 14 EDX spectra, (a) grey, (b) conventional desizing and scouring, and (c) UV-C-assisted combined desizing and scouring.

change in the crystal structure for the UVC-aided desizing-scouring fabric.

Scanning electron microscopy (SEM)

The scanning electron microscopy images for the grey, conventional desizing and scouring and UV-C-assisted combined desizing and scouring fabric are presented in Fig. 13. The starch coating on the untreated grey fabric can be observed in Fig. 13(a–c) images. The removal of starch can be observed in Fig. 13(d–f) for the conventional desizing and scouring. Similarly, for the UV-C-assisted combined desizing-scouring fabric, Fig. 13(g–i) images show that not only has the starch been removed, but a cleaner and smoother fibre surface has been obtained than the conventional sample (Fig. 13(d–f)).

Energy-dispersive X-ray microscopy

The microstructures in SEM were further analyzed for their elemental composition in more detail using the EDX system. EDX was used as a non-destructive analysis to determine the elements and their concentrations in the sample reasonably accurately. The EDX spectra are shown in Fig. 14. Fig. 14(a) shows the spectra for untreated grey fabric where the main element carbon is present with a content of 54.9 as a weight percentage. Fig. 14(b) shows the EDX spectra for

Table 8 Time and water consumption for the conventional process

Sr. no.	Process	Temperature (°C) Initial	Final	Difference	Rate of heating (° min^{-1})	Time (min)	Water (L kg^{-1})
1	Bath heating	25	100	75	5	15	40
2	Desizing	100	100	0	5	60	—
3	Bath heating	25	100	75	5	15	40
4	Hot wash	100	100	0	5	10	—
5	Bath heating	25	100	75	5	15	40
6	Hot wash	100	100	0	5	10	—
7	Bath heating	25	100	75	5	15	40
8	Hot wash	100	100	0	5	10	—
9	Bath heating	25	95	70	5	14	40
10	Scouring	95	95	0	5	60	—
11	Bath heating	25	95	70	5	14	40
12	Hot wash	95	95	0	5	10	—
13	Bath heating	25	55	30	5	6	40
14	Neutralisation	55	55	0	5	10	—
Total						264	280

Table 9 Time and water consumption for the UV-C-assisted process

Sr. no.	Process	Temperature (°C) Initial	Final	Difference	Rate of heating (° min^{-1})	Time (min)	Water (L kg^{-1})
1	UV-C exposure	30	30	0	0	15	—
2	Bath heating	25	60	35	5	7	40
3	Hot wash	60	60	0	5	15	—
4	Bath heating	25	55	30	5	6	40
5	Neutralisation	55	55	0	5	10	—
Total						53	80

Table 10 Energy consumption for the conventional process

Sr. no.	Energy used for	Mass (kg)	Heat capacity (kJ kg^{-1} K^{-1})	ΔT	Energy (MJ kg^{-1})
1	Water heating	160	4.184	348	232.965
2	Water heating	80	4.184	343	114.809
3	Water heating	40	4.184	303	50.710
4	Fabric heating	1	1.340	348	0.466
5	Fabric heating	1	1.340	343	0.460
6	Fabric heating	1	1.340	303	0.406
7	Motor running	—	—	—	16.002
Total					415.818

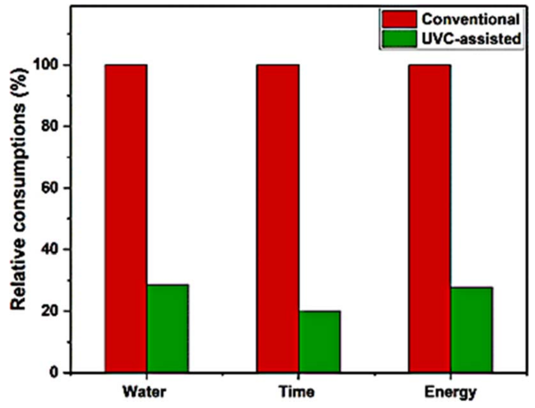

Fig. 15 Comparison of utility of the UV-C-assisted process with the conventional process.

conventional pretreated fabric. The carbon weight percentage for the UVC-treated fabric as shown in Fig. 14(c) is 54.4. It may be inferred from the elementary analysis that the UVC-treated fabric is composed of C, H, and O and free from any contamination.

Evaluation of process benefits

The utility consumption was calculated and compared with that of the conventional process to evaluate the benefits of the UVC-assisted combined desizing and scouring process. Inlet water quantity was computed considering the MLR as 1 : 40. The time and water consumption for the conventional and UVC-assisted processes was calculated according to the process flowchart as given in Fig. 4 and tabulated in Tables 8 and 9. The heat energy was calculated as per eqn (1) given in the methodology. The energy consumption for 1 kg of fabric is shown in Tables 10 and 11 for the conventional and UVC-assisted processes, respectively. The process utility is summarised in Table 12.

Considering the consumption for the conventional process as 100%, the relative consumption for the UV-C-assisted process is shown in Fig. 15. The UV-C-assisted process was carried out at a lower temperature than the conventional process. Therefore, energy consumption was reduced. Water, energy, and time consumption for the UVC-assisted process was reduced by 71%, 72%, and 79% of the conventional processes.

Life cycle analysis (LCA)

The process flow for conventional 2-step desizing and scouring and UVC-treated combined desizing-scouring is shown in the system boundary diagram (Fig. 16). Table 13 shows the input of materials and energy for processing 1 kg of fabric in the conventional and UVC-assisted techniques assuming that there is no system loss. The main impacts

Table 11 Time and water consumption for the UV-C-assisted process

Sr. no.	Energy used for	Mass (kg)	Heat capacity (kJ kg^{-1} K^{-1})	ΔT	Energy (MJ kg^{-1})
1	UV-C lamps	—	—	—	10.044
2	Heating and cooling of the UV-C chamber	—	—	—	0.0001
3	Water heating	40	4.184	308	51.547
4	Water heating	40	4.184	303	50.710
5	Fabric heating	1	1.34	308	0.413
6	Fabric heating	1	1.34	303	0.406
7	Motor running	—	—	—	2.394
Total					115.514

Table 12 Consumption of time, water, and energy

Sr. no.	Process	Temperature of desizing (°C)	Time (min)	Water (L kg^{-1})	Energy (MJ kg^{-1})
1	Conventional	100	254	280	416
2	UV-C-treated	60	53	80	116

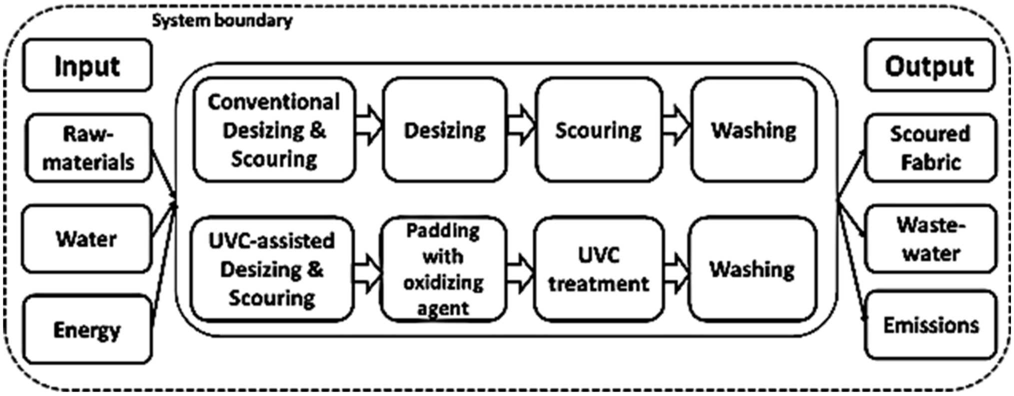

Fig. 16 System boundary for desizing and scouring.

Table 13 Process input for various processes

Sr. no.	Input	Conventional	UVC-treated
1	Cotton fabric (kg)	1.000	1.000
2	NaOH (kg)	2.400	0.600
3	Acetic acid (kg)	0.040	0.040
4	Na_2CO_3 (kg)	0.120	—
5	$NaBO_3 \cdot 4H_2O$ (kg)	—	0.002
6	Water (L kg^{-1})	280	80
7	Energy (MJ kg^{-1})	402	113

generated by these processes are freshwater ecotoxicity, freshwater eutrophication, marine eutrophication, terrestrial acidification, and water consumption related to the aquatic ecosystem measured with species year. The effects of ozone formation and global warming on human health are measured with disability-adjusted life years (DALY). Mineral resource scarcity is measured in USD 2013. Table 14 shows the impact of the conventional and UVC-assisted processes. The impacts of UVC-assisted processes indicate a reduced environmental impact compared to conventional methods. Implementing the UVC-assisted process can reduce the impact on human health due to ozone formation and global warming by approximately 60%. Adopting a newer technology using UVC to pretreat the fabric resulted in 36% savings in mineral resources. Overall, the UVC-assisted process is more environment-friendly than the traditional process.

Table 14 Environmental impact values

Sr. no.	Indicator	Conventional	UVC-assisted
1	Fine particulate matter formation (DALY)	1.54×10^{-3}	4.52×10^{-4}
2	Fossil resource scarcity (USD)	7.71×10	3.01×10
3	Freshwater ecotoxicity (species year)	4.05×10^{-9}	1.69×10^{-9}
4	Freshwater eutrophication (species year)	1.33×10^{-7}	4.27×10^{-8}
5	Global warming, freshwater ecosystems (species year)	1.21×10^{-11}	4.83×10^{-12}
6	Global warming, human health (DALY)	1.46×10^{-4}	5.87×10^{-5}
7	Global warming, terrestrial ecosystems (species year)	4.41×10^{-7}	1.77×10^{-7}
8	Human carcinogenic toxicity (DALY)	3.47×10^{-5}	1.31×10^{-5}
9	Human non-carcinogenic toxicity (DALY)	3.44×10^{-5}	1.22×10^{-5}
10	Ionising radiation (DALY)	3.09×10^{-8}	2.37×10^{-8}
11	Land use (USD)	9.15×10^{-8}	8.98×10^{-8}
12	Marine ecotoxicity (species year)	8.30×10^{-10}	3.34×10^{-10}
13	Marine eutrophication (species year)	2.84×10^{-11}	1.35×10^{-11}
14	Mineral resource scarcity (USD)	1.55×10^{-2}	9.88×10^{-3}
15	Ozone formation, human health (DALY)	3.59×10^{-7}	1.34×10^{-7}
16	Ozone formation, terrestrial ecosystems (species year)	5.12×10^{-8}	1.92×10^{-8}
17	Stratospheric ozone depletion (DALY)	6.74×10^{-8}	5.02×10^{-8}
18	Terrestrial acidification (species year)	1.26×10^{-7}	5.10×10^{-8}
19	Terrestrial ecotoxicity (species year)	1.80×10^{-9}	7.95×10^{-10}
20	Water consumption, aquatic ecosystems (species year)	1.96×10^{-12}	1.59×10^{-12}
21	Water consumption, human health (DALY)	7.21×10^{-6}	5.86×10^{-6}
22	Water consumption, terrestrial ecosystem (species year)	4.38×10^{-8}	3.56×10^{-8}

Conclusions

A considerable amount of heat and water is required while removing starch and other impurities such as oil, wax, and pectins in the desizing and scouring. A novel photocatalytic technique was implemented to reduce the process's time, water, and energy consumption by combining desizing and scouring with the assistance of UVC. The UVC process can reduce the processing time and washing temperature by 79% and 40% of the conventional process. Additionally, the UVC-assisted single-step desizing-scouring method improved pretreatment efficacy without affecting the fabric whiteness, strength, and absorbency time. Fabric dyeability is also found to be superior to that of the conventional process. Moreover, a complete bleaching process can be eliminated for light-to-dark shade dyeing. A saving of 71% water and 72% energy was found for the new desizing and scouring process as compared to the conventional method. The most crucial point here is to be noted from the LCA, which is that the new technique is more environmentally friendly. From an economic and environmental perspective, the process appears promising since it reduces the consumption of water, energy, and time. The limitation of the process is that the pretreatment method may not be suitable for dyeing very pale shades and white fabric.

Data availability

No additional software or code has been included and whatever new data were generated or analysed as part of this research are included in the manuscript.

Conflicts of interest

There are no conflicts to declare.

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