Chemical Modification of Indian Yak Fibre for Development of Jute/Yak Fibres Blended Warm Textile

Kartick K. Samanta and A. N. Roy

Abstract Yak wool, an important speciality protein fibre, is mostly available in China, Mongolia and India. The yak fibre is commonly categorized into down or fine fibre, guard or coarser fibre and middle type fibre based on their fibre fineness. A large quantity of coarser yak fibre, which is quite stiffer and thicker, remains underutilized including its application in textile. In our work, the coarser grade black colour yak (fibre) wool of 9.3 tex was suitably chemically modified for blending with jute (ligno-cellulosic) fibre to develop blended textile with jute to yak fibres blend ratio of 25:75. After chemical modification, the coefficient of friction between the yak fibre and the metal was found to enhance to 0.368 from 0.280 in the unmodified hair sample, which is closer to the coefficient of friction of jute fibre. This facilitates in developing jute and yak fibres blended yarn with higher percentage of yak fibre content in the yarn. Indeed after modification, the natural black colour of yak fibre turned into a colour alike to ligno-cellulosic jute fibre with a marginal decrease in breaking load (12%) and linear density (16%). Scanning electron microscope (SEM) and EDX elemental analysis showed no detrimental changes in surface morphology and chemical composition of the yak wool after requisite chemical modification. Different fabrics were developed from the jute and yak wool blended un-dyed and dyed yarns. The jute–yak fibres (50:50) blended woven fabric of 385 g/m^2 areal density showed a thermal insulation value of 1.4 (Tog).

Keywords Yak fibre · Jute fibre · EDX of hair · Jute–yak fibres textile

1 Introduction

Yak (*Bos grunniens*), an important domesticated bovid animal, plays an important role in the Indian economy of the tribal population living in the foothills of Himalayas [1]. The products and services provided by the yak animal are milk, meat, leather and

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wool that are used for clothing, blankets, bags, implements, rugs and tents [1]. As far as the fibre (hair) part is concerned, it is a specialty animal fibre. The total population yak animal is approximately 14.5 million, and the yield of wool is approximately 410,000 tons per year; out of which 10,000 tons is down wool [2–5]. The yak fleece processes a large quantum of guard/coarse hair, which is quite coarser and stiffer in nature [5, 6]. A yak animal generates approximately 100 g of fine hair fibre (diameter of 16–20 μ) annually that comes with few natural colours, out of those white yak hair is the valuable one [7]. Yak herds are mainly available in the mountainous areas of China, Mongolia, India, Bhutan, Afghanistan, Kyrgyzstan, Russia and Nepal on the Central Asian Plateau. Yaks' coarser hair fibre as well as the fine fibre is seasonal character in nature that is gradually shed and replaced with the newer one, ensuring a requisite thermal insulation to the animal during the cold season [3]. The yak coat is consisting of three different types of fibres, which are greatly varied in properties throughout the seasons [7]. The coarse yak hair fibre (70–90 μ) contributes in forming the outer coat of guard hair fibre that also represents the appearance of the yak; the fibre is mostly used in tent making by the nomads. Down hair (fibre) with a length of 35–50 mm and approximately diameter of 16–20 μ is mostly used for textile application; such hair fibre is generally shed during the late spring or early summer [8]. On the other hand, the middle type yak wool fibre with a diameter of 20–50 μ shows properties in between the finer and the coarser fibre and also used for ropes and tents production. Fabric made of yak down fibre has good lustre and high degree of heat insulation [9]. Naturally occurring hair fibres, such as human and animal hairs consist of α-keratin protein in a filamentous structure [10, 11]. Fine yak fibre has reasonably good crimp and tensile strength (9.18 cN/tex) [4]. The yak animals as well as the hairs are available in four different colours, namely black, white, brown and blue; out of which black colour hair fibre has the major share [7]. Black colour yak hair fibre is some extent alike to human hair that is mainly consists of 65–95% keratotic protein, natural pigments, lipids, trace elements and water [12, 13]. Yak wool fibre was used for making tents, ropes, clothing and blankets by the nomads in the Trans-Himalayan region. In recent time, the yak wool fibre has been utilized to produce premium textile by well-known companies/brands likes, Louis Vuitton, British Heritage Brand Inc., Eileen Fisher and Dunhill [7]. Since the mid-twentieth century, emphasis has been given for encouraging the use of yak wool in the garment industry due to its exotic attribute and favourable performance. In all such above applications, mainly the down or finer fibres have been utilized. On the other hand, due to the higher diameter and rigidity, the coarser yak fibre is typically carded and then spun in worsted yarn production system [13]. Multiple plied guard hair threads are then subsequently braided or weaved into ropes, halters, belts, bags and rugs.

Jute, a ligno-cellulosic vegetable bast fibre, is presently being used as a biodegradable packaging material for food grains and sugar. The traditional usage of jute fibre, i.e. meant for packaging application, has undergone a substantial change in the last few decades. Some of the recent technological advancements and possible applications in this direction are: (i) jute geo-textile, (ii) jute agro-textile, (iii) jute composite in substitute of wood/plastic, (iv) handmade paper and (v) ornamental and decorative items, like shopping bags, jute shoes, jewellery and lifestyle products, either from

100% jute or in suitable blending with other fibres, such as cotton, viscose, ramie, flax, silk, wool, polyester and acrylic [14–16]. The inherent golden colour of jute fibre adds an elegant attribute and aesthetic appeal to the jute products. Jute fibre has high initial modulus along with low extensibility, and it is produced from the plant, genus *Corchorus* [17]. In the recent time, various high valued jute blended textile products, meant for apparel applications have been developed viz., use of jute in a sari, warm garment and jackets, knitted items, and many more after suitable physical and/or chemical intervention of jute or in the fibre processing system. Almost 85% of the world's jute cultivation is concentrated in the Ganges Delta. In the past, several research and developments on jute fibre have been carried out for its commercial application as apparel textile. However, such whole jute products have realized some degree of success owing to its limitation of itchiness, prickling effect, higher drape and higher bending rigidity.

Blending of jute fibre with yak wool fibre will help to exploit the positive attributes of both the individual fibres to produce finer and stronger yarns with a warm feel effect. Moreover, the jute fibre has the potential for colouration in different shades to produce a blended yarn with the decorative look, which can help in the production of fabrics suitable for warm garments with a premium price. On the other, the stiffness of jute yarns can be masked by blending with softer yak fibre to produce a fabric with good handle property. At present, India produces around 150–250 tonnes of guard (coarser) and 20–25 tonnes of down (fine) yak fibres. In our institute, an effort was made to develop jute–yak fibres blended warm textile to produce high-value outer garments that could be used in the cold climatic location. Coarser grade yak fibre mostly does not utilize for high-value products, because of its higher diameter and stiffness along with a high slippery surface that makes it difficulty in developing fine textile yarn, either from the 100% yak hair fibres or in suitable blending with other natural fibre. Also, there is no report on blending of yak wool with ligno-cellulosic jute fibre to produce fashionable textile to the best of our knowledge. It was found that after suitable chemical modification of black colour coarser yak fibre, it was possible to produce jute–yak fibres blended yarn with a higher percentage of yak fibre content in the blended yarn.

2 Experimental

2.1 Materials and Modification of Yak Fibres

Coarser yak fibre with natural black colour was received from ICAR-National Research Centre (NRC) on Yak, Dirang, Arunachal Pradesh, and the jute fibre was procured from the local market of Kolkata. For the purpose of production of jute–yak fibres blended yarn as well as textile, yak hair fibre was initially scoured and then successively bleached with an oxidative bleaching agent as per the standard recipe

Table 1 Yak hair fibre subjected to different dosages of chemical treatment in addition to the standard recipe [18]

Yak hair fibre	NaOH addition (g/l)	H_2O_2 addition (o.w.f.) (%)	Time (min)
Sample 1	0.75	11	60
Sample 2	2.3	27	110

[18]. Additionally, following dosages of chemicals were given to produce modified yak fibres with different degree of coefficient of friction and colour (Table 1).

2.2 Evaluation of Physical Properties

Instron Tensile Tester (Model 5567) was used to measure the physical properties, such as breaking tenacity, elongation percentage and initial modulus of yak hair fibres. Initial modulus and tenacity were measured using the data of stress–strain curve and fibre linear density. The reported data are the average of sixty measurements. Stress–strain curve is plotted for different yak fibres using one of such measurement. The gravimetric method was used to measure the fibre fineness in terms of 'tex'. Photographs of the different yak fibres were taken using Canon 5D Mark III SLR camera. Moisture regain of hair fibre samples was calculated by gravimetric method. Hair fibre to metal coefficient friction was measured using a friction tester that works on inclined plane principle as reported in literature [19]. Different colour parameters viz., L, a^*, b^*, K/S, C, H, R, G and B values were measured using computerized colour matching system (Model Spectrascan–5100). Colour depth of the different fibre samples was measured by measuring the colour strength (K/S) obtained from the reflectance data following the Kubelka–Munk equation. Surface micrograph of the different yak fibres and jute fibre was studied using SEM, Philips XL-30. The X-ray diffractometer (Model Philips PW 1877) was used to estimate the degree of crystallinity of the hair fibre samples.

2.3 Evaluation of Chemical Property

Field emission gun (FEG) scanning electron microscope, Model: JSM-7600F with energy dispersive X-ray (EDX) attachment, was used to measure the elemental composition of the different hair fibre samples.

3 Results and Discussion

3.1 Physical Properties of Fibre

As yak hair is a protein fibre, it possesses lots of surface impurities, such as vegetable matter, fatty matter, dust and dirt on its surface. It was observed that there was a 4.1% weight reduction due to scouring process of yak hair due to the removal of above surface impurities. Likewise presence of around 2.5–3.1% fat and dirt mixture has also been reported in literature for similar fibre [4].

Moisture regain of the untreated and chemical modified yak hair fibres was measured by gravimetric method after drying the samples at 110 °C. It was observed that an untreated yak fibre showed 15.6% moisture regain, and it improved a little (16.5%) after chemical treatment. Such small improvement in moisture regain value was possibly occurred due to removal of surface fatty layer as well as other impurities viz., dust, dirt and suint. The presence of many hydrophilic side polymer chains and peptide bonds of keratin polymer helps the sample to be hydrophilic in nature along with higher moisture regain value [12]. The optical and microscopic images of the different yak and jute fibres are represented in Fig. 1. An untreated yak hair fibre has a black colour; however, after chemical modification in alkaline condition in the presence of hydrogen peroxide (H_2O_2), its colour became blackish brown. With the increasing either alkali, hydrogen peroxide or time, the sample colour slowly turned into deep yellowish brown colour (golden) and the colour could be compared with ligno-cellulosic jute fibre. It can be seen from Table 2 that an untreated hair sample has linear density of 9.3 tex. The value slowly reduced with chemical treatment in the presence of alkali and bleaching agent. This results in 14% change in fibre linear density. The tenacity, breaking load, elongation percentage and initial modulus of yak hair fibres were measured in Instron Tensile Tester and the reported data are the average of sixty measurements. The stress–strain percentage curve of different yak hair fibres has been depicted in Fig. 2 using one of such measurement. From Fig. 2, it can also be seen that initial modulus of the modified fibre two is lower than the untreated sample. It was seen that after chemical treatment, elongation percentage gets reduced. The fibre strength was observed to decrease a little after chemical modification of yak hair fibre.

Fibre length was measured manually using a scale and the length was found to reduce to 11.2 cm in the chemically modified sample from 18.8 cm in the untreated. It may be noted that the fibre length of 11.2 cm was suitable for development of jute–yak fibres blended yarn. As protein fibre is soluble in alkaline solution; therefore, the presence of little amount of sodium hydroxide during chemical modification with temperature near about 80 °C might have removed the surface polymer chain molecules that also lead reduction in hair linear density along with breaking load (12% for sample 1). Indeed, the sample 1 with desired frictional value was suitable for production of jute and yak fibres blended textile yarn in jute fibre processing machines sequence as discussed in successive section.

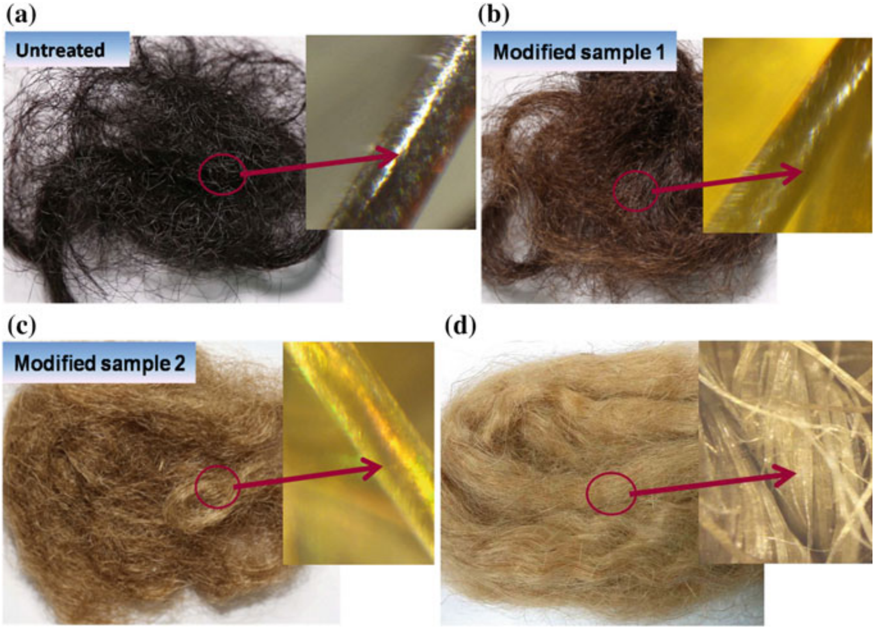

Fig. 1 Pictures of **a** untreated yak fibre, **b** treated yak fibre 1, **c** treated yak fibre 2 and **d** jute fibre

Table 2 Physical properties of jute and yak hair fibres [18]

Different samples	Linear density (tex)	Breaking load (N)	Tenacity (cN/tex)	Initial modulus (cN/tex)	Elongation (%)	Fibre length (cm)
Untreated yak fibre	9.3	0.97	10.4	428	25	18.8
Modified yak fibre: sample 1	7.8	0.85	10.8	455	19	17.6
Modified yak fibre: sample 2	8.0	0.65	8.0	408	6	11.2
Jute fibre (carded sliver)	0.95–4	–	40	500–600	1–2	9–15 (carded sliver)

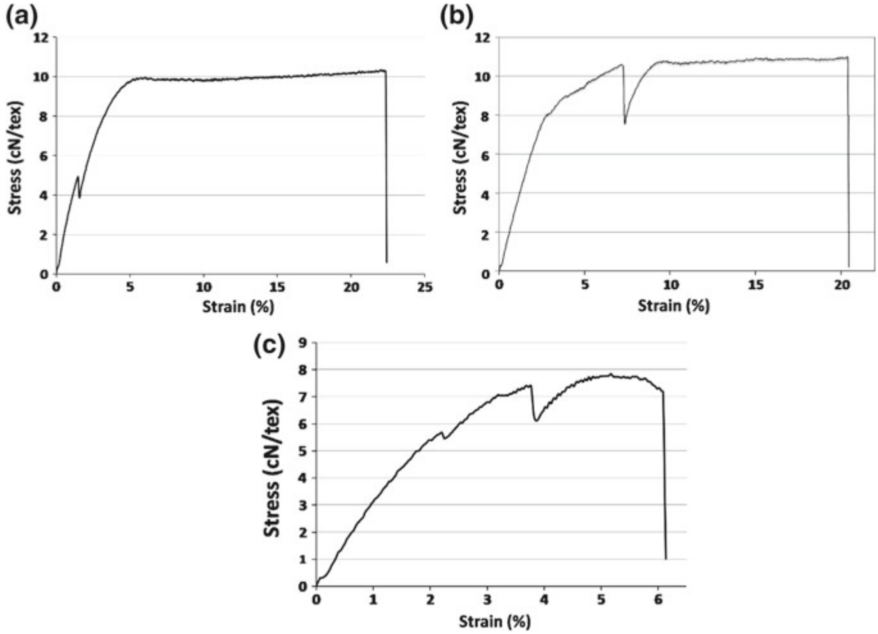

Fig. 2 Stress–strain percentage curves of different yak hair fibres **a** untreated, **b** modified sample 1 and **c** modified sample 2

It was observed that an untreated yak hair fibre possesses very low surface coefficient of friction value of 0.28 possibly due to presence of lipid film (polysaccharide) [10]. This indicates that the hair fibre surface is quite slippery and smoother. There was no noticeable increase in surface coefficient of friction after scouring in the presence of soap and mild alkali. In Sample 1, the coefficient of friction value increased to 0.368 possibly due to etching of fibre surface in the presence of alkali along with crimp development. This is considered as an important desirable requirement for spinning of proteinous yak hair with ligno-cellulosic jute fibre that has higher surface of friction of 0.45 and 0.39, respectively, in the parallel and perpendicular directions [7]. It was observed that with further enhancement in bleaching dosage, no further enhancement in coefficient of friction was noticed.

X-ray Diffraction Analysis

X-ray diffraction was performed in the untreated and modified (samples 2) yak hair fibres in order to investigate the crystalline and amorphous content in these hair fibres. Both the samples did not show any major diffraction peak due to the presence of crystallographic plane or structure as shown in Fig. 3. This implies that both these samples either treated or untreated are quite amorphous in nature. This is a quite different phenomenon as compared to other protein fibres like, silk and wool that have 25–66% crystalline phase. The X-ray diffraction of jute fibre shows clear peak at 2θ values of 14.96, 16.51 and 22.65 with crystallinity percentage of 55%.

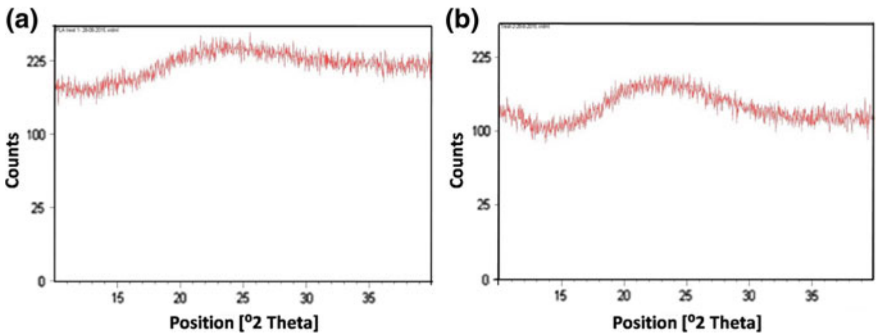

Fig. 3 X-ray diffraction curves of **a** untreated and **b** treated yak fibres

3.2 Measurement of Colour Parameters

As ascribed above, a large quantity of yak wool is obtained with inherent black colour, possibly due to the presence of melanin in the form of eumelanin and phaeomelanin pigments [2, 20]. It is quite fair to assume that black colour coarser yak hair would have a few characteristics alike to human hair. This is because both these hairs are protein fibre also black in colour, thus their properties were considered for comparison. In this study, the black colour coarser yak hair was subjected to chemical treatment to create requisite surface friction and also to change its black colour into a colour, similar to jute. Ultimately, this will help to produce jute–yak fibres blended woven fabrics. Figure 4 shows the spectroscopic reflectance percentage with wavelength for various yak hair fibres. As expected, the sample without any chemical treatment produces the lower reflectance percentage, and the corresponding spectroscopic image is shown in Fig. 5 (code 0), i.e. black in colour. Upon oxidative bleaching of yak fibre with hydrogen peroxide (H_2O_2), sample reflectance percentage was found to improve noticeably as shown in Fig. 4 (sample code 1) and the corresponding spectroscopic image showed in Fig. 5(1). With further addition of chemical agents as well as an increase in treatment time, sample colour slowly turned into blackish brown to strong reddish and deep yellowish brown as shown in Figs. 4(2) and 5(2). Similar results have also been observed in the camera-captured picture as depicted in Fig. 1. Table 3 shows the spectroscopic colour properties of various yak wool and ligno-cellulosic jute fibre samples. The lightness-darkness (L^*) was the lowest in the case of untreated yak fibre, resulting highest colour depth (K/S) of 24.3. As expected after bleaching with H_2O_2, the whiteness value notably enhanced to 34.8. The L^* value further improved to 41.4, with increasing chemical treatment parameters. Likewise in the chemical treated sample, the a^* (red–green) value increased to 8.9 from 1.4 in the untreated and the value could be compared with the a^* value of ligno-cellulosic jute fibre. Furthermore, the yellow-blue colour parameter (b^*) also notably increased as observed for the a^* value. As the a^* value (redness) was found to enhance, the red (R) value was also gradually increased from 41 to 83 and 122 in the untreated to

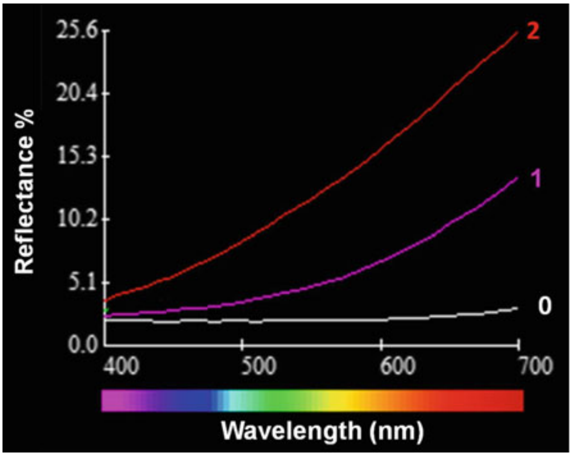

Fig. 4 Reflectance percentage in the untreated (0) and modified yak hair fibres (sample 1 and sample 2)

Fig. 5 Spectroscopic colours generated during colour measurement of various yak fibres: (0) untreated, (1) modified sample 1 and (2) modified sample 2

various treated samples. Similar trend was also noticed for green (*G*) and blue (*B*) colour parameters as shown in Table 3. Similarly, the *C* value (colour strength or saturation) increased from 1.6 in the untreated sample to 16.9 and 22.8 to modified hair samples, respectively. The *H* (a particular colour) values of the different fibre samples were measured using the spectroscopic software.

3.3 Scanning Electron Microscope Morphology

Almost all the hair fibres viz., human hair, angora, wool, pashmina, etc., are well known due to the presence of scale on their hair/fibre surface [21, 22]. Similar to the above hair fibre characteristic, an untreated yak fibre also shows the presence of scale on the surface under scanning electron microscope (Fig. 6a). After the chemical modification, the surface scale looks like smoother, but the features, i.e. the scales, were clearly visible at higher magnification (Fig. 6b) [9]. Therefore, it

Table 3 Colour parameters of the jute and various yak hair fibres [18]

S. No.	Colour parameters	Different yak fibres			Jute fibre
		Untreated sample	Modified sample 1	Modified sample 2	
		Code 0	Code 1	Code 2	
1	*K*/*S*	24.3	18.3	10.3	3.24
2	L^*	25.3	34.8	41.4	59.3
3	a^*	1.4	8.9	8.0	10.3
4	b^*	0.67	14.2	21.4	24.9
5	*C*	1.6	16.9	22.8	27.0
6	*H*	24.7	58.2	69.4	67.3
7	*R* (red colour)	41	83	122	175
8	*G* (green colour)	38	59	92	135
9	*B* (blue colour)	38	44	63	99

can be stated that the yak fibres were chemically treated to develop the requisite surface friction without much alteration in the surface properties. The change in scale morphology of yak hair has been generated possibly due negative interaction (surface etching) of alkali with hair polymer, as it was observed that in the 2.5% concentrated NaOH/KOH solution yak hair was soluble. It is interesting to note that both the untreated and the modified yak fibres cross-sections do not show presence of any medulla (internal open pore) (Fig. 6). The hair fibres are mostly elliptical in shape with notably variation in diameter due to inherent variation in hair diameter from bottom to top. The diameter of coarser yak fibre was measured to be about 50–100 μ, considering the top to bottom part of the fibre. It was also noticed that after chemical treatment with bleaching agent and alkali, fibre cross-sectional morphology remained unchanged. On the other hand, jute fibre showed pillar-like structure with polygonal shape as shown in Fig. 7. In each fibre cross-section, presence of several lumens (open pore) is also clearly visible.

3.4 EDX Elemental Analysis

Figure 8 depicts the energy dispersive X-ray images of the jute, and untreated and chemical treated yak hairs and the corresponding elemental atomic percentage of these fibre samples are reported in Table 4. Natural human hair consists of group of proteins, popularly known as keratins, which are interconnected to form stable fibrils. Such protein chains are very much complex in nature both histologically and chemically due to the presence of a multiplicity cross-linked protein molecules [18]. In hair or wool fibre, the protein part, i.e. the keratin, is composed of eighteen

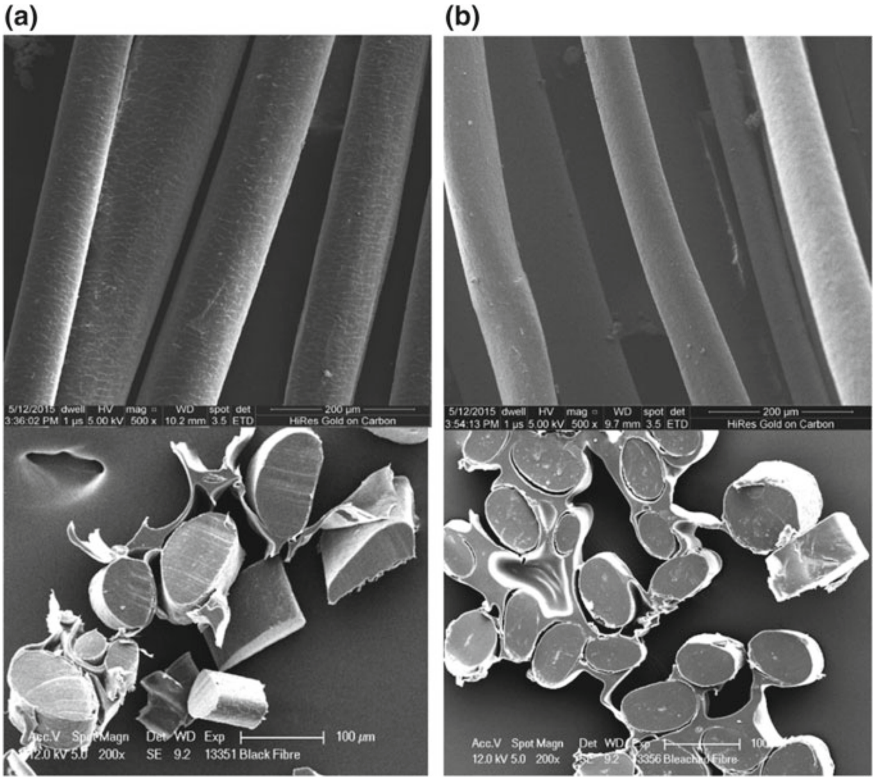

Fig. 6 Scanning electron surface and cross-sectional morphology of yak hair fibres: **a** untreated and **b** modified

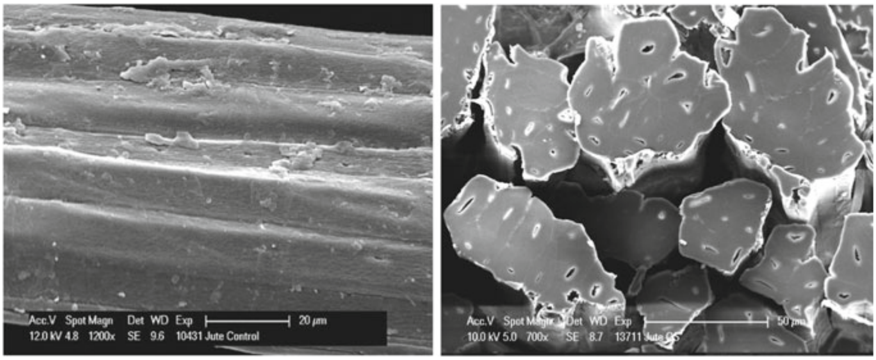

Fig. 7 SEM surface as well as cross-sectional pictures of ligno-cellulosic jute fibre [18]

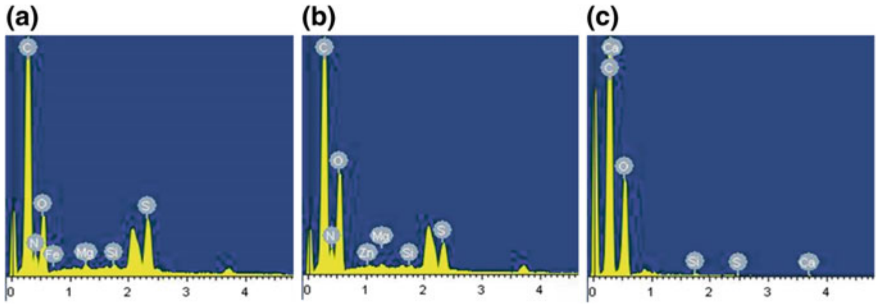

Fig. 8 EDX elemental spectra of **a** untreated yak hair, **b** modified yak hair and **c** jute fibre

Table 4 EDX atomic percentage in the various yak wools [18]

Elements	Yak fibres	
	Untreated	Treated sample 2
C	58.34	51.54
N	18.21	15.78
O	20.76	31.08
Mg	0.19	0.17
Si	0.16	0.12
S	2.26	1.26
Fe	0.10	0.00
Zn	0.00	0.05
Total	100.00	100.00

different amino acids, among those amino acids cysteine is rich in sulphur content [2]. Disulphide linkages (–S–S–) present between the adjacent keratin polymer chains improve the stability of keratin from chemical and biological degradation.

Table 4 depicts the presence of 58.34% carbon in an untreated hair sample and the value notably reduced to 51.54 in samples 2. In the yak hair polymer, elemental percentage could be arranged in the following order carbon > oxygen > nitrogen > sulphur. The EDX sample characterization technique could not detect the hydrogen element. Similarly, nitrogen percentage also decreased to 15.78 after chemical modification from 18.21 in the untreated hair sample. It may be noted that the oxygen atomic percentage profoundly increased to 31.08% after peroxide bleaching from 20.76% observed in an untreated sample, signifying an improvement in the hydrophilic characteristic of the sample. The wool and other similar hair fibres are known for presence of sulphur containing molecules as an important structural constituent of the polymer, thus the sulphur atomic percentage was analysed from the EDX data [19]. An yak hair possesses 2.26% sulphur that significantly decreased to 1.26 after chemical modification. This is happened, possibly due to chain scission of disulphide bond of cysteine and a similar phenomenon is reported for the bleached fine yak and hair fibres [13, 20]. A few more metal elements viz., zinc (Zn), magnesium (Mg), iron (Fe) and silicone (Si) were also observed, and similar elements were also observed for human hair owing to sweat deposition [12]. However, their total quantity is significantly lower as compared to other elements. On the other hand, in jute fibre only the carbon (62.7%) and oxygen (37.1%) elements were detected as major elements in EDX analysis as it is made of cellulose, hemi-cellulose and lignin.

3.5 Development Jute–Yak Fibres Blended Textile

Black colour coarser yak as well as ligno-cellulosic jute fibres were used to develop jute–yak fibres blended yarn (275 tex) with blend ratio of 50:50 in jute processing machineries and the tensile properties of the yarn were measured. Similar to the 50:50 jute–yak fibres blended yarn that was produced from the unmodified yak fibre, a blended yarn was also produced from the chemically modified yak, keeping yak fibre content at 75% and remaining is jute fibre. The aim was to develop jute–yak fibres blended yarn with more yak wool component. However, it was observed that during the spinning of yarn with more than 50% yak fibre in blend, there was a instability and slippage of sliver. After suitable chemical treatment of yak fibre with improved coefficient of friction, 75% yak wool fibre was possible to introduce with 25% ligno-cellulosic jute fibre in order to develop jute–yak (25:75) fibres blended

Fig. 9 Picture of a jacket produced from jute–yak fibre dyed yarns with blend ratio of 50:50

textile yarn. These yarns were thereafter dyed in different shades and utilized for production of 1 × 1 plain woven fabrics in handloom [18]. The jute-yak fibres blended woven fabrics were utilized for developing apparel product as shown in Fig. 9. In this fabric, black colour polyester yarn was used as a warp yarn and the jute–yak fibres blended yarn (50:50) was considered as a weft yarn. The woven fabric of 385 g/m^2 areal density prepared from the 50:50 jute–yak wool fibres blended yarn showed a thermal insulation value of 1.4 (Tog), whereas the twill design fabric made from the same yarn showed a little more thermal insulation value.

4 Conclusion

After the chemical intervention of black colour coarser yak wool fibre with alkali and bleaching agent, it was possible to convert it to strong brown yellow colour, a similar colour to ligno-cellulosic jute fibre. In the treated yak wool, fibre to metal coefficient of friction was observed to increase to 0.368 from 0.280 in an untreated yak hair. The enhancement in surface friction could meet one of the desirable requirements of fibre spinning in making blended yarn with jute fibre. In the treated fibre samples, tenacity at break remains almost unchanged as compared to the untreated sample. There was a little decrease in breaking load of the chemically modified yak hair fibre; a similar result was also observed for fibre linear density. Sulphur atomic percentage gets reduced from 2.26% in the untreated sample to 1.26% in the chemical treated samples, owing to chain scission of cystine linkage. Yak fibre was successfully blended with jute fibre in jute processing machineries to produce yarns with blend ratios of 50:50 and 75:25. Finally, these yarns were utilized for developing plain woven fabrics for apparel application. The jute–yak fibres blended textile products viz., overcoat, blazer and jackets could be used as warm garment.

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