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Impact of Alkali Treatment on Physical and Chromatic Properties of Reactive Dyed Coir Fiber

Ms. Shivani N. Machhi[1], Dr. K. J. Umrigar[2], Dr. S. R. Shah[3]

[1]Department of Textile Chemistry, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda; Kalabhavan, Vadodara 390 001
[2]Assistant Professor, Department of Textile Chemistry, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda; Kalabhavan, Vadodara 390 001
[3]Associate Professor (Retired), Department of Textile Chemistry, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda; Kalabhavan, Vadodara 390 001

ABSTRACT:
Coir fibre, a lignocellulosic natural fibre derived from coconut husk, exhibits high durability but limited dyeability due to the presence of lignin and surface impurities. This study investigates the impact of alkali treatment on the physical and chromatic properties of coir fibre dyed with reactive dyes. Alkali treatment using sodium hydroxide (NaOH) was carried out at varying concentrations to modify the fibre surface by removing lignin, hemicellulose, and waxy substances. The treated fibres were subsequently dyed with reactive dyes under controlled conditions. Physical properties such as tensile strength, elongation, and surface morphology were evaluated, along with chromatic parameters including colour strength (K/S), CIELAB values, and fastness properties. The results indicate that alkali treatment significantly enhances dye uptake and colour strength due to increased fibre porosity and improved accessibility of hydroxyl groups. However, excessive alkali concentration adversely affects mechanical strength. The study demonstrates that optimized alkali treatment improves both dyeability and aesthetic properties of coir fibre, making it suitable for value-added textile applications.

Keywords: Coir fibre; Alkali treatment; Reactive dyeing; Colour strength; Surface modification

INTRODUCTION & LITERATURE REVIEW/RELATED WORK

Coir fibre is a natural lignocellulose multicellular fruit fibre extracted from the mesocarp of coconut (Cocos nucifera L.), primarily cultivated in tropical coastal regions. Commonly known as the "Golden Fibre," coir exhibits high durability, elasticity, and resistance to saltwater degradation. Brown coir from mature coconuts is strong and abrasion-resistant, while white coir from immature coconuts is finer and softer. These fibres are widely used in ropes, mats, brushes, upholstery, bedding, and geotextiles, forming an important agro-based industry in India and Sri Lanka that supports rural livelihoods (Export Potential of Coir and Coir-Based Products of India, 1971; Rethinam, 2018; Banu & Divyabharathi, 2024). Chemically, coir fibre contains a high proportion of lignin (~46%) and cellulose (~43%), imparting stiffness, toughness, moisture resistance, and resistance to microbial degradation (Varma, Varma, & Varma, 1984; Dineth S. Samarawickrama, 2010; Hasan, Horváth, Bak, & Alpár, 2021; Stelte et al., 2023).

These characteristics make coir a promising sustainable alternative to synthetic reinforcements in polymer composites due to its renewability, biodegradability, and cost-effectiveness (Shah, 2014; Adeniyi et al., 2019). However, high lignin, wax, and pectin contents limit fibre–matrix adhesion and dye uptake, necessitating effective pretreatment. Alkaline pretreatment using NaOH is widely reported to enhance surface roughness, expose reactive hydroxyl groups, and improve interfacial bonding, resulting in superior mechanical performance of coir-reinforced composites (Gu, 2009; Yan et al., 2016; Muensri et al., 2011; Darshan Dange & Gnanamoorthy, 2023; Hoang et al., 2022). Complementary ecofriendly approaches, including biological softening and low-impact bleaching and dyeing, improve fibre flexibility, whiteness, and dyeability while reducing environmental burden (Dam, 1999; Dam, 2002; Anita Das Ravindranath, 2010; Samanta, Basu, & Mishra, 2018). The increasing adoption of natural dyes with ecofriendly mordants such as alum and myrobalan aligns coir processing with global environmental regulations and export standards. Recent studies report coir-based polymer composites with enhanced mechanical and functional properties, as well as applications in oil adsorption and wastewater dye removal (Adeniyi et al., 2019; Hasan, Horváth, Kóczán, & Alpár, 2021; Hoang et al., 2022; Ong, Ho, Wong, & Zainuddin, 2013). India remains a global leader in coir production and exports, with diversification into automotive components, packaging, horticulture, construction materials, and engineered biocomposites (Jawaid, 2022; Stelte et al., 2023; Madueke, Ekechukwu, & Kolawole, 2024). Despite these advances, challenges remain in achieving uniform fibre quality, optimizing ecofriendly pretreatments, and improving matrix compatibility, underscoring the need for continued research into advanced processing and value-added coir-based materials (Varma et al., 1984; Adeniyi et al., 2019; Hasan et al., 2021; Stelte et al., 2023).

METHODOLOGY:

Materials:

Raw coir fibres were procured from the Coir Board, Ahmadabad, Gujarat, India. Two reactive dyes, Coracion Blue HEGN - C. I. Reactive Blue 198 and Coracion Red HE3B - C. I. Reactive Red 120 were selected for the study, which is procured from Colortex Dyestuff Pvt Ltd.Surat, Gujarat, India.

Experimental Methods:

Pre-treatment of Coir Fibres:

Alkaline scouring was performed using sodium hydroxide (5, 10 and 20%) concentration at varying temperatures (60, 80 and 100°C) and times (60, 90 and 120 min). The weight loss of alkaline scouring was determined using equation (1).

Weight loss (%) = $\frac{W_1 - W_2}{W_1} \times 100$……………………..Equation (1)

Where, W_1 = weight of Coir fibre before degumming

W_2 = weight of Coir fibre after degumming.

Alkaline scouring was optimized in terms of the maximum weight loss and then Hydrogen peroxide bleaching was applied under controlled pH (10.5–11) using sodium silicate as stabilizer for optimized sample.

Dyeing of coir fiber with reactive dyes:

Dyeing was started with dye solution and fibre at 40°C keeping material to liquor ratio 1:50. After 10 minutes, half amount of 40 gm/lit glauber's salt was added and dyeing was continued with increase in temperature to 60°C at heating rate of 1°C/minute and remaining half amount of 40 gm/lit glauber's salt was added. Then dyeing was continued at 60°C for further period of 20 minute and half amount of 20 gm/lit soda ash was added. The dyeing was continued at this temperature for further period of 15 minute

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and reaming half amount of 20 gm/lit soda ash was added and dyeing is continued for further 15 minutes. After completion of dyeing, soaping was carried out at boiling temperature using 1 gm/lit soap solution for 10 minute and finally wash the samples thoroughly with water and oven dried. The dyeing cycle was shown in **Figure-1.**

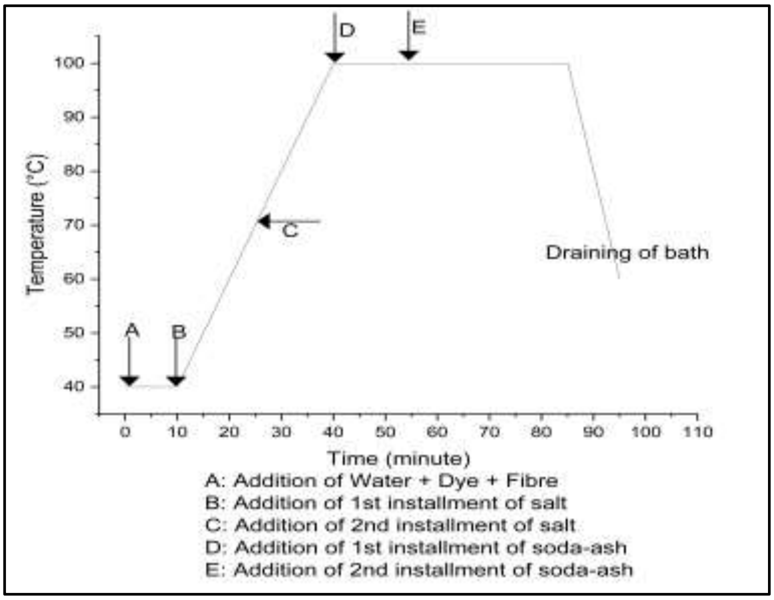

Figure: 1. Dyeing Cycle of Reactive dye

Characterization and analytical Methods:

The control, pre-treated and dyed samples were evaluated for colour strength (K/S), whiteness index, yellowness index and brightness index on spectra scan 5100 spectrophotometers (Made: Premier Colour Scan, India) The color fastness to washing of the dyed samples was measured by ISO washing fastness test (IS:764:79). The Colour fastness to rubbing of both the dyed samples were assessed in dry as well as in wet conditions on crock meter as per AATCC Test Method 8:2005 method. The color fastness to light of all the dyed samples were assessed by AATCC Test Method 16-2004. FTIR spectra of the control, pretreated and dyed samples were recorded using BUCKER FT-IR spectrometer. Scanning was carried out over the spectral range of 4000–500 cm^{-1}. Tensile strength of the fibre was measured on tensile strength tester as per the standard ASTM D3822 methods. (Model: Llyod Tensile Tester). The wettability of hemp fibres was measure by sinking time test method.

RESULT AND DISCUSSION:

Effect of Pre-treatment parameters on weight loss of coir fibre:

The raw coir fibres were subjected to a alkaline scouring treatment and results were expressed in terms of weight loss. The results are tablated in **Table 1** and graphically represented in **Figure 1.**

Table:1 Weight loss(%) of alkaline pretreatment of coir fibre

Sr. No:	Concentration of NaOH (%)	Temperature (^{0}c)	Time (minutes)	Weight loss (%)
1.			60	3.0
2.		60	90	4.2

3.			120	5
4.	5	80	60	3.8
5.			90	5.3
6.			120	6.2
7.		100	60	5.5
8.			90	7.8
9.			120	9.8
10.	10	60	60	3.8
11.			90	4.4
12.			120	5.8
13.		80	60	4.3
14.			90	5.5
15.			120	6.8
16.		100	60	7.2
17.			90	8.4
18.			120	10.1
19.	15	60	60	4.5
20.			90	6.3
21.			120	7.9
22.		80	60	5.8
23.			90	6.9
24.			120	8.8
25.		100	60	7.9
26.			90	9.2
27.			120	11.9
28.	20	60	60	4.8
29.			90	6.4
30.			120	9.4
31.		80	60	6.8
32.			90	7.5
33.			120	9.8
34.		100	60	14.2
35.			90	15.8
36.			120	16.4

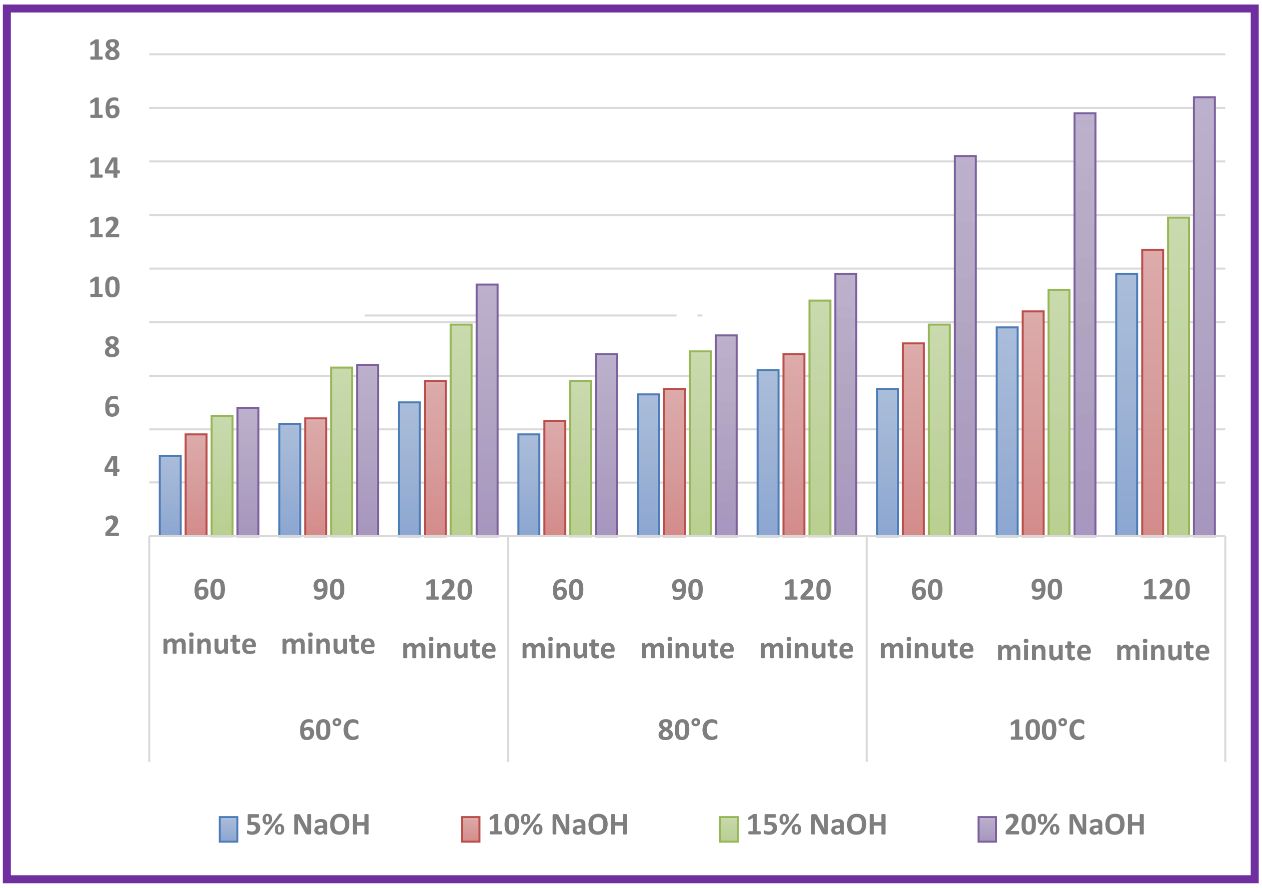

Figure: 2 Effect of Concentration of NaOH on Weight Loss (%) of Coir Fibre.

It can be seen from **Table 1** and **Figure 2** that for fix 60^0c pretreatment temperature and 60-minute treatment time, the weight loss of coir fibre is increased with concentration of NaOH. The higherthe concentration of NaOH, higher is the weight loss. The maximum weight loss is observed at 20% NaOH. The similar kind of pattern was also observed for 80^0c pretreatment temperature and 60-minute treatment time and 100^0c pretreatment temperature and 60-minute treatment time.The alkali, NaOH ionize into Na^+ and OH^- causing hydrolysis of cellulose chain. At lower concentration of NaOH, lower numbers of ions are generated which cannot attack higher cellulose chain. This is suggesting that the rate of hydrolysis of coir fibre is increase as the amount of NaOH increases which directly leads to the higher weight loss. It can also be seen that for fix 5% concentration of NaOH and 60 min treatment time, the weight loss of coir fibre is increased with the pretreatment temperature. The higher the temperature, higher is the weight loss. The maximum weight loss is observed at 100^0c. The similar behavior is also found for the fix 10% concentration of NaOH and 60 min treatment time, fix 15% concentration of NaOH and 60 min treatment time and fix 20% concentration of NaOH and 60 min treatment time. This behavior suggest that the as the energy is applied in the form of the heat to the coir fibre, the structure of the coir fibre is open i.e. swelling of coir fibre is occur which provide the more surface area to the hydroxide ion for attacking the molecular chain of coir fibre. Also, there is more tendency of NaOH to penetrate very easily in loose state of coir fibre. It can be seen that for fix 5% concentration of NaOH and 60^0c pretreatment temperature, the weight loss of coir fibre is increased with the pretreatment time. The higher the pretreatment time, higher is the weight loss. The maximum weight loss is observed at 120 minute of pretreatment time. The similar behavior is also found for the fix 10% concentration of NaOH and 60^0c pretreatment temperature, fix 15%

concentration of NaOH and 60^0c pretreatment temperature and fix 20% concentration of NaOH and 60^0c pretreatment temperature. This behavior suggests that the as the rate of hydrolysis reaction is continue with time which leads to increased weight loss of coir fibre. The maximum weight loss is achieved at 20% concentration of NaOH at 100^0c for 120 minute of treatment time.

Table:2 Optimal condition of pre-treatment of coir fibre

Concentration of NaOH (%)	Pretreatment temperature (^{0}c)	Pretreatment time (minute)
20	100	120

Physical Properties of Coir Fibre:

The physical properties of raw, scoured and bleached coir fibre was tabulated in **Table 3.** Fineness improves consistently across the stages, decreasing from 585 Denier (9.0 Ne) in raw coir to 531 Denier (10 Ne) after bleaching. This reflects the removal of non-cellulosic materials, resulting in a finer, softer fiber with improved texture. Tensile strength decreases considerably, from 2.7 gpd in raw coir to 0.97 gpd in the bleached fiber. This reduction indicates partial degradation of fiber strength due to chemical action during pre-treatment and bleaching, which disrupts structural components like lignin and hemicellulose that contribute to mechanical integrity. Both elongation and extension at break show distinct declines through processing. Elongation drops from 46.70% to 14.36%, and extension at break from 23.35% to 7.18%. This signals a reduction in fiber elasticity and flexibility as binding agents (such as pectin and lignin) are removed, making the fiber more brittle but dimensionally more stable. Moisture content rises from 10.5% in raw coir to 15.5% in bleached fiber. The increase in hydrophilicity stems from the exposure of more hydroxyl groups in cellulose following the removal of fats, waxes, and other hydrophobic substances. Absorbency improves dramatically, changing from over 5 minutes in raw fiber to only 8–10 seconds after bleaching. This rapid absorbency demonstrates increased wettability due to enhanced fiber porosity and surface activation during treatment. Whiteness Index increases from 26.11 to 42.28, showing effective pigment and impurity removal. Yellowness Index decreases from 92.74 to 76.57, indicating reduced natural coloration and greater fiber lightness. Brightness Index improves substantially from 13.53 to 37.12, confirming fiber lightening and suitability for dyeing or finishing applications.

Table:3 Physical Properties of coir fibre

Physical Properties	**Raw Coir**	**Pre-treated Coir**	**Bleached Coir**
Fineness (Denier/Count Ne)	585/9.0	569/9.3	531/10
Tensile strength (gpd)	2.7	1.2	0.97
Elongation (%)	46.70	34.56	14.36
Extension at break (%)	23.35	17.28	7.18
Moisture content (%)	10.5	12.7	15.5
Absorbency (Sec)	>5 min	45-50	8-10
Whiteness Index	26.11	36.52	42.28
Yellowness Index	92.74	82.33	76.57
Brightness Index	13.53	22.82	37.12

Dyeing of Bleached Coir Fibre:

The coir fibres are dyed using synthetic colour like reactive dye and results in terms of colour strength (K/S) and chromacity coordinates (L, a, b) was tabulated in **Table 4**. The dyeing with reactive dye is carried out as perconventional exhaust method produced greenish and reddish shade. CR (K/S = 16.6) exhibits significantly higher colour strength than CB (K/S = 8.4), suggesting that Coracion Red HE3B achieves superior substantivity and fixation efficiency on coir fibre. This difference may be attributed to the molecular size. The moleculart size of CB and CR is 1305 and 1470 respectively. This suggest that the higher molecue interact more effectively with the hydroxyl groups of coir under alkaline fixation conditions. The lightness (L*) values further support this observation. The CB sample shows a higher L* value (32.4), indicating a comparatively lighter shade, whereas the CR sample has a lower L* value (28.4), corresponding to a deeper and darker shade. This is consistent with the higher K/S value of the red dye. The chromatic coordinates (a* and b*) provide insight into hue characteristics. The CB sample shows a negative a* value (-11.7), indicating a shift towards the green region, which is typical for blue shades with slight greenish undertones. In contrast, the CR sample exhibits a high positive a* value (25.9), confirming a strong लाल (red) component. The b* values for both samples are positive (CB: 12.9, CR: 11.5), indicating a yellowish contribution. In the case of CB, the combination of negative a* and positive b* suggests a greenish-blue hue, while for CR, the positive a* and b* indicate a warm reddish-yellow (orangish-red) tone.

Table: 4 Colour parameters of bleached coir fibre with reactive dye

Specimen	**K/S**	**L**	**a**	**b**
CB	8.4	32.4	-11.7	12.9
CR	16.6	28.4	25.9	11.5
CB: Coracion Blue HEGN		CR: Coracion Red HE3B		

(a) (b)

Figure-3 Dyed coir fibre at optimal condition using (a) CB and (b) CR

Colour Fastness:

The colour fastness to washing, rubbing and light of dyed coir fibre was listed in **Table 5**. The colour fastness to washing of coir fibre dyed with reactive dyes. Reactive dye shows better colour fastness. This indicates that the reactive dye form covalent bond with coir fibre. The reactive dye show very good to excellent with 4-5 grade colour fastness in terms of colour change as well as in terms of staining on cotton and wool. The staining on cotton and wool very good to excellent with 4-5 rating for natural colour.

Table: 5 Colour Fastness Rating of Dyed Coir Fibre

Specimen	Washing Fastness			Rubbing Fastness				Light Fastness
				Dry Rubbing		Wet Rubbing		
	CC	SC	SW	CC	SC	CC	SC	
CB: Coracion Blue HEGN	4	4-5	4-5	4-5	4-5	4	4-5	6-7
CR: Coracion Red HE3B	4	4-5	4-5	4-5	4-5	4	4-5	6-7
CC: Colour Change;			SC: Staining on Cotton;			SW: Staining on Wool		

FT-IR Analysis:

The **Figure 4, 5, 6 and 7 shows** the FT-IR spectra of raw, bleached, dyed with coracion red reactive dye and coracion green reactive dye. . 3200 to 3550 wavelength range is associated with O–H stretching vibrations, which is a typical characteristic of natural fibers. The strong absorption peak is associated with the hydrophilic characteristics of the coir fiber, indicating the presence of the –OH group. The peak at 1240 to 1275 wavelength range is associated with C-O-C stretching of lignin and 1375 to 1385 wavelength range is C-H bending vibration, indicating the presence of lignin. The peak at 1600 to 1610 wavelength range is associated with C=O stretching indicating the presence of hemicelluloses. The peak at 860 to 900 wavelength range is associated with C-H indicating the presence of cellulose. This characteristic peak indicating the different component of coir fibre is directly correlated with result of chemical composition of coir fibre. The absorption peak at 1600 to 1610 wavelength range is disappear in bleached and dyed coir fibre which indicate the successful removal of hemicelluloses. Also the intensity of peak at 3200 to 3550 wavelength range is associated with O–H stretching vibrations in bleached coir fibre is increased which further support the removal of non cellulosic impurities from the coir fibre. And the absorption peak at 1240 to 1275 wavelength range & 1375 to 1385 wavelength ranges is decreased that indicated that the some part of lignin is removed. The intensity of peak at 860 to 900 is enhanced indicating the percentage cellulose component is increased. Also the intensity of peak at 3200 to 3550 wavelength range is associated with O–H stretching vibrations is decreased in the spectra of coir fibre dyed with reactive dye indicating hydroxyl group form covalent bond. Also, The absence of the absorption band specific to the C–F connection at 1330 to 1400 wavelength indicates the attachment of the dye to the fabric surface by covalent bonding.

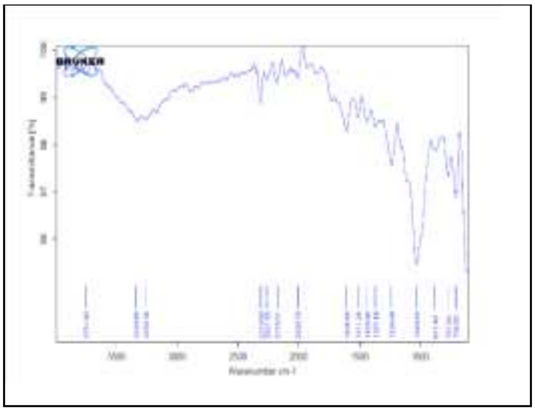

Figure: 4 FT-IR Spectrum of Raw Coir Fibre.

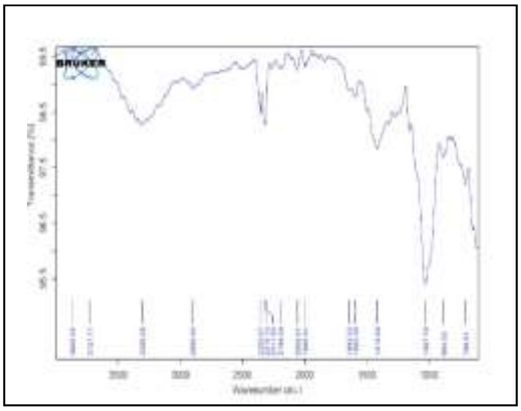

Figure: 5 FT-IR Spectrum of Bleached Coir Fibre.

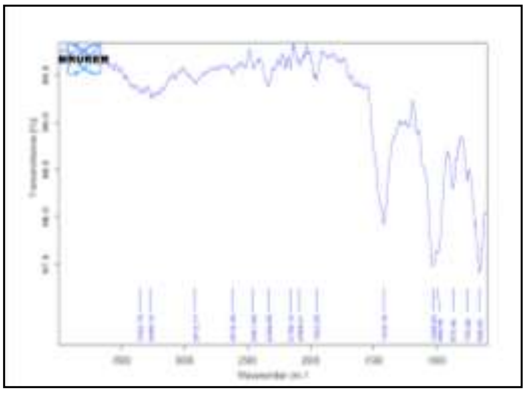

Figure: 6 FT-IR Spectrum of dyed Coir Fibre with Coiacion Red reactive Colour

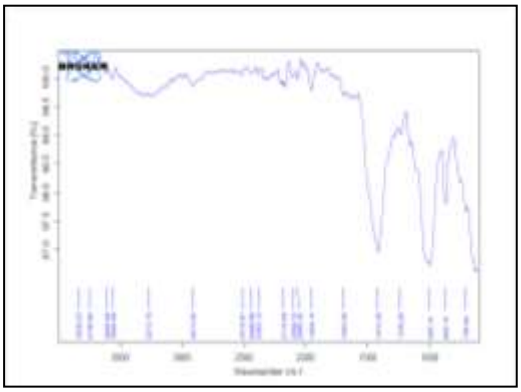

Figure: 7 FT-IR Spectrum of dyed Coir Fibre with Coracion Green reactive Colour

CONCLUSION:

Pretreatment of coir fibre through alkaline scouring significantly enhances dye uptake and colour quality. Optimal pretreatment conditions were found to be 20% NaOH concentration at 100°C for 120 minutes, leading to maximum weight loss and removal of non-cellulosic components like pectin, hemicellulose, waxes, and lignin. This purification improves fibre wettability, absorbency, and brightness, making the fibre more receptive reactive dyes such as coracion blue and coracion red. The treated coir sample is successfully dyed by reactive dye .The colour fastness to washing of reactive dye show very good to excellent result . The colour fastness to rubbing of both reactive dye .The colour fastness to light of reactive dye show very good to excellent result. Overall, the study demonstrates that simple, pretreatment combined with dyeing methods can effectively utilize coir fibre in sustainable textiles and handicrafts, supporting the development of environmentally friendly, value-added products from this abundant natural resource.

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