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Study on tencel fabric dyeing with acacia nilotica bark natural dyes

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ABSTRACT

This research aimed to evaluate the performance of dyes extracted from Acacia Nilotica bark on Tencel fabric dyeing. The extraction of dye was optimized by extracting dyes with different liquor ratios. The dyeing parameters were optimized under pH values from 5 to 14. The effect of different mordants was also observed to see the shades this dye can produce on Tencel fabric. The optimum dye extraction conditions for material-to-liquor ratio were found to be 1:10. The optimum pH was found to be 12. The color yield and fastness characteristics of the dyed materials were measured to assess them. It was determined that the addition of mordants affected the color values; as a result, distinct fashion hues were produced from the same dye extract by employing various mordants. This basic study of dyeing and extracting natural dye showed that this dye has the potential to be used for cellulosic fibers.

1. Introduction

Textile is well-known for its fast response to consumer demands and fashion trends, but it has also come under fire for its undesirable effects on the surroundings and humanity. This makes textile and apparel industries very critical to use sustainable production techniques in their manufacturing processes. By using ecologically responsive resources, production methods, and justifiable manufacturing methods in the textile and apparel industries pursue to decrease the industry’s harmful belongings on the environment and civilization [1].

Using sustainable materials like organic cotton and Tencel in the manufacturing of products helps in achieving sustainable practices for the environment [2]. Moreover, utilizing natural resources to extract nontoxic natural dyes as an alternative to synthetic toxic colorants has also grown as a result of increasing environmental consciousness. Significant promotion of natural colorants is obvious in the fashion and apparel industry [3]. In addition to being low or non-toxic, sustainable, and less or non-allergic, natural dyes typically have some medicinal value in the plant sources from which they are derived. These benefits have led to a resurgence of natural dye use in the food, pharmaceutical, cosmetic, and textile industries throughout the past ten years [4-6].

Tencel is a natural, manmade regenerated cellulosic fiber that is made from wood pulp and is an eco-friendly fabric that represents a milestone in the progress of environmentally sustainable textile [7, 8]. It is a special ecological substrate that denotes a landmark in the environmentally sustainable textiles progress [9, 10]. Tencel offers several advantages over conventional fibers such as cotton and polyester, making it a promising alternative for a more sustainable future. Tencel fiber's exceptional qualities, such as its high strength, softness, and capacity to absorb moisture, make it a great option for a variety of applications, ranging from household textiles to clothing [11].

Acacia Nilotica (L.), often known as babul and Kikar, is a significant decorative and medicinal plant found in tropical and sub-tropical countries. It is a member of the Fabaceae family. The primary phytoconstituents in this plant are polysaccharides (gums), tannins, flavonoids, alkaloids, and fatty acids, according to a thorough review of the literature. This plant contains potent anti-inflammatory, antioxidant, anti-diarrheal, antihypertensive, antispasmodic, antibacterial, anthelmintic, antiplatelet aggregatory, and anticancer properties, according to research from the pharmaceutical database [12].

The tannins in the bark of the Babul tree are composed of gallic acid, a potent natural acid that is employed in the tanning and dying of textiles, the production of inks, and the manufacturing of medications [13]. The appearance of dye powder obtained from the bark of Acacia Nilotica is dark brown and the main coloring components are quercetin, acacetin, and ellagitannins [14] as shown in Fig. 1.

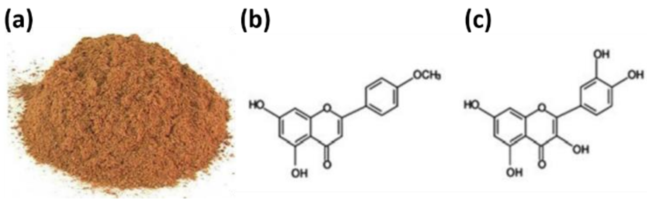

Fig. 1. Coloring Components of Acacia Bark (a) Powder form, (b) Acacetin, and (c) Quercetin

The lack of relevant scientific statistics and optimum dyeing techniques for particular fibers present daily obstacles for textile chemists and dyers working with natural dyes to ensure reproducibility and shade-matching mordant-dye system to provide a consistent and ideal color output with any natural dye. Tencel as a relatively new fiber for apparel purposes has not been used for natural dyes extensively. Though, recently there are some reports available on the study of dying process variables with few other natural dyes on Tencel such as its dyeing with natural indigo dye [15], pomegranate [16], Citrus Aurantium [17], orange peel [18], and recently with onion skins and red cabbage [19]. However, the dyeing of Tencel fabric with babul bark as a natural dye has not been investigated yet. Therefore, it is a very essential need to standardize the dyeing process of Tencel fabric with Acacia Nilotica dye conditions for obtaining uniform and reproducible brown shades with different mordants. So, this study used Acacia Nilotica bark as a natural dye on tencel fabric with different mordants and investigated its behavior. This study holds a broad scope due to the widespread presence of Acacia Nilotica trees across many regions in Sindh. Additionally, Tencel fibers are extensively cultivated in Pakistan and are readily accessible [20]. The abundant availability of Acacia Nilotica trees and Tencel fibers in the study area makes this research highly relevant and applicable to the local textile industry as well as globally. The focus on natural dyes and their potential application in fabric production aligns with the growing demand for sustainable and eco-friendly textile solutions [21].

2. Experimental

2.1 Materials

Tencel fabric was purchased from Popular Fabric Private Limited, Karachi, Pakistan. Acacia Nilotica pods were harvested from Babul trees from Nawab Shah and nearby villages as a natural coloring source. Several fixatives as mordants for dyeing include copper sulfate, potash alum, aluminum sulfate, and ferrous sulfate. All chemicals were obtained from Al-Baruni Scientific Store Hyderabad. Distilled water for dye extraction was used from the textile engineering department's wet processing lab.

2.2 Methods

2.2.1 Dye Extraction from acacia nilotica pods

Acacia Nilotica pods were collected from the Babul tree and dried for a week in the open air with sunlight. The pods were grinded into powder using a regular kitchen grinder machine. The dye was extracted using the Acacia Nilotica pod’s powder. Extraction of dye was performed at HT dyeing machine at 90oC temperature for 60 minutes. The extracted dye was then filtered and used for dyeing Tencel fabric. For the best results for natural dyeing of Tencel fabric with Acacia Nilotica, several attempts were made to extract natural dye with different LR (liquor to good ratio) of 1:5, 1:10, 1:15, 1:20. At the same time, the pH of the solution remains neutral.

2.2.2 Dyeing of tencel fabric by exhaust method

The Tencel fabric was dyed with Acacia Nilotica extracted dye by exhaust method on HT dyeing machine for 60 minutes at 90oC. After dyeing, the samples were washed and dried in the open air. The samples were dyed using an exhaust method at various pH levels while the other factors (time and temperature) remained constant. The pH of the dye bath was 5, 7, 9, 12, 13, and 14. The HT machine's temperature is kept at (90oC) for 60 minutes.

To observe the effect of different mordants on the dyeing of Tencel fabric, a variety of mordants were used to color fabric such as ferrous sulfate, potash alum, and copper sulfate including natural mordant Acacia catechu. Tencel samples were dyed with each mordant at 1% - 2 % to get uniform concentration for each mordant. The schematic representation of the process sequence is given in Fig 2.

2.3 Characterization

The color yield (K/S) was calculated with the Kubelka–Munk equation Eq. 1 [22].

$$K/S = \frac{(1-R\lambda_{max})^2}{2R\lambda} \quad (1)$$

In the above Eq, R represents the amount of the incident light reflected in reflectance % age; K shows the amount of light absorbed in terms of absorption coefficient; and S is the amount of incident light scattered in terms of scattering coefficient of dyes. CIE Lab coordination was used to determine the color characteristics of the fiber samples. According to this system, L* represents the lightness assessment of color (from 100 = white to 0 = black), the higher the lightness value the lower the color produced by colored fabric. Moreover, a* and b* value represents the tendency of the color towards primary color. It means that, positive values of a* and b* show that sample shade is towards redder and yellower tones whereas negative values of a* and b* represent the greener and bluer tones correspondingly. Furthermore, the C* attribute shows the Chroma or strength of color and h° relates to the hue angle. Washing fastness was measured by using the ISO-105C03 Method. Specifically, optimized dyed samples (with and without mordants) were washed with 2.5 g/l of caustic soda and 5 g/l of standard soap solutions with L: R 1:50 for 30 minutes to access the washing fastness test. Rubbing fastness tests (ISO-105-X12) for both dry and wet rubbing fastness were conducted using a crock meter. ISO-105-B02 standard was followed for the light fastness test, a mercury light fastness tester was used to observe light fastness results, and the dyed samples were kept for 24 hours to access the light fastness property.

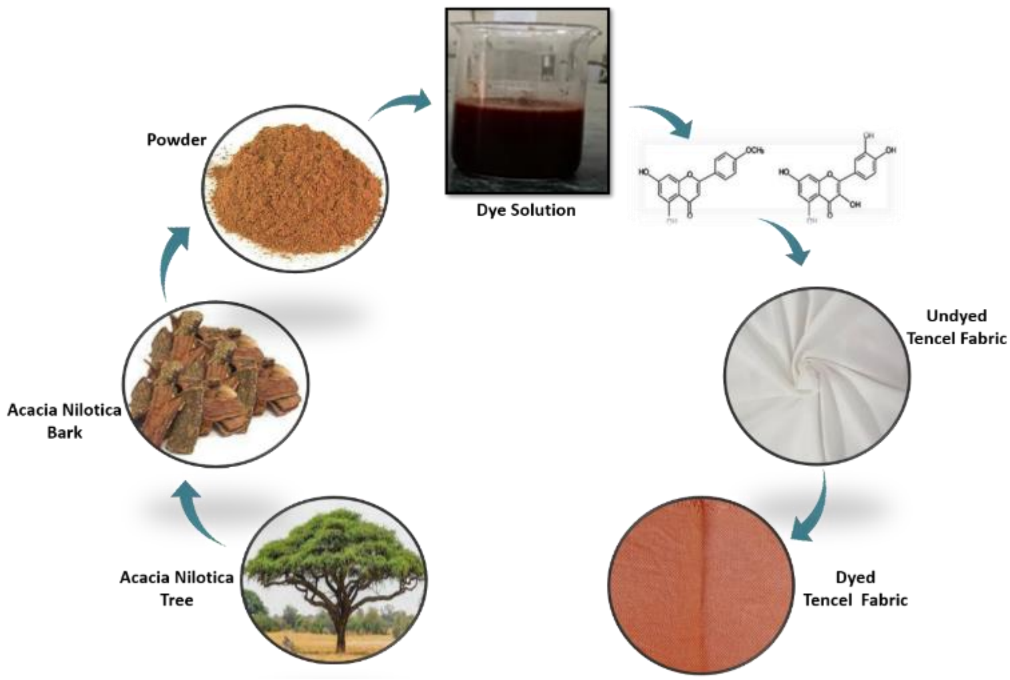

Fig. 2. Schematic Representation of The Process Sequence

3. Results and Discussion

3.1 Effect of Dyeing Methods

Fig. 3. shows the effect of exhaust and continuous dyeing methods respectively on the color strength of Tencel fabric dyed with Acacia Nilotica dye. Table 1. indicates the color strength values and color coordinates of the dyed fabric by exhaust and continuous method. In Fig. 3 (a), it is observed that the color strength of the fabric dyed by the exhaust method is 3.3 which is higher than the color strength of the fabric dyed by the continuous method. This might be due to more time and temperature needed by natural dyes to fix onto the surface of the fabric. Moreover, the Lightness Value 'L' for the exhaust method, as shown in Table 1, is less as compared to the lightness value for the continuous method. This indicates that a higher depth of shade was achieved by the exhaust method. The depth of shade achieved by the exhaust method and continuous method is shown in Fig. 3 (b) and (c) respectively. Therefore, the exhaust method was selected for further studies of Tencel fabric dyeing.

Table 1

CIE L*a*b* and K/S values of dyed tencel fabric using different dyeing methods

Methods	L*	a*	b*	K/S Value
Exhaust	55.97	9.83	17.20	3.31
Continuous	63.34	9.02	19.05	2.24

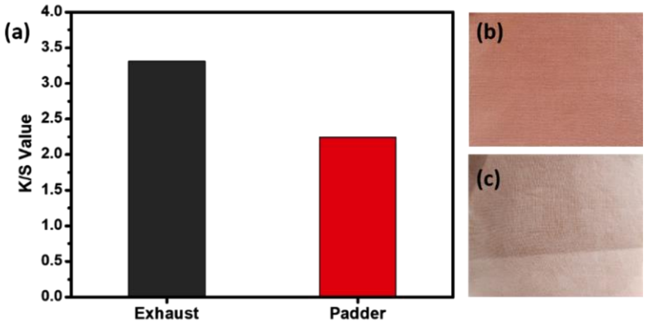

Fig. 3. (a) K/S values, and Shades Achieved by (b) Exhaust, and (c) Continuous Method

3.2. Effect Of Liquor Concentration on Dye Extraction

Fig. 4 (a) and (b) show the effect of different liquor ratios (Weight of crushed dye in grams; amount of water in millilitres) on dye extraction. The darkest shade was observed at LR of 1:10 whereas the other LR values yielded very light shades comparatively, as shown in figures. It can be attributed to the fact that the liquor ratio for dye extraction influenced the depth of shade to a large extent among other factors [23]. The optimum LR was selected based on the relative color strength value (K/S) of the dyed fabric at which the maximum color was extracted. When the LR was increased from 1: 10 to 1:15, a decrease in the color strength of the fabric was observed. It might be due to more water resulting in less available dye for the fabric. On the other hand, 1: 5 dye liquor is very much less to dissolve the dye and hence the extracted dye is not sufficient in the amount to make bondings with the fabric.

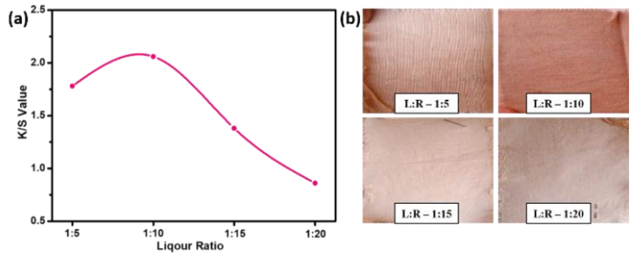

Fig. 4. (a) Effect Of Different Liquor Ratios On K/S of Tencel Fabric, and (b) Shades Achieved with Different Liquor Ratios

Table 2

CIE L*a*b* and K/S values of dyed Tencel fabric at various liquor ratio

Liquor Ratio	L*	a*	b*	K/S Value
1:5	67.43	9.81	18.69	1.78
1:10	61.96	8.14	15.20	2.06
1:15	70.44	9.80	17.84	1.38
1:20	73.54	7.74	13.52	0.86

3.3 Dyeing and Effect of Dye Bath pH

The samples were dyed using an exhaust method at various pH levels while the other factors such as time and temperature remained constant. The fabric was dyed at various pH levels such as 5, 7, 9, 12, 13, and 14 at 90oC for 60 minutes. Fig. 5. Shows the results of the dyed fabric dyeing with Acacia Nilotica bark where pH 12 was found to be optimal for color fixation due to favorable bonding conditions. The optimum color strength value obtained at pH 12 is 2.2. The presence of acidic phenolic groups in Acacia Nilotica, which reacted with alkali to generate more soluble salts in water, may be the reason for extracting more coloring components in an alkaline media. The enhanced ionization of hydroxyl (phenoxide) groups in the alkaline media led to a rise in the solubility of the coloring component. A further increase in pH causes a decrease in the K/S value of the dyed fabric. This could be attributed to the high reactivity and potential hydrolysis of the dye.

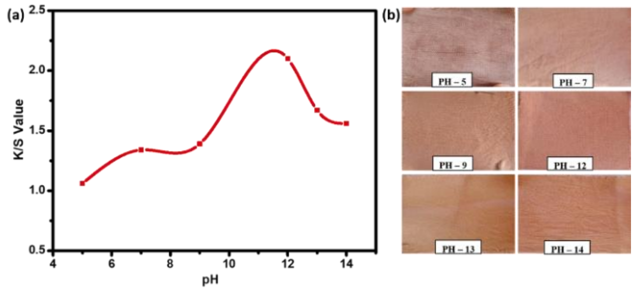

Fig. 5. (a) Effect of Various pH Levels on K/S of Tencel Fabric, and (b) Shades Achieved with Different pH Levels

Table 3

CIE L*a*b* and K/S values of dyed Tencel fabric at various pH

pH	L*	a*	b*	K/S Value
5	73.41	9.45	16.73	1.06
7	64.13	8.88	12.49	1.34
9	68.18	8.42	15.62	1.39
12	67.50	10.22	20.50	2.1

13	66.94	9.12	17.83	1.67
14	62.38	8.28	12.95	1.56

3.4 Effect of Mordant Type

The Tencel fabric samples were dyed with a range of different mordants (ferrous sulfate, copper sulfate, aluminum sulfate, potash alum, and acacia catechu) at L: R 1:10 using 90oC temperature for 60 min. A range of dye shades was observed, however, the use of copper sulfate gives higher color strength as compared to other mordants as shown in Table 4 and Fig. 6.

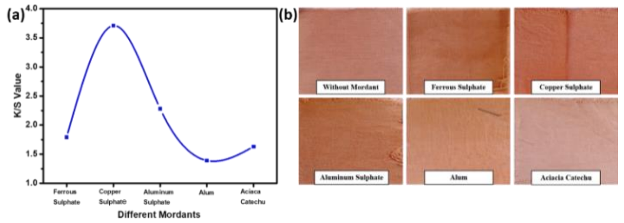

Fig. 6. (a) Effect of Different Mordants On K/S of Tencel Fabric, and (b) Shades Achieved with Different Mordants

Table 4

CIE L*a*b* and K/S Values of dyed Tencel fabric at different types of mordants

Mordants	L*	a*	b*	K/S Value
Ferrous sulphate	76.59	10.35	18.72	1.79
Copper Sulphate	57.59	12.02	22.51	3.71
Aluminum sulphate	63.37	10.76	21.7	2.28
Alum	68.18	8.42	15.62	1.39
Acacia Catechu	69.68	9.51	18.21	1.63

A metal complex with positively charged metals can be formed by the presence of hydroxyl or carbonyl groups in the dye structure. Both the hydroxyl group of the cellulose tencel fabric and dye anions and metal cations are strongly attracted to one another. As a result, they create ionic bonds between metal and fiber, dye and fiber, and ultimately, dye and metal ions. The possible mechanism of dye-metal-fibers bonding is shown in Fig. 7. Furthermore, a single dye molecule may often create a link with a single fiber molecule, but a single mordant molecule can form a bond with two or more dye molecules. Therefore, this might be the reason demonstrating the application of mordants increased the color yield [24]. The lower color strength values of tencel-dyed fabric with other mordants might be due to weak complexes formed between metals and dye, hence fibers result in less interaction of dye and fiber [25].

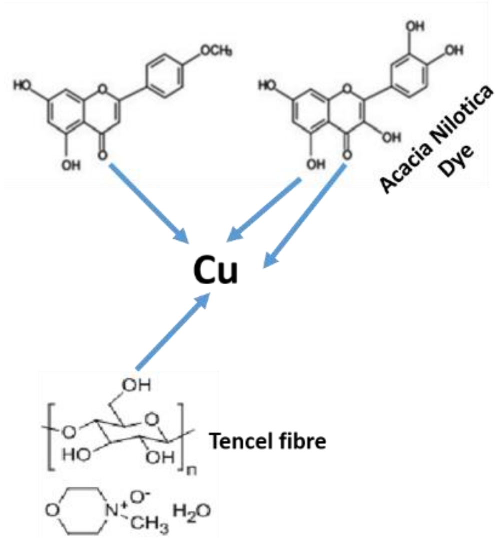

Fig. 7. The Possible Bond Between Dye Fiber and Metal Complex Bond

3.5 Fastness Properties

Table 5 displays the Tencel fabric's fastness to washing, light, and rubbing when dyed with and without the use of a mordant. It was noted that all of the samples had good light, rubbing, and washing fastness outcomes, indicating that the hue of Tencel fabric colored naturally with Acacia Nilotica could be altered by adding mordants. The dye-fiber bond strength, which is impacted by the method of bonding, has a significant impact on fastness. Prior studies have demonstrated that the color characteristics that are added to textiles generally differ based on the kind of mordant utilized and the method of application, such as pre-, simultaneous-, or post-mordanting.

Table 5

Fastness properties of Tencel fabric dyed with Acacia Nilotica and different mordants

	Acacia Nilotica	Ferrous Sulphate	Copper Sulphate	Aluminium Sulphate	Alum	Acacia Catechu
Washing Fastness	3/4	3/4	4	3/4	3/4	3
Light Fastness	6	6	7	5	6	5

Rubbing Fastness (Dry)	5	5	5	5	5	5
Rubbing Fastness (Wet))	4	4	4/5	3/4	4	4

4. Conclusion

The purpose of this study was to optimize the process of dyeing Tencel fabric with naturally extracted dye by extracting dye from acacia Nilotica pods. Using the HT dyeing procedure, the dye was effectively extracted from the pods of Acacia Nilotica. HT dyeing process, an environmentally friendly procedure that uses less energy and time, was developed as a cost-effective way. Numerous aspects, such as the LR, dyeing techniques, pH, and mordant selection, were optimized. The dyeing and mordanting procedures were optimized by analyzing the color intensity of all colored samples. As can be seen from the K/S values, fastness characteristics, mordanting methods, and dye shade of each mordant utilized, the results show excellent properties. This study demonstrates that this dye may be used to generate a variety of hues by adding different mordants, all without harming the final qualities acquired. For future studies, this research can be extended to the potential use of this substrate as an antibacterial material.

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