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ORIGINAL RESEARCH

Eco-Friendly Dyeing of Cotton Fabric Using Neem Leaf Extract and Evaluation of Fastness Properties

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Abstract

The growing demand for sustainable textile processes has increased interest in natural dyes as alternatives to synthetic colorants. This study evaluates the feasibility of using neem (Azadirachta indica) leaf extract as a natural dye for 100% cotton knit fabric. Pigments containing flavonoids and tannins were extracted from neem leaves boiling, and dyeing was performed at 5%, 7.5%, and 10% (owf) at 90°C for 80 minutes under acidic conditions (pH 4–5) using alum as a pre-mordant. Color fastness to washing, rubbing, and light was assessed using standard methods. The results showed that neem extract produced shades ranging from green to yellowish-brown. However, fastness properties were limited, with wash fastness rated fair to poor and light fastness consistently low across all concentrations. Dry rubbing fastness was better than wet rubbing. Overall, although neem extract is biodegradable and non-toxic, its industrial application is restricted by poor color durability, with 5% concentration showing relatively better performance.

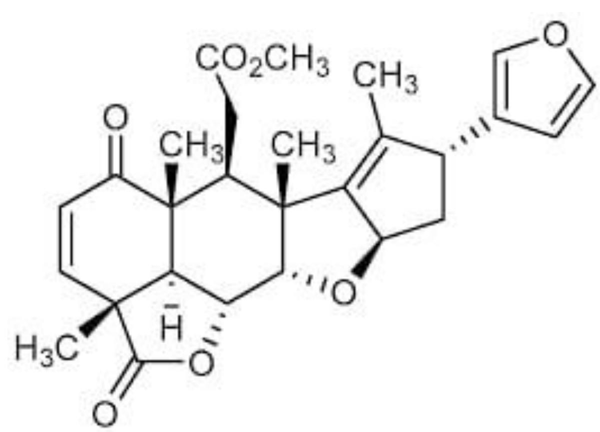
Keywords: Neem Leaf, Natural Dye, Dye Extraction, Mordant, Cotton, Color Value, color fastness.

1 | INTRODUCTION

The global textile industry is currently facing a major challenge. On one hand, it must produce large amounts of textiles to meet market demand, and on the other hand, it must reduce its negative impact on the environment. For many years, textile industries have relied on synthetic dyes made from petrochemicals because these dyes produce bright colors and long-lasting colors on fabrics [1]. However, the wastewater released from textile factories has become a serious environmental problem. When untreated or poorly treated textile wastewater is discharged into rivers and other natural water bodies, it causes severe pollution [2]. These wastewaters often contain harmful chemicals, heavy metals, and non-biodegradable organic compounds that increase Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) levels. This leads to eutrophication in water bodies, which damages aquatic ecosystems and reduces biodiversity [2], [4].

Because of these environmental concerns, there is growing global interest in using natural dyes obtained from renewable biological resources [1], [5]. Natural dyes are considered safer and more environmentally friendly alternatives to synthetic dyes.

Among the many plant sources used for natural dyeing, the Neem tree (Azadirachta indica), which belongs to the Meliaceae family, is considered a promising but underutilized resource for sustainable textile dyeing [2], [6]. Neem trees are widely found in tropical and subtropical regions and are known for their many biological and medicinal properties. The leaves of the neem tree contain various phytochemicals such as flavonoids, tannins, and terpenoids, including compounds like nimbin and azadirachtin [3], [6]. These compounds are traditionally valued for their medicinal properties, such as antibacterial, antifungal, and anti-inflammatory effects. In addition to these health benefits, they can also function as natural pigments [4], [9]. When properly extracted and applied to textiles, neem leaves can produce natural shades ranging from olive green to yellowish-brown. In addition, fabrics dyed with neem may provide functional wellness benefits for the wearer [6],



[15].

Figure 1: Chemical Compound of neem [3]

Although neem-based dyes are environmentally friendly, their use in large-scale textile production still faces several technical challenges, particularly in terms of dye absorption and color durability [7], [10]. Cotton fibers are composed of cellulose and develop a negative surface charge in water, which makes it difficult for natural dye molecules to attach strongly to the fabric [11].

Therefore, the use of a mordant is necessary to improve dye fixation. Mordants, usually metallic salts, act as a bridge between the dye molecules and the cotton fibers, helping the dye to bind more effectively to the fabric [11], [12]. In this study, Aluminum Sulfate (Alum) is used as a mordant because it is relatively safe and can enhance color depth and stability without the toxic effects associated with heavy metal mordants such as chromium or copper [12], [13].

The main aim of this research is to optimize the dyeing process of 100% cotton knit fabric using dye extracted from neem leaves. The study investigates how different dye concentrations (5%, 7.5%, and 10%) influence the color characteristics and durability of the dyed fabrics. A pre-mordanting technique using alum is applied to improve dye fixation. The research also evaluates important fastness properties, including wash fastness, rubbing fastness, and light fastness, to determine the potential commercial applicability of neem dye. Overall, this study contributes to the development of environmentally friendly textile dyeing methods that support the United Nations Sustainable Development Goals (SDGs) related to responsible consumption and sustainable production.

2 | MATERIALS & METHODS

2.1 | Fabric Selection

Pre-treated (scoured and bleached) 100% cotton knit fabric was utilized for this study. The fabric specifications included an Ends Per Inch (EPI) × Picks Per Inch (PPI) of 60 × 58 and a Grams per Square Meter (GSM) of 160. The fabric was sourced from Knit Concern Ltd. and was verified to be free from irritants and toxins.

2.2 | Dye-stuff and mordent

Neem leaves (Azadirachta indica) served as the primary botanical source for natural dye extraction. Approximately 1000 g of fresh leaves were collected from the Sirajganj region. Aluminum Sulfate (Al2SO4), commonly referred to as Alum or Potassium Alum, was used as the mordanting agent. Analytical grade Glauber salt, wetting agents, leveling agents, sequestering agents, and caustic soda were also employed in the dyeing process.

2.3 | Dye Extraction from Neem Leaf

The leaves (1000 g) of neem plants (Azadiracta indica) were collected and washed under flowing water repeatedly to remove dust particles and soluble impurities and were allowed to dry in sunlight until the leaves became crisp; they were crushed into finer pieces. After drying, the weight of the leaves was 650 g. Then crushed leaves were boiled with water (2000 ml), and dye solution was collected.

Figure 2: Dye Extraction Process from Neem Leaf.

2.4 | Experimental Design & dyeing protocol

Table 1: Dyeing Recipe and process parameters

Chemicals	Amount (g/l)	Parameter	Value
Glauber salt	3	Shade%	5%, 7.5% & 10%
Wetting agent	1	M: L	1:20
Levelling agent	1	Fabric sample	5 g
Sequestering agent	1	pH	4-5
Caustic soda	3	Temperature	90^{0}C
Mordant	3	Time	80 min

Table 2: Fabric Sample with shade %

Description	Sample 1 (S1)	Sample 2 (S2)	Sample 3 (S3)
Dye % (On the weight of Fabric)	5%	7.5%	10%

2.4.1 | Pre-mordanting

A pre-mordanting technique was applied to the cotton fabric to enhance the substantivity between the natural dye molecules and the cellulosic fibers. The scoured and bleached fabric was treated with a 3% Al2SO4 solution for 20 minutes at a liquor-to-material (M:L) ratio of 1:20. Following mordanting, the samples were allowed to cool and rinsed thoroughly under running water.

2.4.2 | Dyeing Process

The dyeing was conducted in stainless-steel beakers using a water bath. The pre-mordanted fabric samples (5 grams each) were immersed in the dye liquor at an initial temperature of 80°C. The temperature was then raised and maintained at 90°C for 80 minutes to ensure optimal dye penetration. The pH of the dye bath was standardized between 4.0 and 5.0.

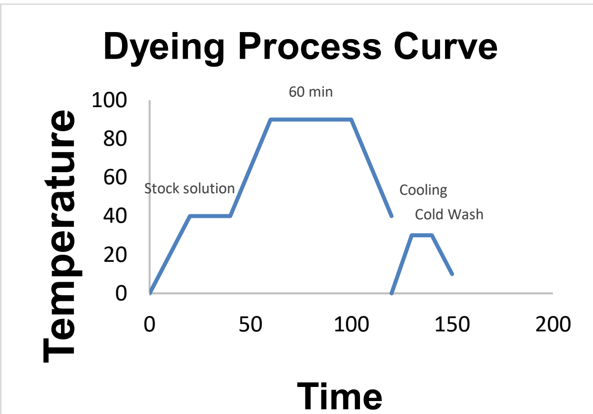


Figure 3: Dyeing process curve

2.4.3 | Post-Dyeing Treatments

Upon completion of the dyeing cycle, the samples underwent a series of rinsing stages in both warm and cold water for 10 minutes at 30°C to remove unfixed dye. The samples were then air-dried in a drying machine at 60°C.

2.5 | Test Procedure

2.5.1 | Color Fastness Properties of Natural Dye

Colorfastness refers to a fabric's ability to maintain its original color without fading or transferring dye to other fabrics when exposed to conditions such as washing, dry cleaning, heat, or light. Color fading occurs when the shade becomes lighter or darker due to environmental or chemical exposure. Color transfer to another fabric is known as bleeding, which often stains adjacent white materials placed with the test sample. Colorfastness is usually evaluated by observing the degree of color change in the original fabric or the staining on accompanying fabrics during testing [14]

2.5.2 | Color fastness to Wash

The dyed samples were washed in the Launder o meter Laboratory apparatus according to ISO 105-C06:2010 standard. The size of the sample was 100×100 mm, the wash bath contained 4g/ ECE phosphate reference detergent B, the volume of the bath was 150 ml, the temperature of the bath was 40°C and time of washing 30 minutes. Ten stainless steel globules were added into each bath to perform washing, which corresponds to five domestic washings. After washing, the samples were rinsed twice in deionized water and air dried at room temperature.

2.5.3 | Rubbing Fastness

The rubbing of dyed samples are tested by Taber Crock meter - Model 418 according to EN ISO 105x12:2016, BS Gray Scale standard. The size of the sample was 15×5cm, arm is weighted to provide a constant 9N load on the sample at all times and a mechanical counter keep track of completed 01 cycles. After completion of the Rubbing samples are dried.

2.5.4 | Color Fastness to Light

The purpose of color fastness to light test is to determine how much the color will fade when exposed to a known light source. The sample is cut and should be exposed (1/2 covered and 1/2exposed) together with standard dyed wool samples (1-8). The standard and the specimen mounted in a frame. The composite sample must be protected from rain.

The test sample is exposed to light for a certain time (24 hrs. 63 hrs., 84 hrs., 27 hrs.) or by customer demand and compared with the original unexposed sample. The changes are assessed by blue scales (1-8).

3 | Result & Discussion

Three fabric samples dyed with different shade percentages during the experiment & various colourfastness tests were done. The figures of tested samples are shown in the following figures 4-6. The results were satisfactory across various samples, as tabulated in Table 3.

Sample - S1	

Sample - S2

Sample - S3

Figure 4: Tested samples of color fastness to wash

Sample-S1

Sample-S2

Sample-S3

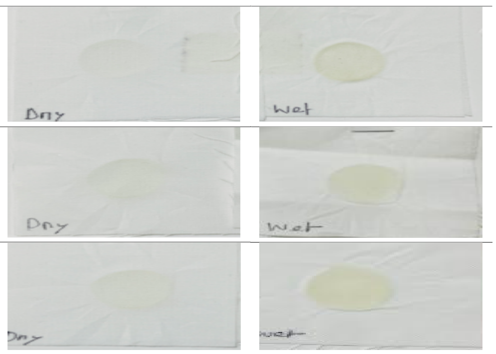


Figure 5: Tested samples of color fastness to rubbing

Sample-S1

Sample-S2

Sample-S3

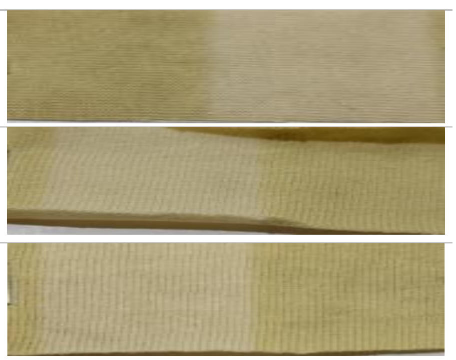


Figure 6: Tested samples of color fastness to light

Table 3: Experimental data of various colorfastness tested samples

Sample Number	Color fastness to wash		Color fastness to light		Color fastness to rubbing	
	Color change	Color stain	Color change	Color stain	Dry	Wet
Sample 1	2-3	2-3	2-3	2-3	4-5	3-4
Sample 2	2-3	2-3	2-3	2-3	4	3-4
Sample 3	2	2	2	2	3-4	3

3.1.1 | Color Fastness to Washing

The samples dyed with 5% and 7.5% dye concentrations exhibit superior efficiency compared to the 10% dye concentration. The ISO grading for 5% and 7.5% concentrations is classified as 2-3, indicating a fair to poor quality. For a 10% concentration, the ISO grading is 2, indicating poor quality. The decline in fastness at higher concentrations suggests a saturation point where the mordant can no longer effectively bind the excess dye molecules, leading to increased "bleeding" or staining of adjacent materials.

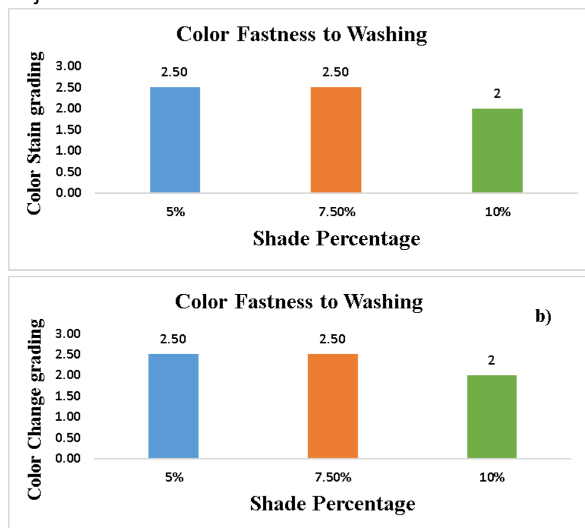


Figure 7: Comparison of color fastness to wash between different samples dyed with 5%, 7.5% & 10% concentration of dye. a) Color fastness wash grading for color stain b) Color fastness wash grading for color change.

3.1.2 | Color Fastness to Rubbing

In the rubbing test, performance diminished progressively with decreasing concentration. The dried sample exhibits superior efficiency compared to the wetted sample at a 5% concentration. The 7.5% concentration demonstrates superior results compared to the dried sample, similar to the 5% shade concentration. Similar to washing, the 10% shade showed a drastic decrease in performance, confirming that lower concentrations provide more stable surface adhesion. The rubbing performance demonstrates superior results in dried form across all concentrations.

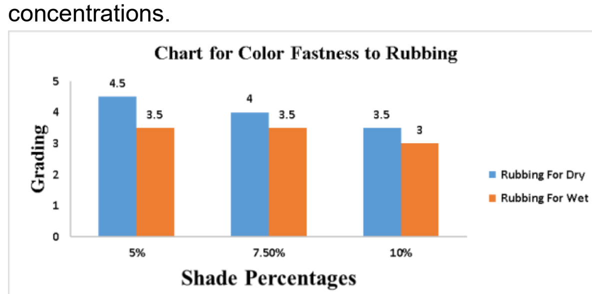


Figure 8: Comparison of color fastness to rubbing between different samples dyed with 5%, 7.5% & 10% concentration of dye.

3.1.3 | Color Fastness to Light

In this experiment the light fastness result shows a poor performance for all concentration. For 5% and 7.5% concentration it shows same result of grading 2-3 which is fair to poor. But the 10% concentration shows poor result, which is not applicable for industrial purpose.

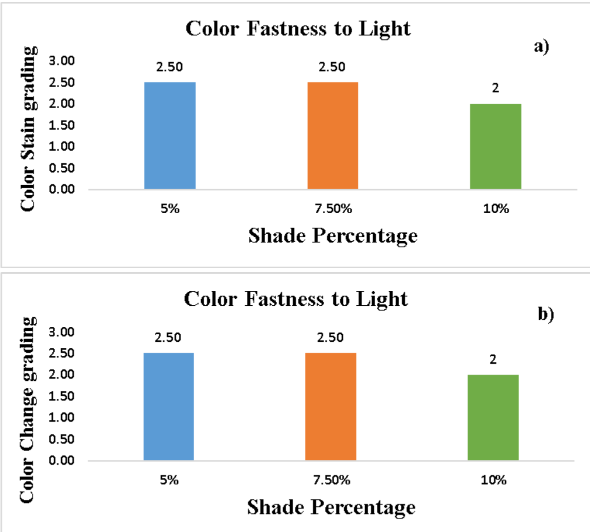


Figure 9: Comparison of color fastness to light between different samples dyed with 5%, 7.5% & 10% concentration of dye. a) Color fastness wash grading for color stain b) Color fastness wash grading for color change.

4 | FUTURE RECOMMENDATION

To move neem dye from a small experiment to a real-world product, a few technical improvements are needed. While the dye looks good on cotton, it does not yet stay on the fabric well enough for everyday clothes. The Alum used in this study is a safe way to help the dye stick tothe fabric, but the "Fair to Poor" wash results show the bond is still weak. Future studies should try "double-mordanting," which means treating the fabric with two different natural fixatives to lock the color in more tightly. Cotton naturally repels many natural dyes because of its electrical charge. Researchers should look into "cationization," a process that gives the cotton a positive charge so it can grab onto the dye much more strongly without needing as many chemicals.

Instead of just boiling the leaves in water, using modern tools like ultrasound could help pull more powerful pigments out of the neem leaves. This might create a more concentrated dye that lasts longer. Even though neem is natural, we still need to test the leftover water from the dyeing process. Measuring things like Oxygen Demand (COD and BOD) would prove exactly how much cleaner this is for our rivers compared to synthetic dyes.

5 | Conclusion

The experiment concentrated on dyeing cotton fabric with neem leaves, representing an environmentally sustainable method for fabric coloration. The experiment demonstrated that neem leaves are ineffective in producing natural dyes with adequate colorfastness. The procedure entailed the extraction of dye from neem leaves, its application to cotton fabric, and the assessment of the resultant color and durability. The results indicated that neem leaves produced a spectrum of colors from green to yellowish, contingent upon the concentration and treatment applied. Analysis of these three tests indicates that a 5% shade concentration is more appropriate for application. For industrial applications, a 5% shade concentration is recommended to achieve optimal results.

The dyed fabrics demonstrated limited resistance to fading and washing, rendering neem leaves a viable alternative to synthetic dyes. This project emphasizes the potential of utilizing indigenous flora for sustainable textile dyeing, thereby promoting environmentally sustainable practices within the textile sector.

References

[1] M. L. 1. .. Gulrajani, " Natural Dyes and Their Applications to Textiles," Indian Institute of Technology ., 2002.
[2] Farnfield, " A Guide to Sources of Information in the Textile Industry. 2nd ed.," The Textile Institute, 1974., 1974.
[3] S. a. Y. ,. Y. 2. Han, "Antimicrobial activity of wool fabric treated with curcumin," Dyes and Pigments , 64 (2) : 157 – 161 ., 2005.
[4] Saima Umbreen, "Dyeing Properties of Natural Dyes Extracted from Turmeric and their Comparison with Reactive Dyeing," Research Journal of Textile and Apparel, 2008.
[5] Y. ,. Q. ,. W. a. L. ,. Y. 2. .. Boling, " Mordant dyeing with rutin and troxerution," International Dyer , , 2005.
[6] A. D. N. K. AK Aggarwal, "Micro encapsulation process and application in textile processing," Colourage August, pp. 22-25, 1998.
[7] K. S. C Hu, "Finishing of silk fabrics with a novel multifunctional epoxide," J Soc Dyers Colour, 2005.
[8] M. S. K Lee, "Silk fabric cross linking," Textile Asia, pp. 26-30, 1991.
[9] M. A.-S. M. G. NA Ibraham, "New approach for imparting antimicrobial activity to cellulose containing fabric," Colourage, 28 , 1998.
[10] A. D. N. K. AK Aggarwal, "Micro encapsulation process and application in textile processing," Colourage August, 45 (8), 2005.
[11] M. H. e. al., "Isolation of a clone encoding a second dragline silk fibroin," J Biol Chem, 1992.
[12] H. Heslot, "Artificial fibrous proteinsa review," Biochimie, pp. 20-28, 1998.
[13] N. M. e. al., "Physico-chemical properties of silk fibroin membrane as a biomaterial," Biomaterials, 1990.
[14] M. Shabbir, "Light Fastness and Shade Variability of Tannin Colorant Dyed Wool with the Effect of Mordanting Methods," color fastness to light, 2017.
[15] G. B. a. J., "G. Borkow and J. Gabbay, Curr. Chem. Biol., 3, 272," 2002.