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Green Eco-Friendly Treatment of Cotton Fabric: A Sustainable Alternative to Chemical Treatment

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Abstract: Eco-friendly technologies have become essential across industries, including textiles. Cotton fabric, a widely used natural fiber, requires effective treatment methods to enhance its properties. This study compares conventional chemical treatment with an eco-friendly alternative using banana tree trunk ash. Cotton fabric samples were categorized into four groups based on treatment variations: 100% chemical (100%CT), 100% natural (100%NT), 75% natural and 25% chemical (75NT:25CT), and 50% natural and 50% chemical (50NT:50CT). These samples underwent textile wet processing and various physico-chemical and physico-mechanical tests. The findings indicate that cotton fabric treated with natural methods demonstrated a higher yield due to reduced degradation and enhanced mechanical properties, with a tensile strength of 24.55 kg/cm² and elongation at break (%) of 62.36, surpassing chemically treated samples. However, dye absorption efficiency was greater in chemically treated fabrics, as confirmed by the dye exhaustion test, while water absorption test and wicking test depicts water absorption as well as transportation capability were slightly lower in naturally treated cotton fabric samples. Overall, this study highlights banana ash as a promising eco-friendly alternative to chemical scouring agents in textile processing.

1. Introduction

Scouring is a crucial wet processing step in textile manufacturing, essential for removing unwanted substances such as oil, fat, wax, solid dirt, soluble impurities, and natural residues that are inherently present in raw fibers. These impurities hinder the uniform absorption of dyes and chemicals, making scouring a fundamental step in textile pretreatment. The effectiveness of scouring directly influences subsequent processes like dyeing, printing, and finishing, ensuring improved fabric quality and performance (Ma *et al.*, 2017). Proper scouring enhances the absorbency of textile materials while minimizing physical and chemical damage to the fibers, which is critical for maintaining fabric integrity and durability (Bar, 2022).

Common synthetic scouring agents used in the textile industry include sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), and calcium hydroxide ($Ca(OH)_2$). The specific scouring conditions, such as temperature, time, and chemical concentration, vary depending on the desired fabric quality and end-use requirements. Conventional chemical scouring typically involves treating fabrics in a heated NaOH solution for a specific duration (Bahrum, 2012). While this method effectively removes impurities, it has several drawbacks. The use of strong alkaline solutions leads to cellulose degradation, increased alkalinity in wastewater, and high Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), contributing to environmental pollution. Additionally, residual chemicals in effluents pose human toxicity risks due to NaOH, detergents, and auxiliaries commonly used in the process (Tabaght *et al.*, 2023; Kabir *et al.*, 2019). In the same time, modified cellulose associated to clay or apatite are efficiency used to remove heavy metals or toxic dyes (Islam *et al.*, 2023; Akartasse *et al.*, 2022; Ndiyae *et al.*, 2022; Errich *et al.*, 2021; Deghles *et al.*, 2019)

To address these environmental and health concerns, the textile industry is shifting towards cost-effective, energy-efficient, and eco-friendly alternatives (Singh *et al.*, 2012). Developing a lower-temperature and low-pH scouring process is highly desirable, as it conserves energy, reduces fiber damage, and minimizes the generation of harmful wastewater. The use of microbial enzymes in textile processing has gained significant attention due to their ability to efficiently remove impurities while preserving fiber quality. Enzymatic scouring is an effective alternative as it causes less fiber degradation, improves fabric softness, requires lower energy input, and reduces the use of environmentally harmful chemicals (Shanthi and Krishnabai, 2013; Mojsov, 2016).

With increasing concerns over pollution and public health risks caused by synthetic chemicals, researchers are actively exploring sustainable and environmentally friendly textile processes (Islam *et al.*, 2011). The demand for greener alternatives has led to the utilization of natural resources in textile pretreatment. Among these, the banana plant has emerged as a promising resource due to its availability and excellent functional properties. In rural Bangladesh, banana tree trunk ash has been traditionally used as a natural detergent for washing heavy fabrics and household textiles. It possesses excellent cleansing properties and is an environmentally friendly, cost-effective alternative to conventional detergents. Furthermore, different parts of the banana plant, including its sap, have been used in traditional medicine to treat conditions such as bronchitis, dysentery, ulcers, diabetes, epilepsy, leprosy, and hemorrhages, highlighting its versatility and benefits (Kumar *et al.*, 2012).

Natural fibers offer several advantages over synthetic fibers, including biodegradability, recyclability, renewability, low cost, high specific mechanical properties, and low density (Peças *et al.*, 2018; Gupta *et al.*, 2021). Among these, cotton is one of the most widely used natural fibers in the textile industry (Miah *et al.*, 2018). It is a cellulosic fiber belonging to the *Gossypium* genus, composed of 1,4-d-glucopyranose structural units (Varghese and Mittal, 2018). Cotton fibers are naturally soft, breathable, dye-absorbent, and highly durable. Due to their excellent absorbency, they can retain huge water to their weight, making them highly suitable for textile applications (Begum *et al.*, 2021). After harvesting, cotton fibers are separated from seeds using cotton gins, pressed into bales, and spun into yarns, which are then used for manufacturing clothing, sheets, towels, and other textile products (Delhom *et al.*, 2020). However, raw cotton contains natural impurities such as wax, oil, and fatty acids, which must be removed before wet processing to enhance water absorbency and dye uptake (Reda *et al.*, 2025).

This study investigates the potential of banana tree trunk ash as an eco-friendly alternative to conventional chemical scouring methods used in the textile industry. By comparing the effects of chemically and naturally treated cotton fabrics through various physico-mechanical and chemical tests, this research provides valuable insights into the effectiveness of natural scouring agents in sustainable textile wet processing. This study introduces banana tree trunk ash as a novel, eco-friendly alternative to conventional chemical scouring agents, offering a sustainable approach to cotton fabric treatment with reduced environmental impact. The findings of this research highlight the potential of natural ash to maintain fabric integrity while minimizing chemical use, energy consumption, and wastewater pollution in textile processing.

2. Methodology

2.1 Materials

The materials used in this study included cotton fabric obtained from Fortis Garments, Dhaka, Bangladesh. For the scouring process, both natural and chemical agents were utilized. Banana tree trunk ash, prepared for this study, served as a natural scouring agent, while Jet Detergent (Kohinoor Chemicals Bangladesh Ltd.), hydrogen peroxide (H_2O_2, 30%) (Merck, Germany), sodium hydroxide (NaOH) (Loba Chemie, India), and sodium carbonate (Na_2CO_3) (Sigma-Aldrich, USA) were used as conventional chemical scouring agents. Additional chemicals, such as acetone (Merck, Germany) for cleaning and solvent purposes and hydrochloric acid (HCl) (Sigma-Aldrich, USA) for neutralization and pH adjustment, were also employed. The dyeing process was carried out using Direct Red 81 dye, sourced from Merck (Mumbai, India). All chemicals were of analytical grade and used without further purification.

2.2 Banana tree trunk ash preparation

Locally collected banana tree trunks were chopped into small pieces and sun-dried to eliminate moisture. The dried pieces were then burned in a fire chamber, and the resulting ash was sieved to remove unwanted residues. This process yielded fresh banana tree trunk ash, which was prepared for fabric pretreatment. The ash was then stored in clean polyethylene bags for further processing. An image of the prepared banana tree trunk ash is presented in **Figure 1(a).**

2.3 Scouring of cotton fabric

The primary objective of cotton scouring is to eliminate natural and artificial impurities, enhancing the fabric's cleanliness and absorbency (Raafi *et al.*, 2023). In this study, cotton fabric was scoured using four different treatment solutions. The first treatment involved only natural banana tree trunk ash solution (100% NT). The second treatment used a mixture of 75% natural banana tree trunk ash and 25% chemical agents (75NT:25CT). The third treatment combined 50% natural banana tree trunk ash with 50% chemical agents (50NT:50CT). Finally, the fourth treatment involved a 100% chemical solution (100% CT).

The scouring process was carried out in a solution containing 10 g of banana tree trunk ash and caustic soda (proportioned according to the respective treatment type) per liter of water. The treatment was conducted at 75°C for 30 minutes in a beaker, maintaining a fiber-to-liquor ratio of 1:50. After scouring, the fabric was thoroughly washed with distilled water and air-dried (K J *et al.*, 2022). An image of the scoured cotton fabric is shown in **Figure 1(b)**.

2.5 Bleaching of cotton fabric

Bleaching is a widely adopted process in the textile industry. Raw cotton fibers contain both cellulosic and non-cellulosic components, such as lignin, pectin, wax, and oils, which contribute to their natural yellowish hue. The primary objective of bleaching is to eliminate these non-cellulosic impurities and enhance the fabric's whiteness (De Oliveira *et al.*, 2015).

In this study, the scoured cotton fabric was bleached using 1% (v/v) hydrogen peroxide with 2 g/L sodium silicate as a stabilizer. The bleaching process was carried out at 60°C for 45 minutes, maintaining a fiber-to-liquor ratio of 1:50. After bleaching, the samples were neutralized with dilute acetic acid, thoroughly washed with distilled water, and then air-dried. **Figure 1(c)** presents an image of the bleached cotton fabric.

2.6 Dyeing of cotton fabric

Direct Red 81 dye solutions were prepared by first making a paste with cold water, followed by the addition of boiling water. The required percentage of dye and electrolyte (sodium chloride) was then incorporated to formulate the dye bath. Before immersion in the dye bath, the cotton fabric was thoroughly washed with distilled water and squeezed to ensure uniform dye absorption.

Dyeing was conducted in a temperature-controlled water bath at 90°C for 90 minutes with occasional stirring, followed by a cooling period of 30 minutes. The fiber-to-liquor ratio was maintained at 1:30. During the dyeing process, boiling distilled water was periodically added to the dye bath to maintain the required ratio. Upon completion, the dyed fabric was carefully squeezed over the dye bath to minimize dye wastage, ensuring that no exhausted dye liquor was discarded. The fabric was then rinsed in cold distilled water and reintroduced into the exhausted dye bath. Finally, the dyed cotton fabric was air-dried at room temperature (Periyasamy, Dutta and Tehrani-Bagha, 2024). **Figure 1(d)** presents an image of the dyed cotton fabric.

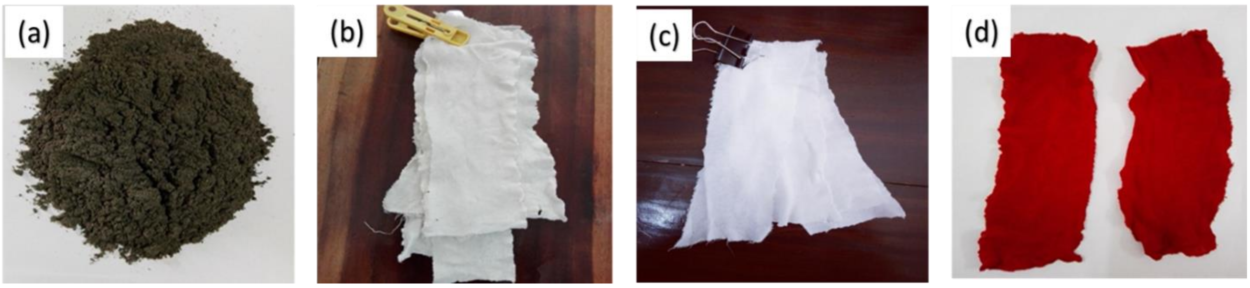

Figure 1. Picture of (a) Banana tree trunk ash (b) Scoured cotton fabrics (c) Scoured cotton fabrics (d) Bleached cotton fabrics

2.7 Characterization

Weight Loss and Yield Test

During the scouring process, cotton fabric undergoes weight reduction due to the removal of impurities such as oil, fat, wax, and gummy substances. The effectiveness of scouring can be evaluated by measuring the weight loss of the fabric. This is determined by calculating the difference in weight between the unscoured and scoured fabric samples while maintaining the same moisture content, and the weight loss is expressed as a percentage (Mr *et al.*, 2016).

Weight loss percent of the sample $\boldsymbol{W}= \{(\boldsymbol{W_i}-\boldsymbol{W_f})/\ \boldsymbol{W_i}\} \times \mathbf{100}\%$ ………. **Eqn. 1**

Where, $\boldsymbol{W_i}$ is the initial weight of the fiber and

$\boldsymbol{W_f}$ is the final weight after scouring.

Yield % **Y**= W_f / W_i or $W_i - W$ ………. **Eqn. 2**

Wicking Test of cotton fabric

The wicking test is a reliable method for analyzing the scouring effect on cotton fabric. In this test, fabric samples of equal length and weight are used along with a standard dye solution (0.1% direct dye). A mark is drawn 1 cm above the fabric's edge, and the sample is suspended from a stick. The fabric is then immersed in the dye solution up to the marked level and held in this position for five minutes, allowing the dye solution to be absorbed and wick upward through the fabric (Chen *et al.*, 2022). The experimental setup of the wicking test is illustrated in **Figure 2**.

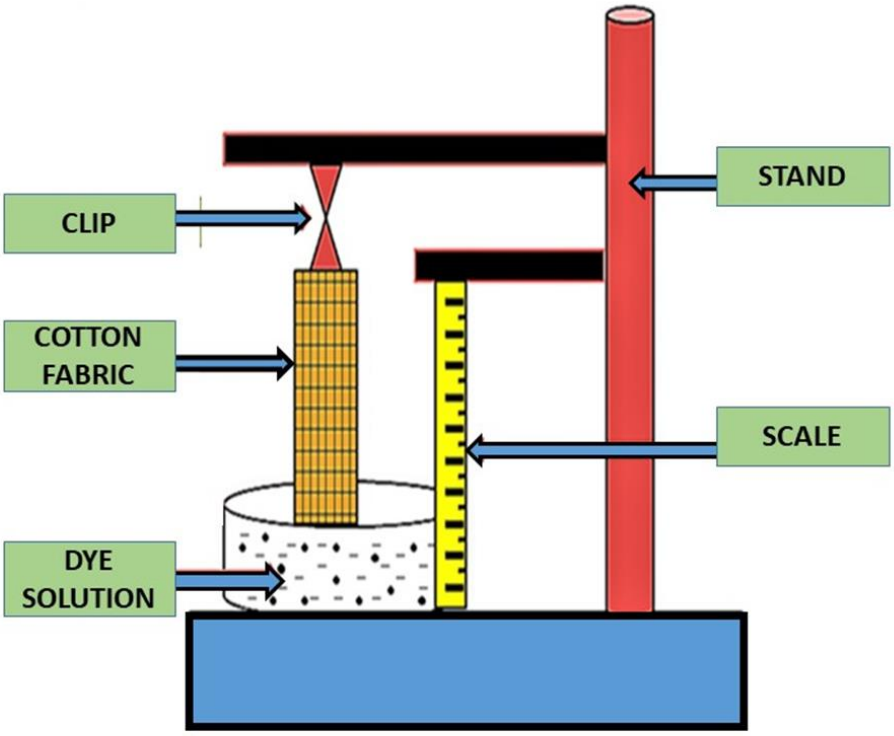

Figure 2. Schematic diagram of experimental setup of wicking test.

Water Absorption Test

Water absorption was evaluated following the ASTM Designation C 67-91 standard. Fabric samples were cut to a length of approximately 10.4 cm and a width of 0.9–1.0 cm. These samples were then immersed in a static water bath maintained at 25°C for a duration ranging from 5 to 35 hours. At specified time intervals, the samples were removed from the bath, gently wiped with tissue paper to remove excess water, and weighed immediately (Begum, Tanni and Shahid, 2021). The absorbency of the samples was then calculated using the following equation.

Water intake (%) = $\{(\boldsymbol{W_f} - \boldsymbol{W_i})\ \boldsymbol{W_f}\} \times \mathbf{100}\%$ ………. **Eqn. 3**

Where, W_i and W_f are the weight of the fiber before immersion and after immersion respectively.

Dye Exhaustion Test

To evaluate the dyeability of the cotton fabric samples, a Spectronic 20 colorimeter was used for analysis.

Absorption of dye percentage = $\{(\boldsymbol{Do}-\boldsymbol{De})/\ \boldsymbol{Do}\} \times \mathbf{100}\%$ ………. **Eqn. 4**

Where, Do and De are the original and exhausted dye bath concentration, respectively.

Tensile Test

The cotton fabric samples were cut into equal pieces, each measuring 15 cm in length. The specimens were placed between the jaws of the Shimadzu Universal Testing Machine (**AGS-X Series)**, with a length of 10 cm maintained between them. A twist was applied every 2 cm along the length of the fabric between the jaws. The breaking load was gradually increased as the machine operated, and at a certain point, the specimen tore. The machine was stopped at the moment of breakage, and the breaking load was recorded on the scale of the tensile tester in kilograms. Using this procedure, the breaking strength of scoured, bleached, and dyed cotton fabric samples was measured (Rahaman *et al.*, 2016).

Tensile strength was estimated by T = $\mathbf{F_{max}}$ x $\boldsymbol{A}$ ………. **Eqn. 5**

Where, F_{max} is the maximum load applied to the sample and A is the cross sectional area of the sample.

Elongation at Break or Percent of elongation at break was calculated by the following equation

EB (%) = $\Delta \mathbf{L_b}\ \mathbf{L_0} \times \mathbf{100}\%$ ………. **Eqn. 6**

Where, ΔL_b is the extension at break point of the sample and L_0 is the Gage length or original length of the sample.

3. Results and Discussion

3.1 Weight Loss Analysis

The percentage of weight loss for scoured cotton fabric samples is presented in **Table 1** and the trend is illustrated in **Figure 3**. These results were obtained by comparing the weight of the fabric samples before and after scouring. It was observed that the 100% natural treated (NT) cotton fabric showed a relatively low weight loss of 1.5%, while the 100% chemically treated (CT) cotton fabric exhibited a significantly higher weight loss of 6.89%. In comparison, the 75% NT and 25% CT sample demonstrated a weight loss of 3.5%, and the 50% NT and 50% CT sample showed a weight loss of 4.5%. The weight loss percentages of the various cotton fabric samples are also graphically represented in Figure 3. It is found that the weight loss of cotton fabric treated with natural agents was much lower than that of samples treated with conventional chemical scouring agents. Furthermore, as the concentration of chemical reagents increased, the weight loss percentage also increased, while the overall yield decreased. The lower weight loss in the 100% natural treated (NT) cotton fabric suggests that natural treatments are gentler on the fabric, preserving its integrity more effectively. In contrast, the higher weight loss in chemically treated (CT) fabrics is due to the more aggressive nature of chemical scouring agents, which remove a greater amount of material from the fiber surface (Mamun *et al.*, 2021).

These findings suggest that combining natural ash with chemical scouring agents might offer a promising alternative for scouring cotton fabrics in bulk production. This mixed treatment could potentially provide an effective balance between weight loss and fabric integrity, offering both environmental and performance benefits over purely chemical treatments. It can be expected that this mixed system would result in a more sustainable scouring process while maintaining the desirable properties of the cotton fabric.

Table 1. Weight loss Percent and Yield% of various cotton fabric sample.

Sample Name	Weight Before Treatment	Weight After Treatment	Average Final Weight	% Weight Loss	Yield %
100% CT	2gm	1.8620	1.86	6.89%	93.11
		1.8492			
		1.8598			
100% NT	2gm	1.956	1.97	1.5%	98.5
		1.972			
		1.984			
75NT : 25CT	2gm	1.9311	1.93	3.5%	96.5
		1.940			
		1.9202			
50NT : 50CT	2gm	1.9120	1.91	4.5%	95.5
		1.907			
		1.901			

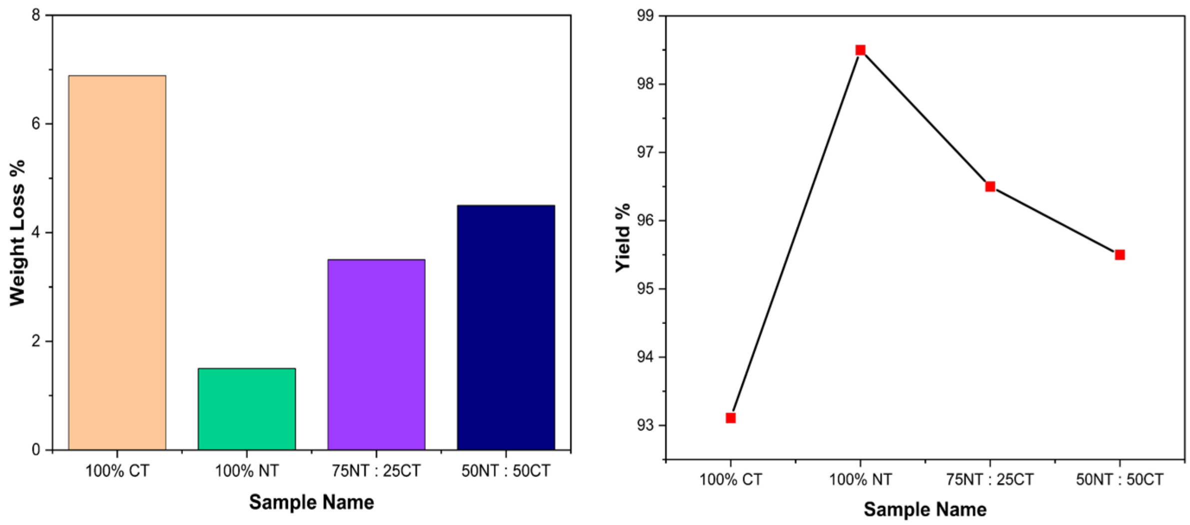

Figure 3. The percentage of weight loss and Yield% of 100% CT, 100% NT, and 75NT:25CT, and 50NT:50CT cotton fabric.

3.2 Wicking Test Analysis

The **Figure 4** illustrates the wicking properties of different cotton fabric samples, including 100% chemically treated (CT), 100% naturally treated (NT), 75% NT and 25% CT (75NT:25CT), and 50% NT and 50% CT (50NT:50CT) and the **Table 2** shows the data as well. Among these samples, the

100% CT fabric exhibited the highest travel length of 30.25 mm, indicating superior wicking capability due to the removal of natural impurities and enhanced capillary action from chemical treatment. In contrast, the 100% NT sample showed the lowest travel length of 22.08 mm, likely due to the presence of residual impurities that hinder moisture movement. The mixed treatments (75NT:25CT and 50NT:50CT) displayed intermediate wicking lengths of 23.28 mm and 25.33 mm, respectively, demonstrating that incorporating chemical treatment with natural methods can improve wicking properties while maintaining some eco-friendly aspects. This analysis suggests that natural treatments, such as banana tree trunk ash, can achieve comparable wicking performance to conventional chemical methods, making them a viable alternative for sustainable textile processing (Öztürk *et al.*, 2011).

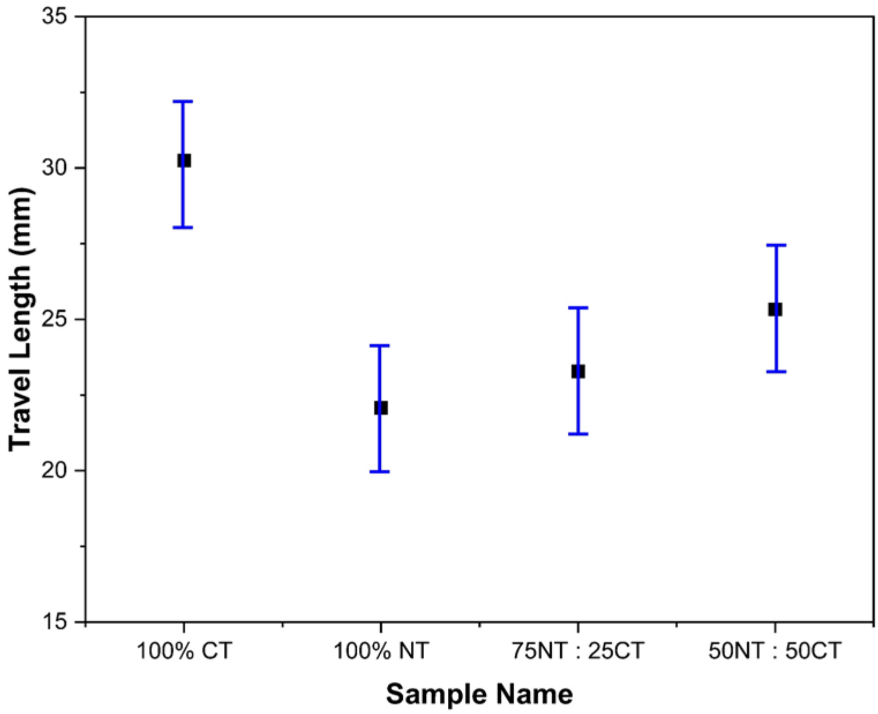

Figure 4. Wicking properties of 100% CT, 100% NT, 75NT: 25CT, and 50NT:50CT cotton fabric.

Table 2. Wicking properties of various treated cotton fabric sample.

Sample Name	Experiment Time (minutes)	Travel of Water (mm)	Average Travel (mm)
100% CT	10	31.15	30.25
		29.50	
		30.10	
100% NT	10	22.20	22.08
		21.00	
		23.05	
75NT : 25CT	10	22.75	23.28
		24.00	
		23.10	
		24.75	

50NT : 50CT	10	25.75	25.33
		25.50	

3.3 Water Absorption Analysis

The water absorption capacity of 100% chemically treated (CT), 100% natural treated (NT), 75NT:25CT, and 50NT:50CT cotton fabric samples is presented in **Figure 5**. The maximum absorbency recorded for the 100% CT sample was 39.815% after 35 hours, indicating excellent water absorption characteristics. Similarly, the 50NT:50CT and 75NT:25CT samples exhibited maximum absorbency values of 37.70% and 36.52%, respectively, at 35 hours, showing only a slight reduction compared to the 100% CT sample. On the other hand, the 100% NT sample demonstrated a slightly lower maximum absorbency of 35.001% at the same time interval.

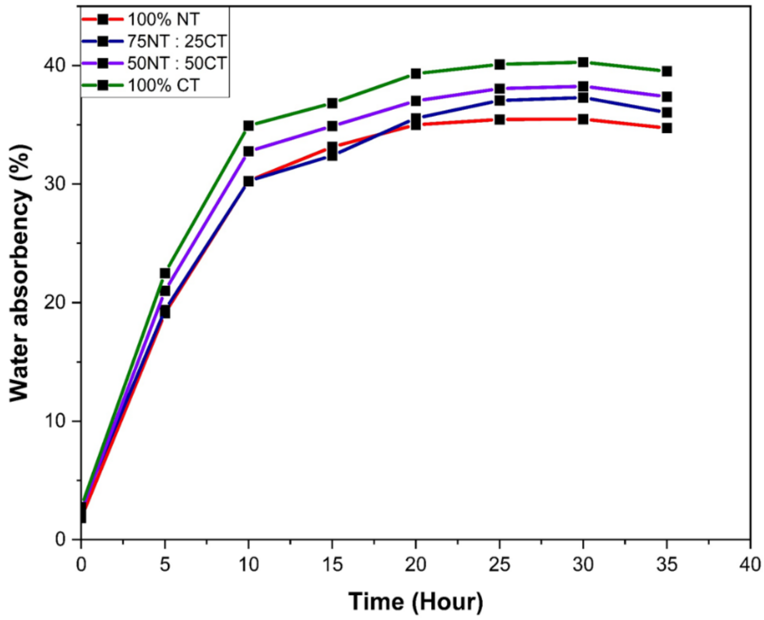

Figure 5. Water absorption vs time for 100% CT, 100% NT, 75NT: 25CT, and 50NT:50CT cotton fabric

Cotton fabric is inherently hydrophilic due to the presence of hydroxyl (-OH) groups in its cellulose structure, which facilitate water absorption. However, in chemically treated fabrics, scouring with NaOH can partially modify or remove some hydroxyl groups, potentially reducing the hydrophilicity of the fibers (Rahaman *et al*., 2016). In contrast, natural treatment methods, such as the use of natural ash, do not involve harsh chemical reactions that alter the hydroxyl groups in cellulose. As a result, the water absorption capacity of naturally treated cotton fabrics remains largely intact while still achieving a comparable level of absorbency to chemically treated samples.

Based on this analysis, it can be anticipated that cotton fabric treated with natural ash presents an eco-friendly alternative to conventional chemical treatments. This method not only retains the hydrophilic nature of cotton but also offers a sustainable approach that minimizes environmental impact. Therefore, the natural treatment process has the potential to compete with traditional chemical treatments in the textile industry, providing a viable option for sustainable textile processing.

3.4 Direct dye (Red) Exhaustion

The relationship between dye exhaustion and dye concentration for 100% chemically treated (CT), 100% naturally treated (NT), 75NT:25CT, and 50NT:50CT cotton fabric samples is presented in **Figure 6**. From the figure, it can be observed that dye absorption initially increases with increasing dye concentration in the dye bath, followed by a decreasing trend after reaching a certain concentration threshold. This pattern occurs because, at lower dye concentrations, there are fewer dye ions available, allowing efficient absorption onto the fiber surface. However, as the dye concentration increases, excess dye molecules in the dye bath start competing for available binding sites on the fiber, leading to saturation and reduced absorption efficiency. The presence of an excessive number of dye ions hinders further absorption due to repulsion effects and the limited availability of unoccupied binding sites. Additionally, at higher dye concentrations, the absolute quantity of absorbed dye diminishes, as previously reported in studies (Idan *et al.*, 2018; Zhai *et al.*, 2022).

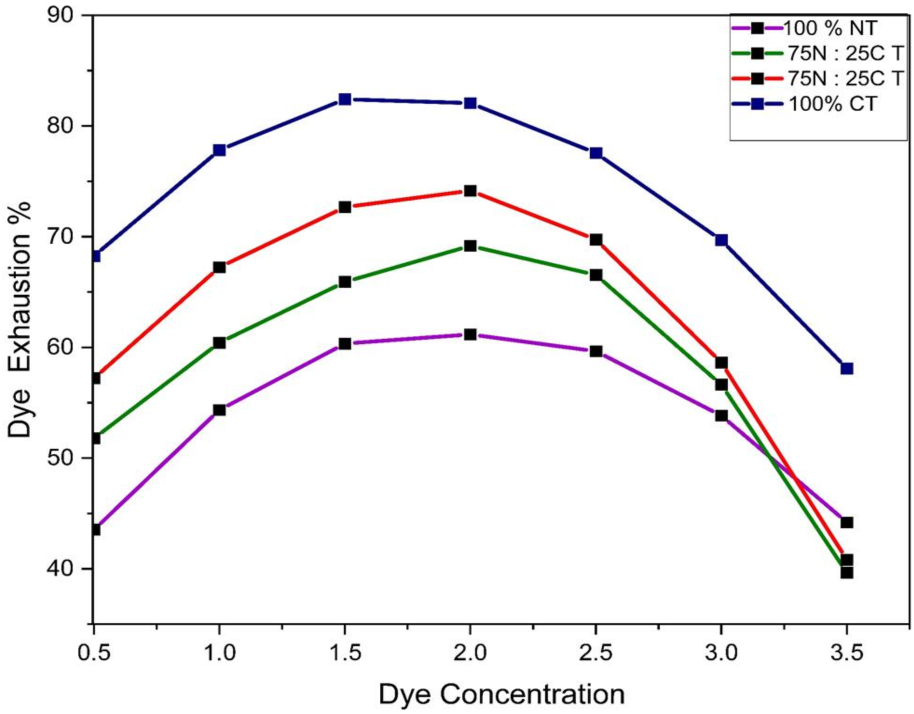

Figure 6. Plots of dye exhaustion vs dye concentration for 100%CT, 100%NT, 75NT: 25CT and 50NT:50CT banana fiber.

Furthermore, the graph indicates that the dye absorbability of 100% NT cotton fabric is significantly lower than that of 100% CT cotton fabric. This discrepancy can be attributed to the differences in surface modification caused by the respective treatments. Chemical treatment often enhances fiber reactivity by removing natural impurities and increasing fiber accessibility, allowing for better dye penetration and fixation. In contrast, naturally treated cotton retains more of its original surface characteristics, which may lead to lower dye affinity and reduced dye uptake.

Overall, this analysis suggests that while chemical treatment enhances dye absorption, natural treatment offers a more environmentally friendly alternative with moderate dye uptake. Understanding the balance between dye concentration and fiber treatment can help optimize dyeing processes for different fabric applications while considering sustainability factors.

3.5 Tensile Strength Testing

The **Figure 7** illustrates the tensile properties of raw, 100% chemically treated (CT), 100% naturally treated (NT), 75NT:25CT, and 50NT:50CT cotton fibers. From the figure, it can be observed that the 100% NT sample exhibits the highest tensile strength of 24.55 Kg/cm², outperforming all other treated samples. A descending trend is noted in the tensile strength of the blended samples, with the 75NT:25CT sample recording 21.25 Kg/cm², followed by 50NT:50CT at 19.11 Kg/cm², and the 100% CT sample at 19.05 Kg/cm². These variations in tensile strength can be attributed to differences in the internal structural composition of the fibers, including cell structure, microfibrillar angle, and the presence of structural defects.

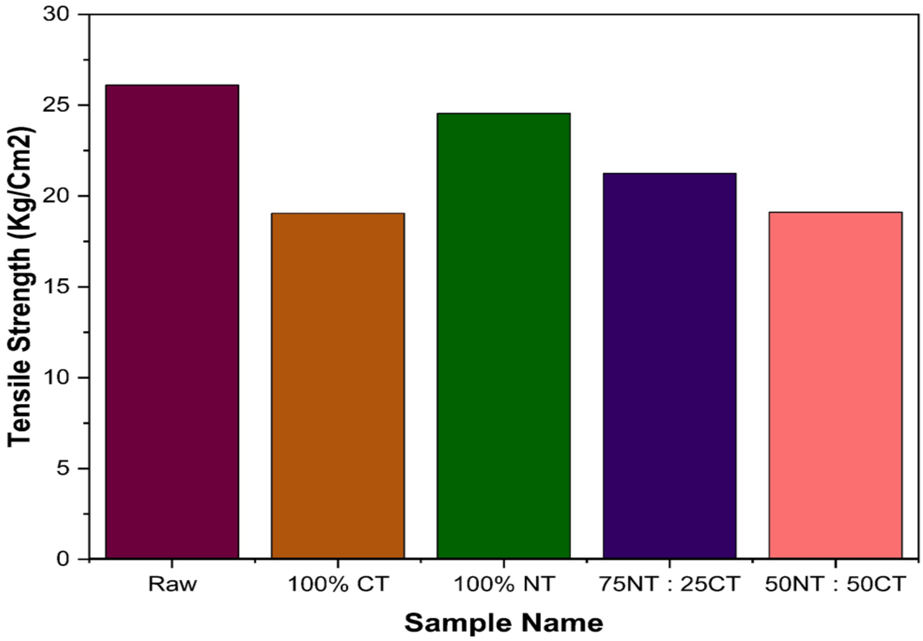

Figure 7. Tensile behavior of Raw, 100% CT, 100% NT, 75NT:25CT and 50NT:50CT cotton fabric.

Additionally, the choice of scouring agents—whether chemical or natural ash—significantly influences fiber integrity. It was observed that eco-friendly treatment with natural ash provides better fiber durability and improved mechanical properties. This can be explained by the ability of banana tree trunk ash to efficiently remove oil, wax, gum, and other surface impurities without causing structural damage to the fiber's surface or its inner cellulose network (Singh *et al.*, 2018). The mild nature of natural treatment helps in preserving the fiber's intrinsic strength, leading to superior tensile properties.

Conversely, in the case of chemically treated fibers, the highly reactive scouring agents, such as NaOH, lead to fiber degradation by aggressively interacting with both the outer and inner surfaces of the fiber. This excessive chemical action weakens the overall fiber structure, reducing its tensile strength and durability (Jain *et al.*, 2021). As a result, while chemical treatment effectively removes impurities, it comes at the cost of decreased mechanical performance compared to natural treatment methods (Arya, Singh and Devi, 2021).

3.6 Elongation Behavior Analysis

The elongation behavior of raw, 100% chemically treated (CT), 100% naturally treated (NT), 75NT:25CT, and 50NT:50CT cotton fabrics is presented in **Figure 8**. The results indicate that the 100% NT sample exhibits the highest elongation at break, reaching 62.36%, outperforming the 100% CT sample, which demonstrates an elongation of 59.09%. The blended samples display intermediate elongation values, with the 75NT:25CT fabric showing 56.81% elongation and the 50NT:50CT fabric exhibiting 53.40%. These variations suggest that the treatment method significantly influences the elasticity and strain capacity of the cotton fibers.

Naturally treated cotton fabrics exhibit superior elongation properties compared to chemically treated counterparts due to the preservation of their intrinsic fiber structure. Natural treatment methods, such as using banana tree trunk ash, effectively remove surface impurities like wax, oil, and gum without causing significant fiber degradation. This allows the cotton fibers to retain their inherent flexibility and extensibility, which contributes to their higher elongation at break.

Conversely, chemically treated cotton fabrics exhibit a lower elongation at break due to the aggressive nature of chemical scouring agents, particularly sodium hydroxide (NaOH). These chemicals interact with both the outer and inner layers of the fiber, leading to structural modifications that weaken the fiber's integrity. Studies have shown that NaOH treatment causes swelling of cellulose fibers, breaking intermolecular hydrogen bonds and altering the microfibrillar arrangement, ultimately reducing elasticity and strain capacity (Cuiffo *et al.*, 2021). Additionally, prolonged chemical exposure can degrade the amorphous regions of the fiber, making it more brittle and less capable of withstanding strain before breaking.

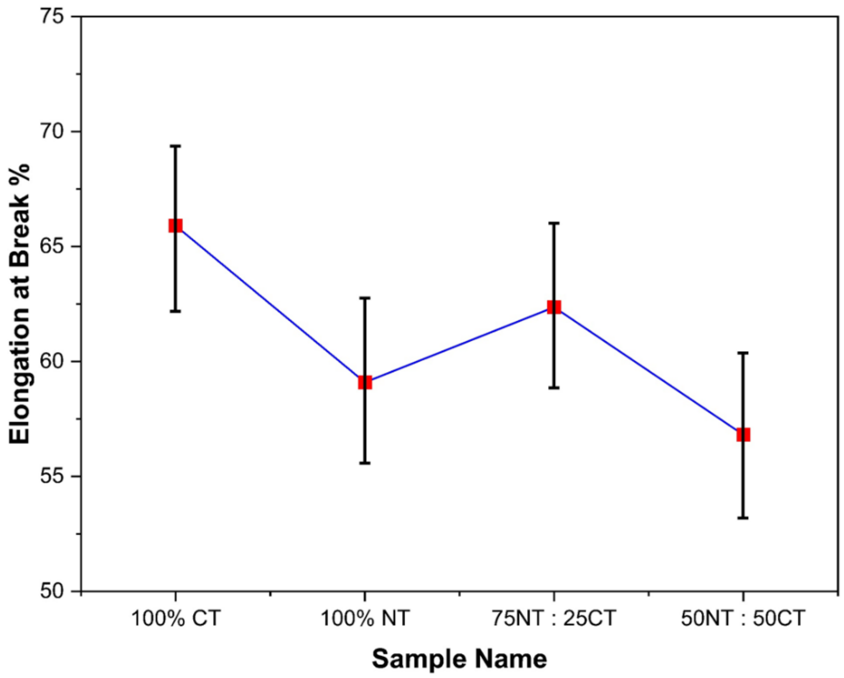

Figure 8. Elongation behavior of Raw, 100% CT, 100% NT, 75NT:25CT 50NT:50CT cotton fabric.

Conclusions

This study demonstrates the effectiveness of banana tree trunk ash as an eco-friendly alternative to conventional chemical scouring in cotton fabric treatment. Comparative analysis of 100% chemically treated (CT), 100% naturally treated (NT), 75%NT:25%CT, and 50%NT:50%CT fabrics revealed key differences in physico-mechanical and physico-chemical properties. The 100% NT fabric exhibited minimal weight loss (1.5%) compared to 100% CT (6.89%), indicating that natural treatment preserves fiber integrity while effectively removing impurities. Blended samples showed intermediate weight losses (3.5%-4.5%), suggesting a balance between durability and scouring efficiency. In wicking performance, 100% CT fabric achieved the highest travel length (30.25 mm) due to enhanced capillary action, whereas 100% NT fabric had the lowest (22.08 mm), likely due to residual impurities. The blended samples (23.28-25.33 mm) demonstrated that incorporating natural treatment can improve moisture movement while maintaining sustainability. Water absorption remained high across all samples, with 100% CT fabric recording the highest absorbency (39.815%) and 100% NT slightly lower (35.001%), showing that natural treatment retains cotton's hydrophilicity. Dye exhaustion analysis indicated higher dye uptake in chemically treated fabrics due to enhanced fiber reactivity, while naturally treated samples exhibited moderate absorption due to retained surface impurities. In mechanical properties, 100% NT fabric showed superior tensile strength (24.55 Kg/cm^2) compared to 100% CT (19.05 Kg/cm^2), highlighting the degradation caused by aggressive chemical treatment. Blended samples showed intermediate strengths (21.25-19.11 Kg/cm^2), indicating that natural treatment enhances fiber longevity. Similarly, elongation at break was highest in 100% NT fabric (62.36%) compared to 100% CT (59.09%), demonstrating that natural treatment preserves fiber flexibility better than chemical scouring. Overall, the study highlights banana tree trunk ash as a viable alternative to chemical scouring, maintaining fiber integrity, mechanical strength, and absorbency while minimizing environmental impact. By reducing fiber degradation, preserving mechanical properties, and offering sustainable processing, natural treatment presents a promising solution for eco-friendly textile manufacturing, reducing chemical dependency, energy consumption, and wastewater pollution.

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Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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