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Effect of Natural Mordant (Lemon Juice) on the Dyeing Properties of Cotton Knitted Fabric Dyed with Natural Dye Extracted from Eucalyptus Leaves

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Abstract: This study investigates the effectiveness of lemon juice as a natural biomordant in the dyeing of cotton knitted fabric using natural dye extracted from fresh eucalyptus leaves through an aqueous extraction method, while lemon juice was extracted manually using a hand press. The scoured-bleached cotton samples (10 g) were dyed without mordant and with varying dye solution to mordant ratios (1:0.1, 1:0.2, 1:0.3, 1:0.4, and 1:0.5). Dyeing performance was evaluated in terms of color fastness to washing (ISO 105 C06) and light (ISO 105 B02), bursting strength (ISO 13938-2) in kPa and color strength (K/S value). The results revealed moderate color fastness to washing, with acceptable ratings for both color changing and staining, and showed good resistance to fading against light. The bursting strength analysis confirmed that the fabric strength increased to a maximum of 511 kPa from 405 kPa due to the presence of citric acid, which helps to facilitate esterification and hydrogen bonding between cellulose and dye molecules, improving dye fixation. The K/S values increased from 2.4 to 3.3 with a dye-to-mordant ratio of 1:0.3, after which the color strength value decreased slightly due to a higher acidic condition. Thereby, the use of lemon juice as a natural biomordant enhances dye fixation and color durability without compromising fabric strength and can serve as an effective, eco-friendly alternative to conventional mordants, contributing to sustainable textile dyeing practices.

Keywords: *Natural Dye, Eucalyptus Leaves, Lemon Juice Biomordant, Cotton Knitted Fabric, Color Fastness.*

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I. INTRODUCTION

Textile dyeing is one of the most chemical-intensive processes in the global manufacturing industry. Although synthetic dyes are widely used because of their broad color range, ease of application, and high reproducibility, they have been increasingly criticized for their negative environmental and health effects, including carcinogenicity, toxic sludge production, and severe water pollution [1-3]. Dyes and pigments are the two major categories of colorants used in a wide range of industries, including textiles, paints, cosmetics, and other applications [4].

Natural dyes (NDs) were the primary colorants used before the development of synthetic dyes. With the advent of synthetic dyes (SDs), they became widely adopted for textile fiber coloration because of their ease of application, cost-effectiveness, and moderate to excellent color fastness properties [5, 6]. However, increasing environmental concerns have renewed interest in natural dyes as sustainable alternatives because they are renewable, biodegradable, and generally less harmful to the environment [7].

However, the application of natural dyes often requires mordants to improve dye fixation and color fastness [7]. The paper explains that conventional metal mordants improve dye fixation but create environmental and toxicity concerns. It presents biomordants derived from plants and agricultural waste as environmentally friendly alternatives [8]. Recent studies have highlighted plant-based biomordants as sustainable alternatives to conventional metallic mordants because they improve dye fixation and color fastness while reducing environmental impacts. Biomordants have shown

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considerable potential for enhancing the performance of natural dyeing on textile substrates [9].

Islam et al. demonstrated that eucalyptus bark extract can be successfully used as a natural dye for cellulosic fabrics, producing good color strength and satisfactory washing and rubbing fastness when mordanting techniques were applied. The study highlighted eucalyptus as a promising sustainable dye source for eco-friendly textile coloration [10].

Karabulut and Atav reported that cotton knitted fabrics could be successfully dyed with various natural plant extracts, including eucalyptus leaves, and that selected natural dyes produced satisfactory color strength and acceptable fastness properties even without mordant treatment [11].

Dutta et al. investigated the dyeing of cotton knitted fabric with onion skin extract using both natural and synthetic mordants and reported that the mordant type significantly influenced color strength and fastness properties. Among the natural mordants, eucalyptus bark showed promising performance, indicating its potential as an eco-friendly mordant for sustainable textile dyeing [12].

Chowdhury et al. reported limited information on cotton dyeing using holy basil leaf extract with lemon juice as a biomordant, highlighting the need for further investigation into sustainable biomordant-assisted natural dyeing systems [13]. Although various natural and metallic mordants have been investigated for natural dyeing, limited information is available regarding the effect of lemon juice concentration as a natural biomordant on the dyeing performance of eucalyptus leaf extract on cotton knitted fabric, particularly in terms of color strength, fastness, and mechanical properties [5].

Although previous studies have investigated natural dyeing of cotton fabrics using various plant extracts and biomordants, limited information is available on the effect of lemon juice concentration as a natural biomordant for eucalyptus leaf extract on cotton knitted fabric. Therefore, this study investigates the influence of different dye solution-to-lemon juice ratios on the color fastness, bursting strength, and color strength (K/S) of eucalyptus-dyed cotton knitted fabric. The findings are expected to contribute to the development of a simple, low-cost, and environmentally friendly natural dyeing process for sustainable textile applications.

II. EXPERIMENTS

A. Materials

100% Cotton single jersey knitted fabric produced with 30S Ne yarn was used in this research. The WPI and CPI of the fabric were 40 and 42, respectively, with a stitch length of 2.82. The fabric was commercially combined, scoured-bleached, and enzyme washed with an areal density of 160 GSM. The fabric was collected from Mother Apparels Ltd., Kashimpur, Gazipur, Bangladesh.

Natural dye solution used in this research was extracted from fresh mature eucalyptus leaves which were collected from a localized eucalyptus tree beside the TMSS Engineering College, Thengamara, Bogura-5800, Bangladesh.

The citrus lemon juice used as a natural biomordant in this research was extracted from raw lemons, which were bought from Fateh Ali Bazar, Satmatha, Bogura, Bangladesh.

B. Methods

- *Extraction of Natural Dye Solution from Eucalyptus Leaves*

The mature eucalyptus fresh leaves were cut into small pieces with scissors. The 100 g of eucalyptus leaves were taken into 300 ml of caustic soda (NaOH) solution (10 g/l) in a sample dyeing machine pot. Then it was boiled at a temperature of 100 ºC with a run time of 60 minutes and was cooled to 50 ºC. The pot was then stored overnight. After storing overnight, the solution was filtered with a nylon strainer in a beaker and was kept in a container for dyeing instantly.

- *Extraction of Lemon Juice*

The raw lemon was collected from Fateh Ali Bazar, Satmatha, Bogura-5800, Bangladesh. The collected lemons were washed properly with fresh water and cut into two halves. Then the lemon juice biomordant was extracted by pressing the pieces of lemon with a wooden presser. The squeezed juice was finally filtered with the nylon strainer for use with the natural dye solution during dyeing.

- *Dyeing of Cotton Knitted Fabric without Lemon Juice*

The cotton knitted fabric was dyed without lemon juice at a temperature of 90 ºC for 60 minutes in a sample dyeing machine with a glycerin bath in the exhaust method. In this case, the fabric to natural dye solution ratio was 1:20. After the dyeing time was complete, the temperature was reduced to 40 ºC, and the fabric was cold washed properly. Then the fabric was treated with a soap solution (1g/l) at 60 ºC temperature for 10 minutes. Finally, the fabric was cold-washed and dried with an air dryer.

- *Dyeing of Cotton Knitted Fabric with Lemon Juice*

The dyeing procedure of cotton fabric with lemon juice as a biomordant was the same as the dyeing procedure without lemon juice. The only difference was that the extracted lemon juice was added with the natural dye solution by varying the ratio of natural dye to lemon juice from 1:0.1, 1:0.2, 1:0.3, 1:0.4 and 1:0.5 with the same material to dye solution ratio as mentioned above.

- *Measurement of Color Fastness Properties*

For measuring color fastness to washing, the ISO 105 C06:2010 testing method has been followed. The test was conducted in a rotawash machine.

In case of determining color fastness to light, ISO 105 B02 (Color fastness to artificial light: Xenon arc fading lamp

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test) has been followed. The test was conducted in YG 611G-III Isolation and climate color fastness tester.

➢ *Measurement of Bursting Strength*

ISO 13938-2:1999 method has been followed for determining the bursting strength of the dyed samples. The bursting strength test was driven by the TruBurst tester manufactured by James H. Heal and Company Ltd.

➢ *Measurement of Color Strength (K/S) Value*

The color strength of dyed samples has been measured by using a reflectance spectrophotometer (Data color 650) at the wavelength of maximum absorbance (λmax). The Data color 650 measured the Reflectance (R) of the dyed sample and gives the color strength (K/S) value of that dyed sample by using the Kubelka-Munk equation.

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

Where, K is the absorption coefficient of the dye and S is the scattering coefficient of the dyed sample and R is the reflectance of the dyed sample.

III. RESULTS AND DISCUSSIONS

➢ *Effect of Dye Solution to Lemon Juice Ratios on Color Fastness to Wash*

It has been observed from Fig.1. that the addition of lemon juice improved the color fastness of the dyed samples. In the case of the control sample dyed without lemon juice, the color fastness to wash value for changing scale was equal to 3.0. After adding lemon juice at the ratios of 1:0.1, 1:0.2, and 1:0.3, the fastness value increased up to 3.5. Adding lemon juice at the ratios of 1:0.4 and 1:0.5 resulted in the highest fastness value equal to 4.0. This means that lemon juice improved the ability of the dyed material to retain the dye. But it is necessary to note that the same fastness values for 1:0.4 and 1:0.5 indicate that higher concentrations of lemon juice have no effect on improving color fastness to wash.

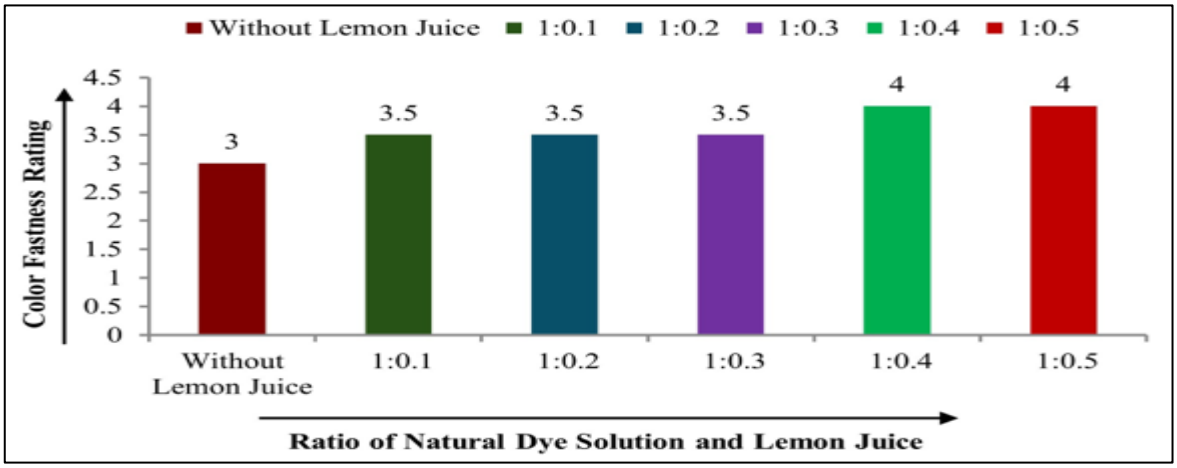

Fig 1 Effect of Variation of the Dye Solution to Lemon Juice Ratios on Color Fastness to Wash for Color Changing Scale.

Fig.2. represents the effect of natural dye solution-to-lemon juice ratios on color fastness to washing for staining of color across various fabric types, including diacetate, cotton, polyamide, polyester, acrylic, and wool. The results have shown us a high level of color fastness to washing for staining across all fabric types and treatment conditions. Di-acetate, polyester, acrylic, and wool consistently exhibited the highest rating of 4.5, which means these fibers have good resistance to staining of color from naturally dyed samples. In contrast, cotton showed a slightly lower and constant rating of 4.0 across all treatments, including the control and lemon juice-added samples. This suggests that, unlike the other fibers, cotton fiber has comparatively lower resistance to staining of color from naturally dyed samples.

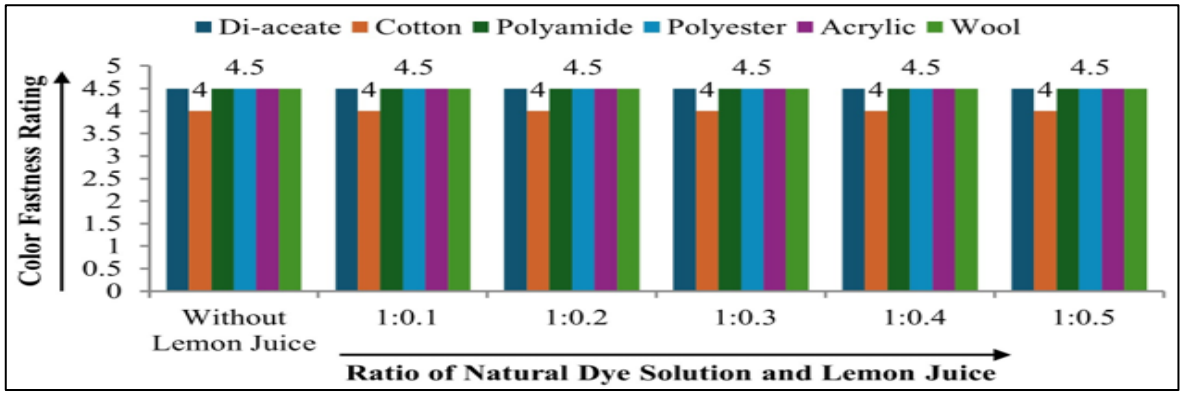

Fig 2 Effect of Variation of the Dye Solution to Lemon Juice Ratios on Color Fastness to Wash for Color Staining Scale.

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➢ *Effect of Dye Solution to Lemon Juice Ratio on Color Fastness to Light*

It has been revealed from Fig.3. that there was no effect on the color fastness in all the experiments conducted.

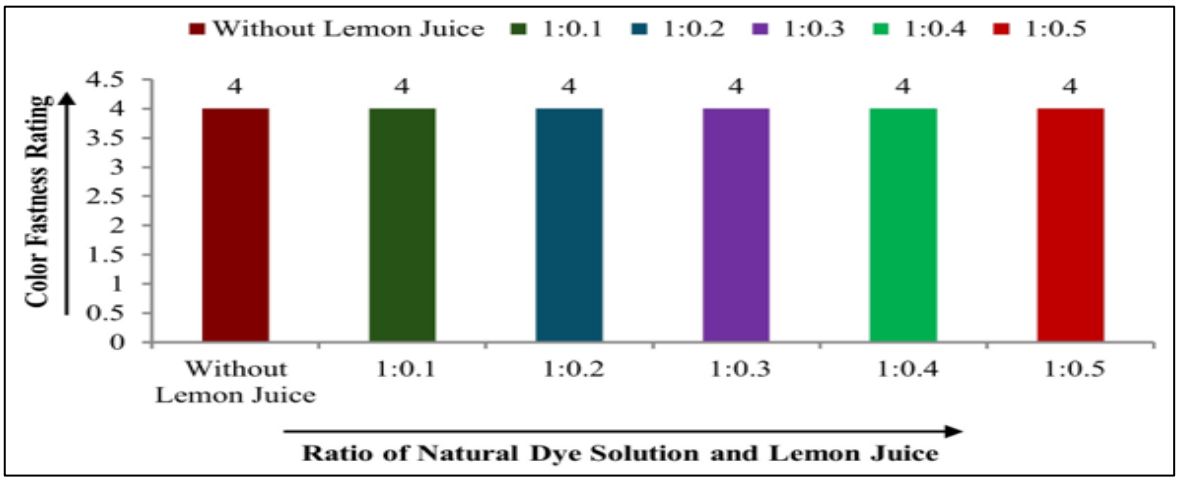

Fig 3 Effect of Variation of the Dye Solution to Lemon Juice Ratios on Color Fastness to Light.

This was because the control sample dyed without lemon juice, together with the samples dyed with different lemon juice concentrations, from 1:0.1 to 1:0.5, showed a color fastness rating of 4.0 on the blue wool scale. This means that lemon juice has no major impact on color fastness to light when dyed with eucalyptus leaf. According to reports, a 4 rating is usually considered a good color fastness, meaning that the color was well preserved after being dyed. Therefore, from the study above, it has been seen that the use of lemon juice, within the concentration tested, did not improve or worsen the color fastness of the natural dye extracted from eucalyptus leaf.

➢ *Effect of Dye Solution to Lemon Juice Concentration on the Bursting Strength*

Results reveal from Table 1 and Fig.4. that the use of natural mordant, such as lemon juice, caused considerable changes in the bursting strength of cotton knitted fabric after it was dyed with eucalyptus leaf extract. Fabric that was not subjected to the treatment with the mordant had a bursting strength equal to 405 kPa. The amount of lemon juice had an influence on the bursting strength of fabric: the more juice used during the treatment, the higher the strength became. When the ratio of dye solution to lemon juice reached 1:0.1, the bursting strength increased to 443 kPa. The maximum strength of 511 kPa was registered at ratios of 1:0.2 and 1:0.3, which was almost 26.2% more than that of the untreated fabric.

Table 1 Bursting Strength Test Results

Dye solution to Lemon Juice ratios	Method & Testing Area	Bursting Strength (kPa)
Without lemon juice	ISO: 13938-2 Testing Area: 30.5 mm	405
1: 0.1		443
1: 0.2		511
1: 0.3		511
1: 0.4		477
1: 0.5		473

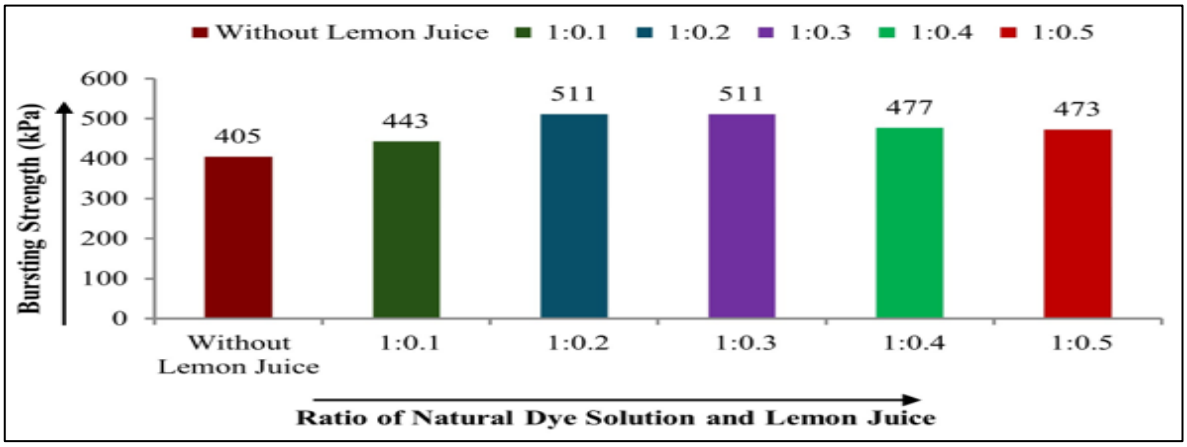

Fig 4 Effect of Variation of the Dye Solution to Lemon Juice Ratios on Bursting Strength.

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It seems that there is a connection between the increase in fabric strength due to the application of moderate amounts of lemon juice and the formation of stronger links between dyes and the cellulose of cotton. However, further increase in the amount of mordant had an adverse effect on fabric strength as the latter started declining: ratios of 1:0.4 and 1:0.5 resulted in bursting strength being 477 kPa and 473 kPa, respectively. The decrease in strength at higher concentrations of lemon juice may be due to the increased acidity, which could have harmed the cellulose structure and disrupted the fiber network. Even though the strength was reduced, all the treated samples still had higher bursting strength compared to the untreated fabric, indicating that using the right amount of lemon juice can enhance the fabric's performance. These findings suggest that maintaining a balanced concentration of lemon juice is important for achieving optimal mechanical properties in cotton fabric dyed with eucalyptus leaf extract, with the most effective results observed at ratios of 1:0.2 and 1:0.3.

- *Effect of Dye Solution to Lemon Juice Ratios on the Color Strength (k/s) Value*

The color strength of the eucalyptus-dyed cotton knitted fabric was highly affected by the quantity of lemon juice acting as a mordant on the fabric. The result has been shown in Table 2 and Fig.5. A sample without lemon juice showed a K/S value equal to 2.4. As lemon juice was included in increasing ratios, the K/S value was progressively increased to 2.7, 3.0, and 3.3 for dye solution to lemon juice ratios of 1:0.1, 1:0.2, and 1:0.3, respectively. The maximum value of color strength, 3.3, has been obtained from dyeing the fabric in the ratio of 1:0.3, where there is a 37.5% increase in the K/S value compared to the untreated sample. The increase in K/S value means more dye fixation and a stronger bond between eucalyptus dye and cotton fibers. In addition, a higher content of citric acid may have improved dye properties and helped to improve color properties. As the concentration of lemon juice has been increased beyond the optimal one, the K/S value has been reduced to 2.8 and 2.2 in the dye solution to lemon juice ratios of 1:0.4 and 1:0.5, respectively. It can be assumed that a high content of citric acid has caused excessive acidity, which has led to a weak bond between dye molecules and fiber. Thus, less dye has been fixed. Therefore, a moderate amount of lemon juice proved to be beneficial for achieving richer and more intense shades on eucalyptus-dyed cotton fabric. The optimum performance was observed at a ratio of 1:0.3, where the fabric developed the darkest appearance and showed the highest ability to absorb and retain the natural dye. This concentration appears to provide the ideal balance for maximizing color yield without adversely affecting the dyeing process.

Table 2 K/S Value Test Result

Dye Solution to Lemon Juice Ratios	Weave Length (nm)	K/S Value
Without lemon	400	2.4
1:0.1	410	2.7
1:0.2	420	3.0
1:0.3	425	3.3
1:0.4	413	2.8
1:0.5	397	2.2

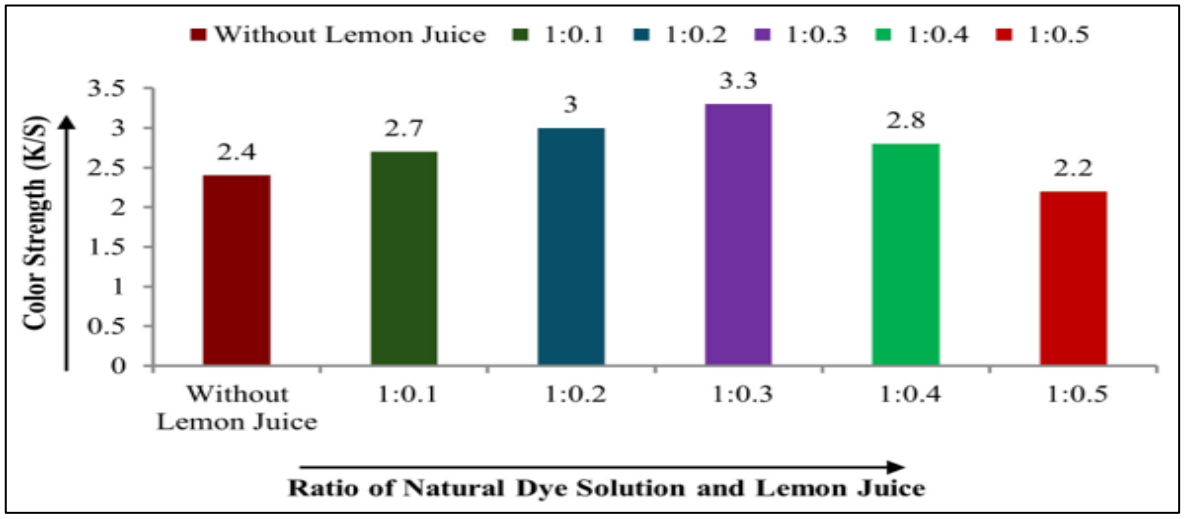

Fig 5 Effect of Variation of the Dye Solution to Lemon Juice Concentration on the Color Strength (K/S) Value.

IV. CONCLUSIONS

This study has shown the natural dyeing of cotton knitted fabric by using an environmentally friendly processing route with the extraction of dye solution from eucalyptus leaves. The dyeing process completely replaced the toxic synthetic mordants with the natural biomordant lemon juice. The exploration has shown that the dyed fabrics exhibited satisfactory color fastness properties, indicating that lemon juice can improve the color fastness to washing property from average to good. The application of lemon juice significantly enhanced the fixation of the natural

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colorants onto the cellulose structure of cotton, resulting in improved dye uptake during dyeing. The naturally dyed fabric has also been given good color fastness to light in the blue wool scale, with no significant effect of lemon juice. The results of bursting strength of dyed fabric indicate that it has reached a maximum level (from 405 to 511 kPa) at1:0.2 & 1:0.3 of the dye solution to lemon juice ratio, after which the strength has fallen. The color strength (K/S) value has been gradually increased up to 3.3 at the dye solution to lemon juice ratio of 1:0.3, and then declined to 2.2, which was lower than that of the dyed fabric without lemon juice. The findings highlighted the potential of combining eucalyptus leaf dye with lemon juice as a green and cost-effective dyeing system for cotton knitted single jersey fabrics, promoting the utilization of renewable plant-based resources. Here, it has been worked with lemon juice only, so to find out the dyeing properties and economic viability, future studies can be focused on finding other sources of natural mordants and dyes. Pre- and post-mordanting methods can be executed as well, and a mordant-containing source may be searched for to avoid mordanting.

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