PROGRESS
IN COLOR, COLORANTS AND COATINGS

available online @ www.pccc.icrc.ac.ir

Progress in Color Colorants Coating 20 (2027), 83-93

Ministry of Science, Research and Technology
Institute for Color Science & Technology

Green Coloration of Polyester Fabric through Auxiliary-Free Dyeing with Syzygium samarangense Leaf Extract

Md. Anamul Haque*, Md. Hanif Munshi, H. Bahar, S. Hossain
Department of Textile Engineering, Uttara University, P.O. Box: 1230, Dhaka, Bangladesh.

ARTICLE INFO

Article history:
Received: 21 Feb 2026
Final Revised: 10 June 2026
Accepted: 12 June 2026
Available online: 04 Jul 2026

Keywords:
Eco-friendly dyeing
Additive-free coloration
Bio-based material
Plant-based colorant

ABSTRACT

With the increasing demand for sustainable textile processing, plant-based colorants have emerged as promising alternatives to conventional synthetic dyes due to their renewable nature, biodegradability, and lower environmental impact. This study demonstrates auxiliary-free dyeing of 100 % polyester fabric using Syzygium samarangense leaf extract as a bio-based dye, achieving satisfactory coloration and fastness properties. The present study explores the dyeing potential of Syzygium samarangense leaf extract,a tannin-rich natural resource for the coloration of 100 % polyester fabric. The dyeing process was conducted using the exhaust method at 80, 90, and 100 °C for 60 minutes. The colorimetric evaluation revealed K/S values of 1.2, 1.3, and 1.1, indicating that dye uptake was most favorable at 90 °C. FTIR analysis confirmed that the Syzygium samarangense leaf extract adhered to the polyester surface through possible hydrogen bonding, enabling effective coloration even in the absence of auxiliaries. The dyed fabrics exhibited acceptable fastness properties to wash, light, perspiration, and rubbing. The findings suggest that Syzygium samarangense leaf extract offers a promising, sustainable route for auxiliary-free dyeing of polyester fabrics, aligning with the global drive toward greener textile processing. Prog Color Colorants Coat. 20 (2027), 83-93© Institute for Color Science and Technology.

1. Introduction

In recent years, increasing concerns about the environmental impact of textile dyeing have led to a growing interest in finding natural alternatives to synthetic dyes. While synthetic dyes have historically been the standard coloring agents in the textile industry, concerns over their adverse effects on human health, including allergies, carcinogenic effects, and mutagenic properties, have sparked significantly. The disposal of synthetic dyes causes severe environmental damage, with approximately 200,000 tons of these dyes being released into wastewater every year, thereby disrupting aquatic ecosystems and endangering biodiversity [1, 2]. Recent studies highlight that textile dyeing and finishing processes are among the most resource-intensive stages, consuming large amounts of water, energy, and chemicals, thereby contributing significantly to environmental pollution [3].

The textile dyeing industry is highly water-intensive, consuming 30-150 L of water per kg of fabric, depending on the process and fiber type, with some reports showing even higher ranges up to 250 L/kg in conventional dyeing [4]. On an industrial scale, a medium textile plant can consume approximately 1.6 million liters of water per day, which is used in dyeing and washing [5]. Around 80-90 % of input water is discharged as wastewater, making textile dyeing one of the largest contributors to industrial effluent generation [6]. In response, natural dyes derived from renewable biomass have gained increasing attention due to their

*Corresponding author: * anamul.haque@uttarauniversity.edu.bd
https://doi.org/10.30509/pccc.2026.167777.1498

biodegradability, low toxicity, and reduced environmental impact compared to synthetic dyes [7]. However, despite their ecological advantages, natural dyes face several limitations, including poor fibre affinity, low color yield, and inadequate fastness properties, which restrict their large-scale industrial application [8]. These environmental impacts have sparked the search for more eco-friendly alternatives, those derived from renewable biomass and agro-waste, which offer lower toxicity and better biodegradability [3, 7].

Among these alternatives, tree leaves have gained attention as valuable natural colorants due to their high content of tannins and flavonoids. These compounds form strong bonds with textile fibers, making tree leaf extracts an excellent substitute for synthetic dyes [9]. Despite the promising potential of plant-based dyes, many studies still depend on chemical treatments, such as synthetic mordants, to improve dye uptake and fastness properties. While these chemicals can enhance dyeing results, they also pose significant environmental concerns, as the toxic effluents produced are difficult to treat and can persist in the environment [10]. To overcome these limitations, recent advancements have focused on eco-friendly surface modification techniques such as plasma treatment, enzymatic processing, and ultrasonic methods, which enhance dye uptake without the use of harmful chemicals [8]. Ongoing research is exploring auxiliary-free and mordant-free dyeing approaches to improve sustainability while maintaining acceptable color performance. In response to these challenges, auxiliary-free dyeing methods have gained attention as a promising solution. Such methods aim to minimize environmental impact while delivering acceptable color performance, making them better aligned with current global sustainability goals [9]. One promising source of natural dye is *Syzygium samarangense*, a tropical plant known for its high content of polyphenols, including tannins. The tannins in its leaves can form possible hydrogen bonds with cellulose fiber, enhancing the fixation of the dye onto cotton fabric [11]. Previous research by Molino et al. [12] explored the use of *Syzygium samarangense* fruit peel as potential biowaste dyes. Although their study found that the wash-fastness of the dyed cotton fabrics was poor without the use of mordant. Kamal et al. [13] explored *Syzygium samarangense* leaf extract that eco-friendly, mordant-free dyeing of cotton and silk fabrics is feasible, where the presence of polyphenolic compounds contributes to acceptable coloration and fastness properties under sustainable conditions. Hossen et al. [14] utilized mango leaf extract for silk fabric dyeing revealed that natural mordants can effectively enhance color strength and fastness properties compared to metallic mordants, highlighting the role of plant-based tannin-rich extracts in improving dye fiber interactions in sustainable textile applications.

Polyester presents significant challenges for dyeing due to its hydrophobic nature, high crystallinity, and lack of reactive functional groups, which limit dye fiber interactions [15]. Recent research emphasizes that dye uptake in polyester primarily occurs through diffusion into amorphous regions at elevated temperatures, rather than through chemical bonding. This process is governed by weak intermolecular interactions such as van der Waals forces, with minimal contribution from hydrogen bonding due to the limited polarity of polyester chains [15]. Supporting studies on natural dyeing of polyester also confirm that dye molecules are physically entrapped within the fiber matrix, which directly affects dye fixation and fastness properties [16]. However, the potential of *Syzygium samarangense* as a natural textile dye, especially the application of its leaf extract on synthetic fibers such as polyester, remains largely underexplored. Despite these advancements, effective auxiliary-free dyeing of polyester with plant-derived dyes remains insufficiently explored.

This study aims to fill that gap by investigating the potential of *Syzygium samarangense* leaf extract for dyeing 100 % polyester fabric without the use of any auxiliaries, marking a significant step towards eco-friendly textile dyeing. The research focuses on evaluating the dyeing performance, including color strength, color difference, and fastness properties,and aims to contribute to the development of more sustainable and functional methods of textile coloration.

2. Experimental

2.1. Materials

For this study, commercially available scoured and bleached 100 % polyester single jersey knitted fabric with an areal density of 150 g/m² was sourced from Gildan Active Wear Ltd., Dhaka, Bangladesh. The *Syzygium samarangense* leaf extract used as a natural dye in this study was collected from Gazipur, Dhaka, Bangladesh. Distilled water was used both as the solvent for extracting the dye from the leaves and as the dyeing medium. For the soaping process, the soaping agent INDOCLEAN MFD, sourced from Hue and Chem Global Ltd., Bangladesh, was used to ensure proper cleaning and enhance the color fixation on the fabric.

2.2. Dye extraction

The leaves were first collected from the plant, rinsed thoroughly with distilled water, and then sun-dried for 8 hours. After the initial drying, the leaves were placed in a laboratory dryer at 80 °C for 10 minutes to remove any remaining moisture. Once dried, the leaves were ground into a fine powder using a blender to facilitate the extraction process [17]. To prepare the dye extract, 100 g of the powdered leaves was boiled in distilled water at 90 °C for 1 hour, with a powder-to-water ratio of 1:10. After boiling, the extract was filtered through filter paper and was ready to be used for dyeing the fabric [18].

2.3. Dyeing procedure

The dyeing solutions were prepared as outlined in Table 1. Polyester samples weighing 5 g each were dyed in a laboratory dyeing machine, manufactured by Xiamen Rapid Precision Machinery Co., Ltd., Taiwan, at three different temperatures: 80, 90, and 100 °C for 60 minutes using the prepared solutions [19]. Figure 1 illustrates the process curve for dyeing polyester fabrics with leaf extract. After dyeing, the bath was allowed to cool, and the liquor was drained.

For the soaping process, a bath was prepared with 2 % soaping agent, and the temperature was gradually raised to 70 °C. The temperature was maintained for 15 minutes before the bath was cooled and drained [20]. Finally, the dyed fabrics were dried at 80 °C for 5 minutes using laboratory mini dryer, also manufactured by Xiamen Rapid Precision Machinery Co., Ltd., Taiwan [21].

Table 1: Sample codes for the different conditions used for dyeing polyester fabrics using *Syzygium samarangense* leaf extract.

Sample code	Fabric type	Temperature
S0	Undyed	N/A
S1	Dyed	80 °C
S2	Dyed	90 °C
S3	Dyed	100 °C

Figure 1: Dyeing process flow for polyester fabrics using *Syzygium samarangense* leaf extract.

2.4. Characterization

2.4.1. Fourier-transform infrared (FTIR) spectroscopy analysis

Fourier-transform infrared (FTIR) spectroscopy (JASCO 4700, Japan) was used to examine the chemical properties of both dyed and undyed polyester fabrics. The analysis was performed in transmission mode, covering a spectral range from 4000 to 500 cm^{-1} [17, 22].

2.4.2. Assessment of color properties and characteristics

The color strength and color difference of the dyed fabrics were evaluated using a Datacolor 650 spectro-photometer. Shade depth, expressed as the K/S value, was calculated according to the Kubelka-Munk equation 1, where K represents the absorption coefficient, S the scattering coefficient, and R the reflectance of the dyed fabric [23, 24].

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

To assess the color difference, CIE LCh color coordinates were employed. The lightness of the fabric, ranging from black to white, is represented by the L* value on a scale from 0 to 100. In addition, the a* value indicates the redness–greenness axis, while the b* value corresponds to the yellowness–blueness axis. Furthermore, the color's brightness or dullness is quantified by the C* value, while the hue angle is represented by h*. The color difference of the dyed samples compared with the undyed sample was determined using the CIE LCh* color coordinates, as described in equation 2 [17].

$$(\Delta E)^2 = (\Delta L)^2 + (\Delta C)^2 + (\Delta h)^2 \quad (2)$$

2.4.3. Color retention characteristics

Wash fastness testing is very important for evaluating how well natural dyes on polyester fabrics resist fading during washing. This test ensures that the color remains intact through repeated washing, which is important for consumer satisfaction and the commercial success of naturally dyed polyester products. The wash fastness test was carried out according to the ISO 105-C06 method [9, 25]. The perspiration fastness test measures the resistance of dyed textiles to color changes or staining caused by sweat. This test was performed on all samples in accordance with the ISO 105-E04:2013 standard [26], assessing both acidic and alkaline sweat effects on the fabric. The rubbing fastness test determines the amount of color transfer from the surface of dyed fabrics to a standard test cloth when rubbed under both dry and wet conditions. This was conducted using the ISO 105-X12:2016 standard, with a crock meter [25].

Finally, light fastness testing is essential to assess the durability of the color on polyester fabrics dyed with natural dyes, as these dyes generally show less resistance to fading under sunlight or artificial light compared to synthetic dyes. The light fastness was evaluated according to the ISO 105-B02:2013 standard [27].

3. Results and Discussions

3.1. FTIR analysis

The FTIR spectra of polyester fabric before and after dyeing with *Syzygium samarangense* leaf extract show several noticeable changes in Figure 2, indicating successful dye adsorption onto the fiber surface without the use of auxiliaries. Untreated polyester displayed absorption bands characteristic of aromatic C–H stretching at 3081 cm^{-1}, ester carbonyl (C=O) stretching vibration in the range of 1715-1730 cm^{-1}, and asymmetric C–O–C stretching of the ester group at 1238 cm^{-1}. These modifications suggest possible hydrogen bonding between the tannin of the leaf extract and the ester groups of polyester, similar to interactions reported for other polyphenol-based natural dyes [7, 28].

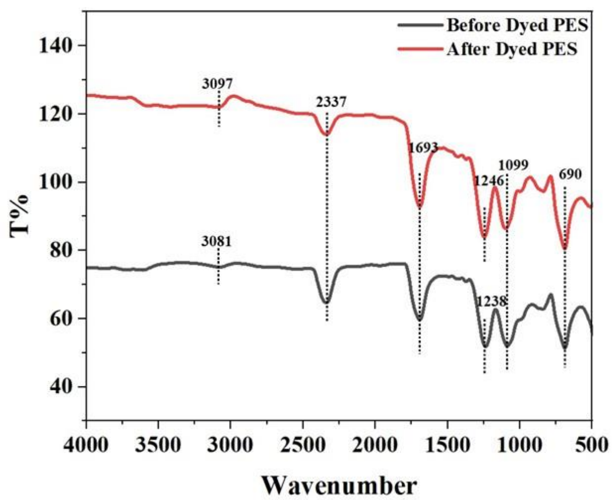

Figure 2: FTIR spectra of undyed and *Syzygium samarangense* leaf extract dyed polyester.

After dyeing, a broad band appeared at 3097 cm^{-1}, which is due to O-H stretching vibrations of hydroxyl-rich phytochemicals such as tannins and flavonoids present in the leaf extract [29]. The widening of this band is a sign of the establishment of intermolecular hydrogen bonding between the –OH groups of polyphenols and the carbonyl (C=O) groups of polyester. Moreover, the shift of the ester C–O stretching vibration from 1238 cm^{-1} to 1246 cm^{-1} indicates changes in the local chemical environment, probably due to dipole–dipole interactions between dye molecules and the polymer backbone. Also, the reduction and slight shifts of aromatic and carbonyl-related peaks (2337, 1693 cm^{-1}) in the dyed fabric further support the formation of surface-level interactions, which is expected for hydrophobic polyester dyed under aqueous, auxiliary-free conditions [30, 31]. The appearance of absorption around 690 cm^{-1} in the dyed sample also suggests enhanced aromatic stacking from phytochemicals present in *Syzygium samarangense,* consistent with previous findings on plant-derived anthocyanins and flavonoids binding to PET surfaces [32]. These spectral changes collectively confirm that the dye molecules adhered to the polyester surface through secondary interactions, enabling visible shade development despite the absence of carriers or dispersing agents. Figure 3 illustrates the proposed mechanism by which tannin-rich compounds present in *Syzygium samarangense* leaf extract interact with the polyester surface, primarily via hydrogen bonding and aromatic stacking, enabling effective dye attachment.

3.2. Color strength analysis

The color strength (K/S values) of polyester fabrics dyed with *Syzygium samarangense* (jamrul) leaf extract, as shown in Figure 4 where K/S values for the samples were 1.2 for S1, 1.3 for S2, and 1.1 for S3, indicating that the dye uptake from the jamrul leaf extract on 100 % polyester was highest at 90 °C, indicating the best between fiber swelling and dye penetration during the exhaust dyeing process. This optimal uptake supports the idea that higher dyeing temperatures improve the absorption of natural colorants into synthetic thermoplastic fibers [33, 34].

However, beyond a certain temperature (90 °C), the uptake begins to decrease, likely due to dye desorption, degradation, or reduced interaction between the dye and the fiber, as seen by the drop in uptake at 100 °C. While there is limited research on the use of jamrul extract for dyeing polyester, previous studies have shown that *Syzygium samarangense* (jamrul) is rich in tannins and flavonoids, which are known to contribute to strong dye-fiber interactions when applied to natural fibers [35]. These compounds are known to enhance dye fiber interactions by forming possible hydrogen bonds and complexes. For example, research on jamrul has shown that it contains a high level of phenolic compounds, which contribute to its dyeing potential [36], suggesting that jamrul extract holds strong potential for natural dyeing applications. While there is limited research on using jamrul extract for dyeing cotton or wool, our findings offer new evidence of its effectiveness on polyester. The K/S value of 1.3 highlights the challenges of dyeing hydrophobic polyester fibers with natural extracts without using mordants. Similar studies on other natural dyes for polyester report comparable dye uptake limits, unless auxiliaries are applied [37]. The data indicate that jamrul leaf extract can produce consistent and noticeable dyeing results on polyester at 90 °C, without the need for synthetic mordants.

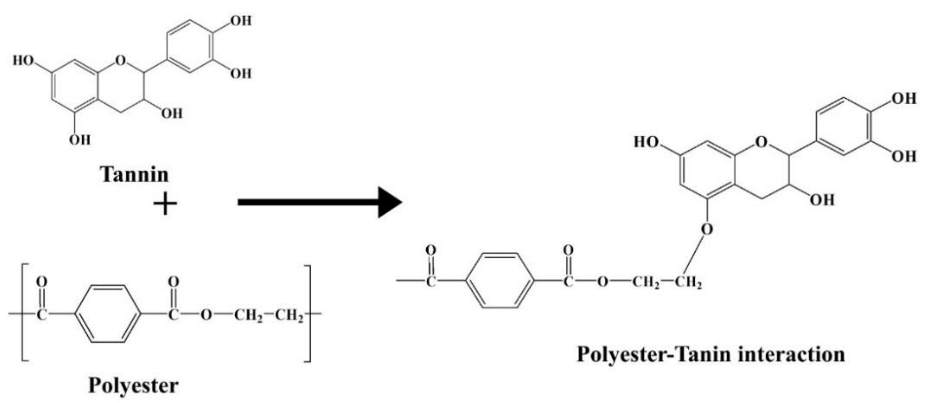

Figure 3: Possible bonding mechanics between the tannin of *Syzygium samarangense* leaf extract and polyester fabric.

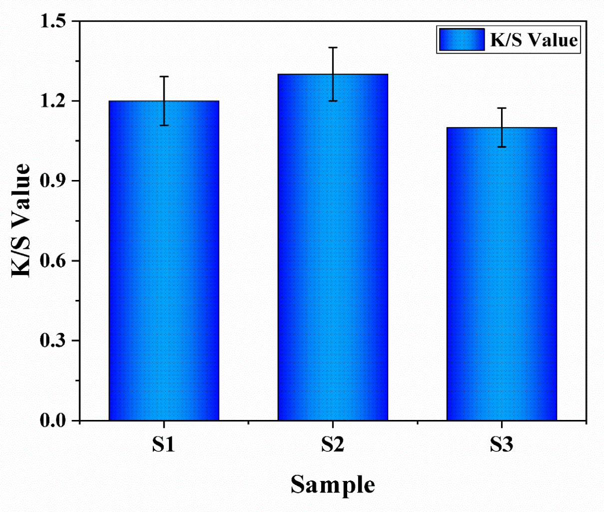

Figure 4: Color strength (K/S values) of polyester fabric dyed with *Syzygium samarangense* (jamrul) leaf extract.

3.3. Assessment of color differences using CMC

The CMC results for polyester dyed with *Syzygium samarangense* leaf extract,as shown in Table 2 a clear trend of increasing color difference (ΔE*) with higher fixation temperatures: S1 = 20.95, S2 = 23.30, and S3 = 24.26. This suggests that higher temperatures enhance dye uptake and color intensity, though it also leads to greater deviation from the original shade. The ΔL* values indicate that all samples become darker after dyeing, with the most pronounced darkening observed at S1 (80 °C), suggesting a stronger interaction between dye and fabric at this temperature.The increasing values of Δa* (red-green shift) and Δb* (yellow-blue shift) with temperature show that the fabric becomes more reddish and yellowish as the temperature rises, resulting in a warmer, more saturated tone. The increase in ΔC* (chroma) indicates higher color intensity, while Δh* (hue angle) shows a slight shift towards warmer hues.In conclusion, higher temperatures (90 and 100 °C) produce richer, more vibrant shades, making S3 (100 °C) ideal for applications requiring deep, saturated colors. However, the darker shade at S1 suggests that a balance between lightness and saturation should be considered depending on the desired color profile. These findings align with previous studies on natural dyeing of polyester, where ΔE* values typically range from 22 to 25 under similar conditions [16, 38, 39]. Figure 5 shows the shade card of undyed and dyed polyester fabric samples treated with jamrul leaves at different temperatures.

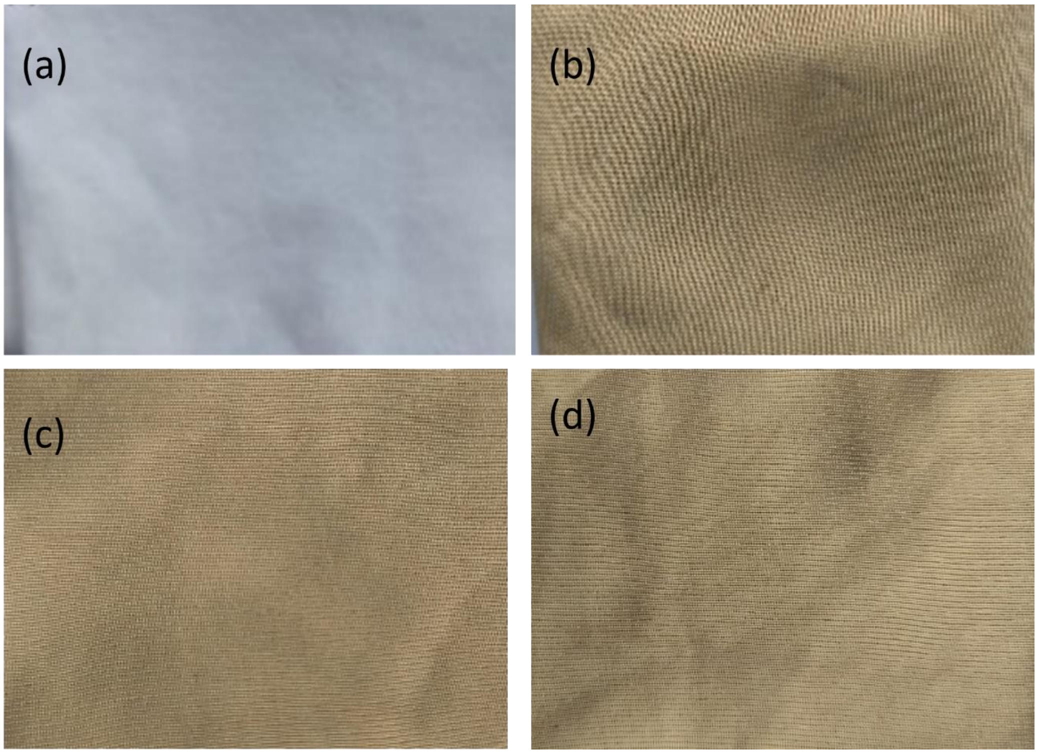

Figure 5: Shade card of undyed and dyed polyester fabric samples at different temperatures with jamrul leaves, where (a) to (d) sections represent the sample codes from S0 to S3, respectively.

Table 2: Color measurement committee (CMC) report of polyester fabric dyed with *Syzygium samarangense* leaves extract.

Sample code	ΔE*	ΔL*	Δa*	Δb*	ΔC*	Δh*
S1	20.95	-25.43	5.61	12.94	13.82	-2.85
S2	23.30	-21.80	6.96	14.79	16.02	-3.24
S3	24.26	-21.94	7.10	15.54	16.77	-3.26

Table 3: Evaluation results of wash fastness for the dyed polyester fabrics.

Sample code	Grading for color change	Grading for color staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
S1	4	4-5	4-5	4	4-5	4	4
S2	4-5	4-5	4-5	4-5	4-5	4	4-5
S3	4-5	4-5	4-5	4-5	4-5	4	4-5

3.4. Assessment of color fastness

3.4.1. Wash fastness evaluation

The wash-fastness results presented in Table 3 demonstrate consistently high performance for all dyed samples (S1, S2, and S3). Each sample achieved color-change ratings of 4-5 and staining ratings ranging from 4 to 4-5 across all multifiber components, including acetate, cotton, nylon, polyester, acrylic, and wool. These ratings indicate that the dye showed strong resistance to washing, with minimal color loss and negligible staining on adjacent fibers. Among the three samples, S2 exhibited slightly superior performance, with uniform 4–5 staining grades across most fibers, suggesting that the dyeing condition associated with S2 enabled more effective dye fixation. This behavior is consistent with natural dye, where an optimized dyeing temperature enhances dye fiber interactions, promotes diffusion into the fiber matrix, and reduces dye desorption during washing [31]. The high wash-fastness across S1–S3 suggests that the extracted dye formed stable interactions, likely through possible hydrogen bonding and multipoint interactions facilitated by phenolic and tannin-based compounds naturally present in dye sources [13]. Such compounds are well-known for their ability to anchor effectively onto cellulose, resulting in improved stability during washing. The excellent wash fastness observed in this study is comparable to previous findings on natural dyes derived from *Syzygium samarangense* leaf extract [13]. Thus, our results mark a meaningful step forward in demonstrating that jamrul leaf extract can yield commercially acceptable wash fastness on textile fibre, especially under optimized conditions.

3.4.2. Perspiration fastness evaluation

The perspiration fastness results (both acidic and alkaline) in Table 4 show consistently high ratings of 4-5 for color change and staining across all tested fibre types for S1, S2, and S3. This strong performance indicates that the jamrul leaf extract secures effective fixation on the fibres, resisting color transfer even under sweat conditions. The fact that each sample achieved 4-5 grade suggests that the extract's bonding to the fibre is durable. The optimum dyeing temperature of 90 °C (S2), which earlier yielded the highest K/S value, also shows excellent fastness under perspiration, confirming that this condition offers the best balance of dye uptake and durability. The excellent perspiration fastness results (rating 4-5) observed for all samples (S1, S2, and S3) are consistent with previously reported findings for *Syzygium samarangense*leaf extract–based dyeing systems, where dyed fabrics exhibited very good to excellent fastness (4-5) under both acidic and alkaline perspiration conditions [13]. This indicates that the phenolic-rich dye molecules form stable interactions with the fiber, minimizing color change and staining. A similar level of perspiration fastness (4-5) has also been reported in polyester dyeing systems using disperse-type dyes, where strong dye–fiber affinity and diffusion into the amorphous regions of polyester result in minimal dye transfer under sweat conditions [40]. In the present study, the optimum dyeing temperature of

Table 4: Test results for the color fastness of dyed polyester samples against perspiration in both acidic and alkaline conditions.

Sample code	Color fastness to perspiration (acidic)							Color fastness to perspiration (alkaline)						
	Color change	Grading for color staining						Color change	Grading for color staining					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
S1	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
S2	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5
S3	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5	4-5

90 °C (S2), which produced the highest K/S value, also demonstrated superior perspiration fastness, confirming that enhanced dye uptake at this temperature leads to stronger dye entrapment and improved resistance to color transfer. This agreement with previous studies highlights that both high dye affinity and proper dyeing conditions are important factors governing perspiration fastness performance.

3.4.3. Evaluation of fastness to rubbing and light

The rubbing fastness results in Table 5 show that the dyed samples exhibited moderate to good resistance to mechanical abrasion. Under dry rubbing, samples S2 and S3 achieved ratings of 3-4, indicating better surface dye fixation, while S1 showed a slightly lower rating of 3. Wet rubbing performance followed a similar pattern: both S2 and S3 obtained a grade of 3, whereas S1 recorded a slightly weaker value of 2-3, reflecting the greater tendency of natural dyes to loosen under moisture-assisted friction. These results collectively suggest that the dyeing condition asso-ciated with S2 promotes slightly stronger dye-fiber interactions, consistent with its earlier superior color strength and wash-fastness behavior.

The light fastness of the dyed samples was com-paratively moderate, with ratings of 3 for S1 and S3 and 3-4 for S2, indicating fair resistance to fading. A similar trend has been reported in studies using *Syzygium samarangense* leaf extract, where dyed fabrics exhibited light fastness ratings in the range of 3-4, confirming the limited photostability of phenolic-rich natural dyes. This behavior is widely attributed to the susceptibility of flavonoids and tannins to UV-induced degradation, leading to gradual color fading under light exposure [13]. Comparable findings have also been observed in polyester dyeing systems, where natural dyes generally show lower light fastness compared to washing or perspiration fastness due to the photochemical instability of chromophoric groups [38]. In the present study, the slightly improved light fastness of S2 (3-4) at 90 °C corresponds with its higher K/S value, suggesting that enhanced dye uptake and better dye entrapment contribute to marginal improvements in photostability. These findings are consistent with earlier natural dye studies, which identify light fastness as the most critical limitation of plant-based colorants unless stabilization strategies are applied. Previous research demonstrates that the incorporation of bio-mordants, natural UV absorbers (e.g., flavonoid-rich extracts), or antioxidant finishes can significantly improve resistance to light-induced fading by reducing photo-oxidative degrada-tion and enhancing dye–fiber interactions.

Table 5: Evaluation outcomes of color fastness to rubbing and light of dyed polyester fabrics.

Sample code	Grading for color fastness to rubbing		Grading for color fastness to light
	Dry	Wet	
S1	3	2-3	3
S2	3-4	3	3
S3	3-4	3	2-3

4. Conclusion

In conclusion, this study demonstrates the potential of *Syzygium samarangense* leaf extract as an effective, eco-friendly alternative to conventional synthetic dyes for the coloration of 100 % polyester fabric. The use of this tannin-rich natural resource offers a promising auxiliary-free dyeing approach, aligning with the growing global focus on environmental sustainability. The dyeing process, conducted at temperatures of 80, 90, and 100 °C, showed the best dye uptake at 90 °C, with satisfactory color strength (K/S values) and favorable interactions between the dye molecules and polyester fibers, as confirmed by FTIR analysis. Additionally, the dyed fabrics exhibited acceptable fastness to washing, water, light, perspiration, and rubbing. However, some limitations were observed, particularly in light and rubbing fastness, which did not achieve the same level of durability as other properties. To address these challenges, Future research should focus on improving dye fixation on hydrophobic polyester through eco-friendly surface modification and bio-based carriers, along with the use of locally available bio-mordants derived from plant and agricultural resources to enhance dye–fiber interaction while reducing reliance on metallic salts. In addition, scalability studies are required to assess industrial feasibility in terms of energy consumption, cost efficiency, wastewater management, and process optimization. Further work should also evaluate long-term durability under repeated washing, UV exposure, and abrasion conditions to ensure practical performance. Moreover, the exploration of agrowaste as sustainable dye sources, particularly in Bangladesh, offers strong potential for resource valorization and environmentally friendly textile coloration systems.This study supports the use of *Syzygium samarangense* leaf extract as a promising, multifunctional bio-based dye for sustainable textile processing, contributing to greener practices in the dyeing industry and minimizing its chemical footprint.

5. References

1. Khatun MH, Mostafa MG. Phytochemical screening and extraction of natural dye from leaves of Polyalthia longifolia and its application on silk fabric. J. Life Earth Sci. 2019; 14:87-92. https://doi.org/J. Life Earth Sci., Vol. 14: 87-92, 201.
2. Khatun MH, Mostafa MG. Optimization of dyeing process of natural dye extracted from Polyalthia longifolia leaves on silk and cotton fabrics. J. Nat. Fibers. 2022;19(16):12996-13011. https://doi.org/10.1080/15440478.2022.2081281.
3. Pizzicato B, Pacifico S, Cayuela D, Mijas G, Riba-Moliner M. Advancements in sustainable natural dyes for textile applications: a review. Molecules. 2023;28 (16):5954. https://doi.org/10.3390/molecules28165954
4. Arastou K, Hosseinzadeh A, Jamshidi S, Tafazzoli P. Grey water and carbon footprint of textile industry: A case study. Ain Shams Eng. J. 2025;16(10):103593. https://doi.org/10.1016/j.asej.2025.103593.
5. Kant R. Textile dyeing industry an environmental hazard. Nat. Sci. 2012;4(1):22-6. https://doi.org/10.4236/ns.2012.41004.
6. Espinosa M, Afonso C, Saraiva B, Vione D, Fernandes A. Textile Wastewater Treatment by Membrane and Electrooxidation Processes: A Critical Review. Clean Technol. 2026; 8(1):9. https://doi.org/10.3390/cleantechnol8010009.
7. Uddin MA, Rahman MM, Haque AN, Smriti SA, Datta E, Farzana N, Chowdhury S, Haider J, Sayem AS. Textile colouration with natural colourants: a review. J. Clean. Prod. 2022; 349:131489. https://doi.org/10.1016/j.jclepro.2022.131489.
8. Haji A, Naebe M. Cleaner dyeing of textiles using plasma treatment and natural dyes: A review. J. Clean. Prod. 2020; 265:121866. https://doi.org/10.1016/j.jclepro.2020.121866.
9. Lambrecht L, Capablanca L, Bou-Belda E, Montava, I, Díaz-García P, Gisbert-Payá J. Enhancing polyphenols and tannins concentration on cotton dyed with red tea. Sustainability. 2023;15(4):3062. https://doi.org/10.3390/su15043062.
10. Yahaya, I., Gyasi, S. F., Hamadu, A. Phytochemical screening of bioactive compounds and antimicrobial activity of different extracts of Syzygium samarangense leaves. Pharmacol. Res. Nat. Prod. 2024;4:100059. https://doi.org/10.1016/j.prenap.2024.100059.
11. Abbas SK, Aneesa M, Jaseena A. Characterization and therapeutic potential of syzygiumCumini: A review on sources, morphology and future research. Saudi J Med Pharm Sci. 2024; 10(12): 929-946. https://doi.org/10.36348/sjmps.2024.v10i12.009.
12. Molino RJEJ, Rellin KFB, Nellas RB, Junio HA. Sustainable hues: Exploring the molecular palette of biowaste dyes through LC-MS metabolomics. Molecules. 2021;26(21):6645. https://doi.org/10.3390/molecules26216645.
13. Kamal SA, Hossain S, Arju SN, Kader A. Natural Dyeing of Cotton and Silk Textiles With Syzygium samarangense Leaf Extract: An Eco-friendly and Mordant-Free Approach. J. Chem. 2026;2026(1): 7002037. https://doi.org/10.1155/joch/7002037.
14. Hossen MR, Sayam S, Akter S. Sustainable dyeing of silk fabric with mango leaf extract: comparative

assessment of natural and metallic mordants on colorimetric and fastness properties. Prog. Color Colorants Coat. 2026; 19(2): 231-245. https://doi.org/10.30509/pccc.2025.167632.1433.
15. Moges G, Pawlos M, Ademasu Y, Tesfaye T. A review of exploring ionic and nonionic dyeing of polyester: sustainable solutions and applications. Text. Res. J. 2025;95(19-20): 2500-2515. https://doi.org/10.1177/00405175251322133.
16. Liman ML, Islam MT, Hossain MM, Sarker P. Sustainable dyeing mechanism of polyester with natural dye extracted from watermelon and their UV protective characteristics. Fibers and Polymers. 2020; 21(10):2301-2313. https://doi.org/10.1007/s12221-020-1135-7.
17. Bhuiyan, M. R., Bakkar, A., Ali, A., Uddin, M. N., Talha, A. R., Mohammad, R. M. Synergistic effect of henna and betel leaf extract on dyeing and anti-microbial performance of silk fabric. Fiber Poly. 2024; 25(7):2683-2693.https://doi.org/10.1007/s12221-024-00595-4.
18. Adeel S, Ahmad S, Habib N, Saif MJ, Batool F, Aftab M. Environmental friendly pollution free bio-dyeing of wool with haarsinghar (Coral Jasmine) flower extract. Environ Sci Pollut Res. 2023; 30(5): 12453-12465. https://doi.org/10.1007/s11356-022-22992-z.
19. Radei S, Carrión-Fité FJ, Ardanuy M, Canal JM. Kinetics of low temperature polyester dyeing with high molecular weight disperse dyes by solvent microemulsion and agrosourced auxiliaries. Polymers. 2018;10(2):200. https://doi.org/10.3390/polym10020200.
20. Rehman A, Irfan M, Hameed A, Saif MJ, Qayyum MA, Farooq T. Chemical-free dyeing of cotton with functional natural dye: A pollution-free and cleaner production approach. Front Environ Sci. 2022;10: 848245. https://doi.org/10.3389/fenvs.2022.848245.
21. Haque MA, Omio MA, Saha R. Sustainable chemical-free dyeing of cotton-polyester blended (CVC) fabric with punica granatum extracts: a green approach. Prog. Color Colorants Coat. 2026;19(3):317-27. https://doi.org/10.30509/pccc.2025.167652.1443.
22. Ji X, Zhao Z, Ren Y, Xu F, Liu J. Dyeing properties, color gamut, and color evaluation of cotton fabrics dyed with Phellodendronamurenserupr. (amur cork tree bark). Molecules. 2023; 28(5): 2220. https://doi.org/10.3390/molecules28052220.
23. Vashist P, School S, Basak S, Ali W. Bark extracts as multifunctional finishing agents for technical textiles: a scientific review. AATCC J. Res. 2021; 8(2): 26-37. https://doi.org/10.14504/ajr.8.2.4.
24. Sivajiganesan S. Eco-friendly natural dye from bark of Acacia leucophloea for dyeing of cotton fabric using different temperature and mordant. Asian J. Res. Chem. 2017; 10(1): 1-5. https://doi.org/10.5958/0974-4150.2017.00001.3.
25. Freymann E, Carvalho S, Garbe LA, Dwi Ghazhelia D, Hobaiter C, Huffman MA, Schultz F. Pharmacological and behavioral investigation of putative self-medicative plants in Budongo chimpanzee diets. PLoS One. 2024; 19(6): e0305219. https://doi.org/10.1371/journal.pone.0305219.
26. Habib, N., Adeel, S., Ali, F., Amin, N., & Khan, S. R. Environmental friendly sustainable application of plant-based mordants for cotton dyeing using Arjun bark-based natural colorant. Environ Sci Pollut Res. 2021;28(38):54041-54047.https://doi.org/10.1007/s11356-021-14536-8
27. Rahman MM, Kim M, Youm K, Kumar S, Koh J, Hong KH. Sustainable one-bath natural dyeing of cotton fabric using turmeric root extract and chitosan biomordant. J Clean Prod. 2023;382:135303. https://doi.org/10.1016/j.jclepro.2022.135303.
28. Samanta AK, Agarwal P. Application of natural dyes on textiles. Indian J Fibre Text Res. 2009 34(4): 384-99. https://doi.org/Vol. 34, December 2009, pp. 384-399.
29. Kainat S, Gilani SR, Asad F, Khalid MZ, Khalid W, Ranjha MM, Bangar SP, Lorenzo JM. Determination and comparison of phytochemicals, phenolics, and flavonoids in Solanum lycopersicum using FTIR spectroscopy. Food Anal Methods. 2022; 15(11): 2931-9.
30. Elnagar K, Abou Elmaaty T, Raouf S. Dyeing of polyester and polyamide synthetic fabrics with natural dyes using ecofriendly technique. J Text. 2014; (1): 363079. https://doi.org/10.1155/2014/363079.
31. Rahman Bhuiyan MA, Ali A, Islam A, Hannan MA, Fijul Kabir SM, Islam MN. Coloration of polyester fiber with natural dye henna (Lawsonia inermis L.) without using mordant: a new approach towards a cleaner production. Fash Text. 2018; 5(1):2. https://doi.org/10.1186/s40691-017-0121-1
32. Siemińska-Kuczer A, Szymańska-Chargot M, Zdunek A. Recent advances in interactions between poly-phenols and plant cell wall polysaccharides as studied using an adsorption technique. Food Chem. 2022; 373:131487. https://doi.org/10.1016/j.foodchem.2021.131487.
33. Rápó E, Tonk S. Factors affecting synthetic dye adsorption; desorption studies: a review of results from the last five years (2017-2021). Molecules. 2021; 26(17):5419. https://doi.org/10.3390/molecules26175419
34. Burkinshaw SM. The roles of elevated temperature and carriers in the dyeing of polyester fibres using disperse dyes: Part 2. Analysis of conventional models of dye adsorption. Color Technol. 2024; 140(3): 317-92. https://doi.org/10.1111/cote.12716.
35. Tarigan C, Pramastya H, Insanu M, Fidrianny I. Syzygium samarangense: review of phytochemical compounds and pharmacological activities. Biointerface Res Appl Chem. 2022;12(2):2084-2107. https://doi.org/10.33263/BRIAC122.20842107.
36. Biswas T, Al-Amin M, Shoeb M, Hasan MK, Islam MN, Rhaman MM. Proximate and biological activity studies of Syzygiumsamarangense. Curr Res Biosci Biotechnol. 2021;3(1):172-177. https://doi.org/10.

5614/crbb.2021.3.1/NKTEH76W.
37. Viana TC, Pagnan CS. Ayres, E. Natural dyes in the design of textile: how to make them more competitive face to synthetic dyes. J Int Colour Assoc. 2015; 14: 14-27.
38. Nakpathom M, Somboon B, Narumol N, Mongkholrattanasit R. High temperature dyeing of PET fabric with natural colourants extracted from annatto seeds. Pigm Resin Technol. 2019; 48(2): 129-36. https://doi.org/10.1108/PRT-04-2018-0035.
39. Al Mamun, M. A., Hossain, M. M., & Khan, M. A. Dyeing of polyester fabric with natural colorants extracted from mahogany (Swieteniamahagoni) seed pods. J Eng Sci. 2020;11(1):37-42. https://doi.org/www2.kuet.ac.bd/JES/ISSN 2075-4914 (print); ISSN 2706-6835 (online).
40. Gaffer HE, Fouda MM, Khalifa ME. Synthesis of some novel 2-amino-5-arylazothiazole disperse dyes for dyeing polyester fabrics and their antimicrobial activity. Molecules. 2016;21(1):122. https://doi.org/10.3390/molecules21010122.

How to cite this article:
Anamul Haque Md, Hanif Munshi Md, Bahar H, Hossain S. Green Coloration of Polyester Fabric through Auxiliary-Free Dyeing with Syzygium samarangense Leaf Extract. Prog Color Colorants Coat. 2027;20(1):83-93. https://doi.org/10.30509/pccc. 2026.167777.1498.