Dyeing of 100% Cotton Fabric Using *Thunbergia Erecta* Flower Extract

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Abstract – *Natural dyes, derived from renewable plant, animal, and mineral sources, offer an eco-friendly alternative to synthetic dyes, which are often associated with environmental and health risks. This study investigates the use of Thunbergia erecta extracts on 100% cotton fabric, examining the effects of dyeing conditions, mordants, and fastness properties to evaluate its potential as a sustainable textile dye. Acidic extraction provided the highest intensity of color in the dye extract. Dyeing was conducted with and without mordants, specifically alum and ferrous sulfate, to evaluate their impact on the color fastness. Non-mordanted samples displayed good wash fastness, comparable to alum-mordanted samples, which also preserved the original hue of the Thunbergia erecta flower. In contrast, ferrous sulfate mordanted samples resulted in a brownish tone with reduced wash and light fastness due to photooxidation. Optimal wash fastness was achieved at a 1:20 material-to-liquor ratio and 60°C, with no significant improvement at higher temperatures. Light fastness remained low across all samples, reflecting the inherent limitations of anthocyanins under UV exposure. While Thunbergia erecta shows potential as a sustainable dye, particularly in terms of wash fastness, further treatments are needed to address its light stability limitations.*

Keywords*: Thunbergia Erecta, Natural Dye, Anthocyanins, Cotton dyeing, Mordants, Color fastness*

1 INTRODUCTION

Natural dyes have been used for centuries starting from ancient civilizations that utilized plants, animals, and minerals for coloring textiles, food, and other materials. The renewed interest in natural dyes comes from the harmful impacts of synthetic dyes, including toxic chemicals, high energy use, and environmental pollution. Synthetic dyes such as azo-based and benzidine-based dyes are known to be carcinogenic and toxic which pushes a towards eco-friendly and safer alternatives. Natural dyes derived from renewable resources are biodegradable and harmonize well with nature, which offer a sustainable option that aligns with modern ecological and health standards.

Thunbergia erecta plant is a member of the Acanthaceae family (Huxley et al.,1992).It is recognized as a robust, woody shrub which is native to tropical regions of Africa and South Asia. It possess a height of around six feet. The plant produces striking purple flowers with a distinctive yellow center. Fig.1 shows the Nilakantha Flower *(Thunbergia Erecta).*

Fig.1. Nilakantha Flower*(Thunbergia Erecta)*

The primary pigments in *Thunbergia erecta* flower is anthocyanins. They are water-soluble and responsible for its vibrant colors. Marpaung et al. (2020) mentioned that anthocyanins of *Thunbergia erecta* flower extract which extracted using ethanol, show significant color changes across pH levels, with the red flavylium cation dominating at low acidic pH (1–3), a colorless hemiketal form at pH 4–6, and blue or purple quinonoidal bases at higher pH values (7–10). This pH sensitivity highlights the potential of *Thunbergia erecta* as a natural dye. Especially in acidic conditions its pigments are most stable. According to Marpaung et al., 2020), at pH 3, the *Thunbergia erecta* extract demonstrated remarkable color stability which shows its suitability as a dye for acidic environments. At neutral or alkaline pH, the pigments rapidly degraded due to hydration and tautomerization reactions, significantly reducing their color stability. These findings highlight the importance of maintaining an acidic pH during the experiment, to preserve anthocyanin integrity during application on 100% cotton.

Compared to other anthocyanin-rich plants like *Clitoria ternatea* and *Melastoma malabathricum*, *Thunbergia erecta* shows a unique ability to display all colored anthocyanin species (red, purple, and blue) within one absorption spectrum. This behavior supports its versatility as a natural dye across various pH ranges, though its optimal performance lies in acidic conditions.

Mordants play an important role in natural dyeing. They work by forming a coordination complex with the dye molecules which then binds to the fibers. Therefore it improvs the color fastness of dyed fabric to washing, light, rubbing, and perspiration. Traditional mordants such as alum, ferrous sulfate, copper sulfate ($CuSO_4$), stannous chloride ($SnCl_2$), and potassium dichromate have been widely utilized to improve the fastness properties of natural dyes (Patil et.al, 2016, More et.al,2022, Grover & Patni 2011, Jothi , 2008) . Alum is effective for achieving bright and clear colors, while ferrous sulfate deepens hues, often producing darker shades. Copper sulfate dominates green and blue tones and stannous chloride brightens colors and enhancing overall vibrancy. Potassium dichromate, although effective in improving colorfastness, is less favored due to its environmental and health hazards. The choice of mordant significantly impacts the final hue, intensity, and fastness properties of the dyed fabric, making it a crucial factor in sustainable textile production. Based on the literature and experimental results, this research focused on utilizing two of these natural mordants, particularly alum and ferrous sulfate, to fix the dye extracted from *Thunbergia erecta* flowers on 100% cotton, aiming to achieve optimal colorfastness and eco-friendly dyeing outcomes.

In case of extraction of dyes from natural sources such as *Thunbergia erecta* it is required to consider the methods to ensure the stability and quality of the pigments. In their study on the extraction of natural dyes from rose flowers, (Junsongduang et al., 2020) highlighted the importance of optimizing extraction techniques to preserve the pigment's stability and color intensity. Similarly, other studies have explored various extraction methods, including aqueous, alkaline, acidic, and alcoholic techniques to maximize the yield and stability of natural dyes from plant sources. (Patil et al., 2016) It was reported that use of different solvent extraction methods, including aqueous and acidic processes, for extracting dyes from red rose petals, achieving strong coloration suitable for textile applications. (Prabhu and Bhute, 2012) It has also been found that the efficacy of ultrasonic extraction and supercritical fluid extraction, which are advanced techniques offering higher purity and efficiency in dye extraction. Selected extraction methods from these approaches were employed in this research, in order to ensure that the extracted dye would exhibit strong coloration and be suitable for textile applications.

Dyeing techniques are also important factors when the natural dyes are used for textile dyeing. The effectiveness of these methods depends on several factors. These factors include temperature, dye concentration, and the use of mordants. A research shows that natural dyes can achieve high color fastness with optimized dyeing techniques. This is particularly true when combined with appropriate mordants (Shahid et al., 2013). This research build on these findings which explores suitable dyeing parameters for *Thunbergia erecta* extracts. It also examines different mordants to achieve desirable fastness properties on cotton fabrics.

The potential of *Thunbergia erecta* as a natural dye for textiles is supported by studies on other anthocyanin-rich plants. Anthocyanin dyes from grape pomace have been used in textile dyeing. They produced red and violet shades on cotton fabric pre-mordanted with tannin. These dyes showed good water-fastness. Improvements in light-fastness were suggested for textile applications. The correlation between anthocyanin concentration and color depth shows the viability of natural dyes from plants for textiles. (Bechtold, 2007). Another study optimized anthocyanin extraction from purple sweet potatoes using an ultrasound-assisted two-phase system. This system used ammonium sulfate and ethanol aqueous solutions. It demonstrated eco-friendly dyeing for silk fabrics. The dyes showed improved color strength and fastness properties. Mordant dyeing methods significantly enhanced these properties compared to direct dyeing. (Yunjie, 2017).

Building on this foundation, the current study on *Thunbergia erecta* explores the specific properties of its pigments and their application in textile dyeing. The literature indicates that Thunbergia erecta has significant potential as a sustainable dye source, because of its rich anthocyanin content and the capability to produce a wide range of colors. This research aims to contribute to the development of eco-friendly textiles with good fastness properties, by optimizing extraction and dyeing processes.

2 METHODOLOGY

2.1 Materials

2.1.1 Textile Material

100% woven bleached cotton fabric was used for application of the dye extracted by *Thunbergia Erecta.*

2.1.2 Plant Material

Fresh *Thunbergia Erecta* flowers

2.1.3 Chemicals

Ethanol (50%) for extraction, 1% Citric acid solution for extraction, Buffer solutions (pH 1–12) for pH adjustments, Alum (Potassium aluminum sulfate) as a mordant, Ferrous sulfate as a mordant, , distilled water for for extraction, solution preparation and rinsing fabrics.

2.1.4 Lab Equipment

Borosilicate beakers, Measuring cylinders, Glass rods, Filter paper, Pipettes Weighing balance, Hot plate, Thermometer, Stopwatch

2.1.5 Testing Equipment

UV-Visible Spectrophotometer, Gray scale, Xenon Arc Light fastness tester, GyroWash machine

2.2 Preparation of *Thunbergia Erecta* petals for extraction

Thunbergia erecta flowers were carefully harvested from plants grown under uniform conditions to ensure consistency in the dyeing process. All flowers were collected from the same location and at the same stage of bloom to minimize variations in pigment concentrations. The selected flowers displayed a vibrant purple color, indicative of their peak maturity. Harvesting was conducted early in the morning when the flowers were freshest, and all flowers were processed within 24 hours of collection to preserve the integrity of the pigments. Fresh *Thunbergia erecta* flower petals were cut into small pieces and soaked in distilled water at a 50% w/w ratio at room temperature for 24 hours. The soaked flower solution was directly used for the extraction process. The solution was well sealed until the extraction, to avoid contamination. Fig.2 shows the arranged *Thunbergia Erecta* Flower Petals for Extraction.

Fig. 2 Arranged *Thunbergia Erecta* Flower Petals for Extraction

2.3 Extraction of the Dye from *Thunbergia Erecta*

The dye extraction was conducted using three different methods: aqueous, alcoholic (ethanol), and Acidic (Citric acid) extractions.

The soaked petals of *Thunbergia Erecta* were processed separately under the following parameters for each extraction method. The final extract solutions were filtered using a filter paper, to remove any solid particles so that it ensures a clear extract solution. Table 1 shows the dye extraction parameters used for the extraction from *Thunbergia Erecta* flower.

Table 1. Dye extraction parameters from *Thunbergia Erecta* flower

Extraction method	Liquor Concentration(%)	Raw Material to Liquor Ratio(g:ml)	Temperature (^0C)	Extraction Time(min)
Aqueous extraction	100% distilled water	1:10	100^0C	30 min
Alcoholic extraction	50% Ethanol	1:10	100^0C	30 min
Acidic extraction	1% Citric Acid	1:10	100^0C	30 min

2.4 Examination of color intensity of extracted dyes using UV visible spectrophotometer

2.4.1 Preparation of the extracted samples for UV-Visible spectrophotometer

All the dye extraction solutions were prepared to be used in the spectrophotometer, by diluting them by 25%, ensuring it falls within the measurable range of colour intensity in the spectrophotometer. Here, the amounts of light absorbed at the wavelengths between 200nm – 800nm were captured and these absorbency values were plotted in a graph.

2.4.2 Observe the color intensity of dye extractions by UV-Visible spectrophotometer

Ultraviolet-Visible (UV-Vis) spectrophotometry measures the absorbance of light in the ultraviolet (UV) and visible (Vis) regions of the electromagnetic spectrum, typically ranging from 200 nm to 800 nm. The absorbance spectrum can give an indication of the color intensity of the extracted dye. Higher absorbance at certain wavelengths corresponds to more intense coloration. According to the Beer Lambert Law, the color intensity of the dye extract is directly proportional to the amount of light absorbed by itself. UV-Visible spectrophotometer was used to test the color intensity of each dye extract mentioned above, by capturing their UV absorbance values at the wavelengths between 200nm – 800nm and plotting them in a graph. The dye extract which resulted the highest absorbency value was selected as the extract which has the highest color intensity and continued the dyeing process using the selected extraction method.

2.5 Treatment of 100% cotton fabrics with pre mordants

2.5.1 Pre Mordanting 100% Cotton with Alum [$KAl(SO_4)_2 \cdot 12H_2O$]

In a separate beaker, 1 liter of clean well water was heated to 90°C. Six grams of Alum and 40 grams of bleached cotton fabric were added to the heated water. The mixture was maintained at 90°C for 45 minutes to ensure thorough mordanting. Following this, the fabric was left to steep in the solution for 24 hours. After steeping, the fabric was rinsed with cold water and dried in the shade.

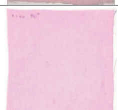
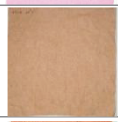
2.5.2 Pre Mordanting 100% Cotton with Ferrous Sulphate ($FeSO_4$)

In a beaker, 1 liter of clean well water was heated to 75°C. 0.8 grams of Ferrous sulfate and 40 grams of bleached cotton fabric were added to the water. The mixture was maintained at 75°C for 30 minutes to ensure effective mordanting. The fabric was then left to steep in the solution overnight. The following day, it was rinsed with cold water and dried in the shade.

2.6 Dyeing Process

The non-mordanted and pre-mordanted cotton samples were dyed with the selected best dye extract under different material-to-liquor ratios and temperature values. The temperature was raised from room temperature to the desired level over 30 min and maintained at the same level for 1 hour. The pH level was maintained at 3- 4 throughout the process. The dyeing process was performed in a borosilicate beaker. Following the dyeing process, the dyed fabrics were rinsed with cold water to remove the loosely attached dye and then air-dried under sunlight. The process parameters and corresponding sample images are summarized in the table below. Table 2 shows the dyeing process parameters and corresponding sample images.

Table 2 : Dyeing Process parameters and corresponding sample images

Sample Type	MLR	Temperature	Sample Image
Non-Mordanted	1:20	60°C	
Non-Mordanted	1:20	90°C	
Alum-Mordanted	1:10	60°C	
Alum-Mordanted	1:20	60°C	
Alum-Mordanted	1:40	60°C	
Alum-Mordanted	1:10	90°C	
Alum-Mordanted	1:20	90°C	
Alum-Mordanted	1:40	90°C	
$FeSO_4$ Mordanted	1:10	60°C	
$FeSO_4$ Mordanted	1:20	60°C	
$FeSO_4$ Mordanted	1:40	60°C	
$FeSO_4$ Mordanted	1:10	90°C	

$FeSO_4$ Mordanted	1:20	90°C	
$FeSO_4$ Mordanted	1:40	90°C	

2.7 Testing of dyed fabrics for color fastness

The dyed samples were tested for wash fastness and light fastness properties. Wash fastness tests were conducted following the ISO 105-C06 method, while light fastness tests adhered to AATCC -16 standards. The color change was evaluated using a gray scale.

3 RESULTS AND DISCUSSION

3.1 Evaluation of the dye extraction by spectrophotometry results

The UV absorbance values at the wavelengths between 200nm – 800nm of the dye extractions obtained from *Thunbergia Erecta* petals were plotted in a graph. Fig. 3 shows the absorbency values of different extractions showed in the spectrometer.

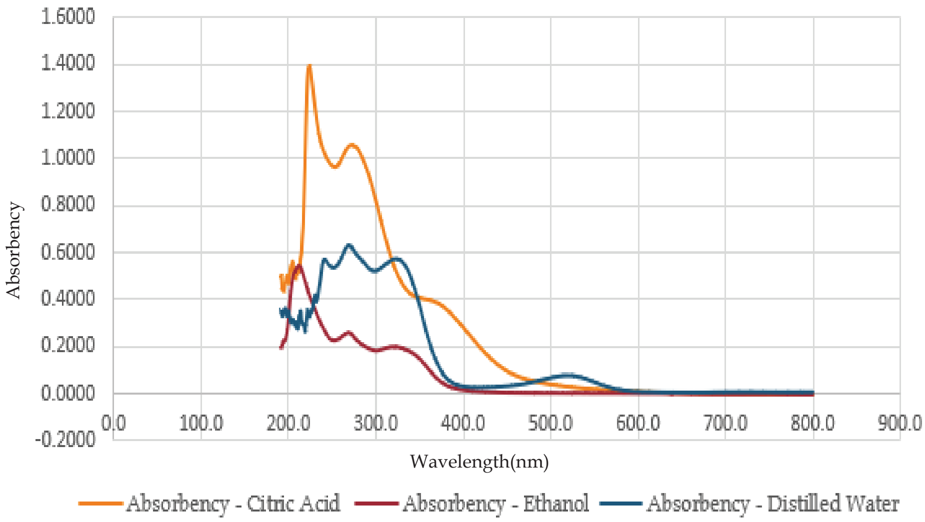


Fig. 3 : Absorbency Values of Different Extractions in Spectrometer

The highest absorbance peak of 1.4 at 223 nm in the UV region was noted for the acidic extraction, which does not fall within the visible spectrum. Normally, natural dye extractions can show peaks at both UV zone and visible zone in the spectrophotometer results. (Samanta et al . 2011). Anthocyanins, the primary pigments in *Thunbergia erecta*, have conjugated double bonds and aromatic rings, which enable strong absorption in both the UV and visible spectra. The acidic environment enhances anthocyanin stability and solubility, as these pigments are pH-sensitive and are more soluble and stable in acidic conditions. The peak at 200 nm indicates significant π-π* transitions in the anthocyanin structure, particularly in the benzoyl rings, which absorb UV light. This reports that acidic extraction supports a high concentration of anthocyanins, even if visible light absorption was less dominant.

3.2 Assess the color fastness of the dyed cotton samples with mordants

The wash fastness and the light fastness results of the dyed samples with mordants are shown in Fig. 4.

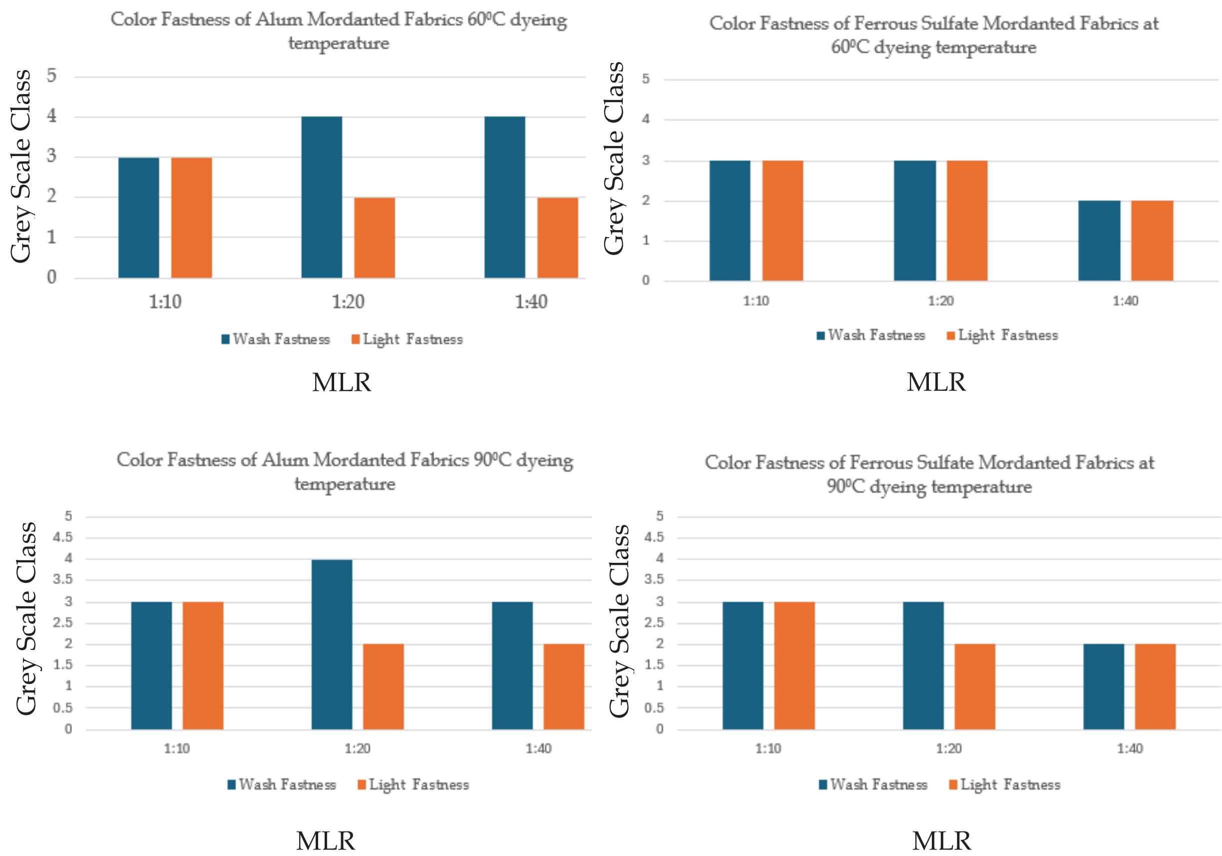


Fig.4 : Color Fastness results with different dyeing parameters with mordants

At 60^0C, higher wash fastness are given by material ratio 1:20 and 1:40 with Alum mordant, compared to the results obtained with Ferrous sulphate mordant. Gray scale 4 with Alum mordant indicated that the dyes samples have very acceptable wash fastness properties. With 90^0C dyeing temperature, again Alum modanted samples showed higher Gray scale result of 4 in wash fastness, compared to Ferrous sulphate mordanted dyed samples.

However, dyeing with high temperature is not economical in the mass scale production. Therefore, it is found that dyeing cotton materials with *Thunbergia erecta* natural dye using Alum mordant at 60^0C with 1: 20 MLR, gives very good wash fastness properties. Light fastness result gave as maximum as 3 according to the gray scale in all samples which dyed with 1:10 MLR. Thus, the same light fastness of value 3 has also given with Ferrous sulphate mordant, 1:20 MLR and 60^0C. This may happen because the bonds between ferrous ions and anthocyanins may weaken or degrade due to thermal stress at higher temperatures,. The value of 3 is in the minimum satisfactory level of light fastness and it has to be improved. However, use of Ferrous sulphate mordant may have a problem , as Fe is prone to photooxidation, which can degrade the anthocyanin pigments under light exposure (Tabata et al., 2021).

As a conclusion, it can be reported that dyeing cotton materials with *Thunbergia erecta* natural dye using Alum mordant at 60⁰C with 1: 20 MLR will give very good wash fastness properties. This may happen due to the aluminum ions (Al^{3+}) in Alum, which can bind to the hydroxyl groups (-OH) and other reactive sites in anthocyanins and also to the hydroxyl groups in cotton, forming stable metal-dye complexes. (Wallace et al. , 2015)

3.3 Evaluation of the effect of mordants on color fastness

The color fastness results of the fabrics dyes with non-mordants is given in Fig. 5.

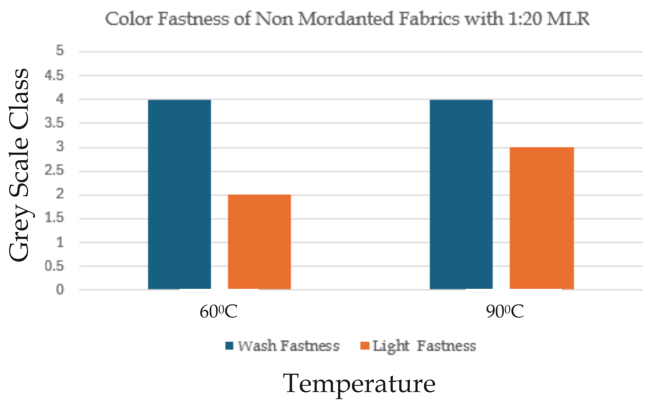


Fig. 5. Color Fastness results with different dyeing parameters without mordants

The main reason for using a one MLR value for non-mordanted samples is to create a consistent reference point for comparison. Non-mordanted samples have a straightforward dye-fibre interaction since there are no mordants altering the process. Testing with one MLR allows a clear focus on how the dye naturally behaves with the fabric under standard conditions. Here, a moderate MLR(1:20) was used, because very low MLRs(1:10) can lead to uneven dye distribution and higher MLR (1:40) can dilute the solution leading to less dye-fibre interaction.

According to the Figure 4 and 5, non-mordant samples have also shown the very much better wash fastness results same as the some of the mordanted samples with the wash fastness of value 4. But, the non-mordanted dyed samples at 90⁰C showed better light fastness properties with the scale value of 3 than 60⁰C dyed samples, as in Figure 5. Additionally, the final color of the ferrous sulfate mordanted samples appears brownish and does not prominently display the specific color of the *Thunbergia erecta* flower as shown in Table 2. Therefore, if non-mordanted dyeing of cotton with *Thunbergia erecta* natural dye is performed, it is recommended to use a temperature of 90°C with a 1:20 MLR.

3.4 Evaluation of the effect of Material-to-Liquor Ratio (MLR) and temperature on dyeing

Moderate MLR (1:20) generally showed higher wash fastness, resulting in darker shades. However, very low MLRs(1:10) can lead to uneven dye distribution. Higher MLR (1:40) may have diluted the dye solution, leading to lighter shades and possibly reducing wash and light fastness as less dye was available to bond with the fabric.

Samples dyed at 60°C and 90°C showed comparable wash fastness ratings, with no significant improvement observed at the higher temperature. This suggests that increasing the dyeing temperature does not enhance the wash durability of *Thunbergia erecta* extracts on cotton. Instead, it indicates that 60°C is sufficient to achieve stable bonding between the dye and fiber. There is no notable difference in light fastness between samples dyed at 60°C and 90°C. Both temperatures resulted in low light fastness. Therefore, high temperatures do not seem to strengthen anthocyanin bonds under light exposure and it is not economical in mass scale production as described previously.

4 CONCLUSION

This study focused on the use of Thunbergia erecta as a natural dye for 100% cotton fabric, examining various extraction methods, mordant types, dyeing conditions, and color fastness properties. Among the extraction techniques evaluated, acidic extraction yielded the highest color intensity, producing shades with different hues. This observation was further supported by absorbance values obtained through spectrophotometric analysis. However, it is recommended for future research to evaluate the CIELAB color coordinates of the dye extracts to provide more objective and quantitative confirmation of the visual assessments.

The results obtained show that both alum mordanted and non mordanted samples at 60°C with a 1:20 MLR have the best overall wash fastness, with a gray scale value of 4. It indicates a very good resistance to washing. This performance can be linked to the ability of aluminum ions to form stable complexes with anthocyanins and cotton fibers. Use of Ferrous sulfate mordant resulted a brownish hue that deviated from the specific color of *Thunbergia erecta* and showed lower light fastness, possibly due to the photooxidation of ferrous ions, which degrades anthocyanin stability under light exposure. Using lower and higher MLR must be avoided for this dyeing procedure, because, lower MLR will give uneven dyeing and dilution effects can be occurred with higher MLRs such as 1:40.

Finally, increasing the dyeing temperature to 90°C did not significantly enhance wash fastness, but may degrade anthocyanins. However, 60°C dyeing conditions give a more economical and effective temperature for sustainable dyeing practices in mass scale production. To obtain the minimum acceptable lightfastness, it has to use 1: 10 MLR with Alum or Ferrous mordant at 60^0C or dye without mordant but at 90^0C with 1:20 MLR.

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