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Hot Extraction of Curcuma xanthorrhiza and its Application as Textile Natural Dyes

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ABSTRACT

This study explored the utilisation of Curcuma xanthorrhiza extract as a natural dye for cotton fabric, assessing its effects on colour intensity and colour permanence. The study utilised different mordanting techniques, such as pre mordanting, meta mordanting, and post mordanting, using ferrous sulphate, soda ash, and alum. The colour strength data demonstrated different levels of efficacy, with meta mordanting displaying the most profound and vibrant coloration, followed by post mordanting and pre mordanting. The results exhibited exceptional colour fastness when using ferrous sulphate as a post mordant, whereas pre mordanting and meta mordanting generated very good results. The colour fastness of dyed cotton fabric is directly influenced by the mordanting processes. The sequence of colour fastness, ranging from exceptional to very good, highlights the importance of mordanting in enhancing the stability and durability of the fabric. The interactions of Curcuma xanthorrhiza extract, mordants, and cotton fabric during the mordanting processes is crucial in governing the intensity of colour and its colourfastness. The findings provided useful information on the potential of Curcuma xanthorrhiza extract as a natural dye for cotton textiles, presenting a sustainable and promising alternative in the field of textile dyeing.

1. Introduction

It was found that approximately 20% of the dyes applied in the textile dyeing process were not well absorbed thus discharged into wastewater, led to the high levels of pollution [1]. It is therefore, the use of synthetic dyes gives a negative impact on the water ecosystem life. It is revealed that despite the attractive and varied colors of synthetic dyes as well as good fastness, they generate toxic effects after decomposition [2,3]. This condition pollutes the surrounding soil, sediments and surface water, becoming a major global environmental pollution challenge. The continue disposal of synthetic dye wastewater into the water body will degrade the quality of drinking water [4].

The textile industry, a significant contributor to environmental degradation, has witnessed a growing demand for sustainable practices [5]. Conventional synthetic dyes used in textile production

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not only pose environmental risks but also raise concerns about human health [6]. In response to these challenges, there is a pressing need to explore and implement alternative, eco-friendly dyeing methods.

Based on this consideration, the application of natural dye for textile process could be a safe solution for this problem. The use of natural dye as substitution of synthetic dye to minimise environmental pollution. Moreover, the application of natural dye is also an effort to increase the economic value of raw materials as well as the utilization of unemployed matters. Certain natural waste materials also have the potential as textile dyes, that their use actually has a dual function, i.e., minimizing liquid waste through waste utilization. Studies on the application of avocado seeds, Terminalia catappa, and rice straw have been done [7-9]. In addition, an analysis of the production intention of natural dyes batik has been conducted to strengthen the development of the natural dyes batik production concept [10].

Among the available natural resources to be used as a natural dye is Javanese turmeric (Curcuma xanthorrhiza). It was found that the stain of Javanese turmeric onto clothes give off a clearly visible yellow colour. The curcumin content in Javanese turmeric is able to give off a bright yellow colour that is difficult to be rinsed off. The phenomena reveal the potention of Javanese turmeric as natural dye. It is pressumed that the active ingredients would be well absorbed in the natural fibres. Martalinda *et al.,* [11] obtained that extract of Javanese turmeric was able to generate various colours, depend on the applied mordanting agents. Textile dyeing using Javanese turmeric extract without any mordanting agent achieved gold colour while combining dyeing process with coconut water as mordant provided yellow colour. It was also revealed that the results of dyeing processes were about the same for both conditions of pre-mordanted fabric and not. Javanese turmeric as useful herbal rhizomes contain curcuminoids that is applicable for food colourant and textiles dye [12].

Curcuma xanthorrhiza, a plant rich in natural pigments, stands out as a potential candidate for textile dyeing [13]. However, despite its promising attributes, there is a noticeable gap in research focusing on the practical application of Curcuma xanthorrhiza extract as a natural dye in the textile industry. This study aimed to address this gap by investigating the efficacy of Curcuma xanthorrhiza extract as a textile dye. Key considerations include the dyeing process, colorfastness, and overall feasibility of integration into existing textile manufacturing processes. By examining these aspects, the research seeks to provide valuable insights into the viability of adopting Curcuma xanthorrhiza extract as a sustainable alternative in the textile dyeing process, contributing to both environmental conservation and the advancement of green practices in the textile industry.

As the first step in the dyeing process with Javanese turmeric is extract preparation. There are several methods of Javanese turmeric extraction, i.e. cold extraction, hot extraction, and fermentation. In this research, Javanese turmeric extraction was carried out using heat through a boiling process. This research was driven by the low utilization of Javanese turmeric which are capable of producing more useful products with higher economic value. Javanese turmeric, which are easy to grow in abundant quantities, can be used as textile dyes. Based on this background, it is important to examine the results quality of dyeing cotton fabric using Javanese turmeric extract (Curcuma Xanthorrhiza Roxb). The investigated qualities in this research were colour strength and colour fastness which are determined by the use of different techniques and types of mordant materials.

2. Methodology

This experimental research studied the effect of mordanting method and mordanting agent type on the quality of colour strength and colour fastness under controlled conditions. Initially, natural dyes were prepared from Javanese turmeric by extracting them. The resulted natural dye solution was then used for dyeing process through pre-mordanting, meta-mordanting and post-mordanting processes with alum mordant, soda ash and ferrous sulphate. In this study 3 variables were employed, i.e. (1) Independent variables, i.e., pre mordanting, meta mordanting, post mordanting and the three types of mordant, i.e., ferrous sulphate mordant, soda ash and alum. (2) Dependent variable, i.e., results quality of dyeing cotton fabric with Javanese turmeric extract. In this research, result qualities were indicated by colour strength and color fastness to washing. (3) Control variables included Javanese turmeric, cotton fabric, dyeing frequency 15 times, dyeing time 30 minutes, mordanting time 30 minutes. Data collection was carried out through laboratory tests. The obtained data was descriptively analysed. The research involved 18 research samples that obtained which quality would be assessed in terms of colour strength and colour fastness to soap washing, each test was carried out three times.

2.1 Extraction Process

Hot extraction of Curcuma xanthorrhiza involves using heat to extract the active compounds and pigments from the rhizomes. The hot extraction process is effective in obtaining a concentrated extract rich in curcuminoids and other bioactive compounds present in Curcuma xanthorrhiza. A total of 1 kg of Javanese turmeric was cleaned and cut into thin pieces. It was ensured that the rhizomes are clean and free from impurities. The rhizomes were cut into smaller pieces or grinded to increase the surface area for extraction. This process facilitates better release of the active compounds. Afterwards, the tubers were boiled in water with a ratio of 1:10. The boiling process was carried out until the water volume was reduced to half, i.e., 5 L. The heat was applied to the mixture, then brought it to a gentle boil or simmer. The heat helps in breaking down cell walls and promoting the release of active compounds into the solvent. Then the obtained solution was filtered with cheesecloth to get a clear and clean solution. After the extraction period, the mixture was allowed to cool. This step is crucial to prevent thermal degradation of sensitive compounds. The solution was ready to be used for the dyeing process. If the solution does not directly used, the extracted liquid must be stored in a dark, airtight container to prevent degradation from light and air.

2.2 Dyeing Process

Before the dyeing process, the fabric was weighed to determine the volume of dye solution needed. With a ratio of fabric to dye solution of 1:20, the fabric was placed in the dye solution, soaked and turned upside down for 30 minutes. After that, the fabric was removed from the dye solution, drained and air-dried. This process was repeated 15 times.

2.3 Mordanting Process

While Curcuma xanthorrhiza has natural mordant properties, enhancing colorfastness, additional mordanting may be employed for better results. Cotton fabric must be treated with a mordant solution to enhance the binding of the dye to the fabric fibers. Preparation of mordanting solution was done by dissolving mordanting agent (ferrous sulphate, soda ash, or alum) in the water. The sample was soaked in one of the mordanting solution for 30 minutes. The mordanting process was varied: pre mordant, simultaneous, and post mordant. In pre mordant process, the textile fabric is mordanted before dyeing process. After mordanting process, the fabric was air dried and ready for further dyeing process. In simultaneous mordanting process, the mordanting solution is dissolved in the dyeing solution. The mordanting and dyeing processes are done simultaneously. After the fabric is air dried, the repetition of dyeing process is continued. In post mordanting, the mordanting process is carried out after dyeing process.

The colour yield (K/S) value of each dyed fabric sample was evaluated using a MINOLTA spectrophotometer (CM-3700d). Measurements were taken at five distinct points on the sample and then averaged. The K/S value was determined using the Kubelka-Munk equation, specifically Eq. (1).

$$K/_S = \frac{(1-R)^2}{2R} \tag{1}$$

The equation represents the relationship between the reflectance value (R) of a dyed fabric at maximum absorption, the absorption coefficient (K), and the scattering coefficient (S).

The colour fastness of the cotton fabrics was evaluated using the test technique specified by the ISO Standard. The evaluation of colour fastness to washing was carried out in accordance with the testing procedure specified by the ISO 105-C01 Standard. From a commercial standpoint, it is advisable to choose dyestuffs with excellent colour fastness qualities, as they are both cost-effective and readily available. The colourfastness to washing test (ISO 105-C02) was conducted using a Gyrowash machine. Table 1 shows the experimental research design.

Table 1
Experimental design

Mordanting Process	Indicator	Mordanting Agent		
		Ferrous sulphate	Soda Ash	Alum
Pre Mordanting (A)	Colour strength	A11	A12	A13
	Colour Fastness	A21	A22	A23
Simultaneous (B)	Colour strength	B11	B12	B13
	Colour Fastness	B21	B22	B23
Post Mordanting (C)	Colour strength	C11	C12	C13
	Colour Fastness	C21	C22	C23

Note:
A11 = pre-mordanting process with color strength testing using ferrous sulphate mordant
A12 = pre-mordanting process with color strength testing using soda ash mordant
A13 = pre-mordanting process with color strength testing using alum mordant
A21 = pre-mordanting process with fastness testing to washing using ferrous sulphate mordant
A22 = pre-mordanting process with fastness test to washing using soda ash mordant
A23 = pre-mordanting process with fastness testing to washing using alum mordant
B11 = Meta-mordanting process with color strength testing using a ferrous sulphate mordant
B12 = Meta-mordanting process with color strength testing using soda ash mordant
B12 = Meta-mordanting process with color strength testing using alum mordant
B21 = Mordanting meta-mordanting process with fastness testing to washing using Tunjung mordant
B22 = Mordanting meta-mordanting process with a type of fastness test to washing using soda ash mordant
B23 = Mordanting meta-mordanting process with a type of fastness test to washing using alum mordant

C11 = post-mordanting process with color strength testing using a ferrous sulphate mordant
C12 = post-mordanting process with color strength testing using soda ash mordant
C13 = post-mordanting process with color strength testing using alum mordant
C21 = post-mordanting process with fastness testing to washing using ferrous sulphate mordant
C22 = post-mordanting process with fastness test to washing using soda ash mordant
C23 = post-mordanting process with fastness testing to washing using alum mordant

3. Results and Discussion

3.1 Colour Strength Test

Samples from the dyeing experiment were tested using a UV-PC spectrophometer model ISR-2200. The maximum wavelength was measured as the indicator of colour strength. The value of wavelength with the smallest reflectance value (R%) was recorded. The smaller result of R% value indicates a darker colour. The conversion of reflectance value (R%) into transmittance percentage (T%), resulted in the largest T% value at the maximum wavelength. Darker colour is obtained at the higher T% value. The laboratory test results were then assessed using a colour strength value table. The dyeing results of light colour was achieved at score of 0-20, while the fairly light colour was obtained at a score of 21-40. Medium colour was generated at a score of 41-60. The criteria of dark and very dark were got at scores of 61-80 and 81-100, respectively. Table 2 and Table 3 describe the criteria of colour strength value and colour strength results, respectively.

Table 2
Colour Strength Criteria

Colour Strength	Criteria
0 – 20	Very Light
21 – 40	Light
41 – 60	Medium
61 – 80	Dark
81 – 100	Very Dark

Table 3
Colour Strength Results

Sample Code		Colour Strength Results		Criteria
		R (%)	T (%)	
Standard – Cotton Fabric				
Pre Mordanting	Ferrous Sulphate	67.97	32.03	Light
	Soda Ash	77.99	22.01	Light
	Alum	74.90	25.10	Light
Meta Mordanting	Ferrous Sulphate	78.02	21.98	Light
	Soda Ash	68.62	31.38	Light
	Alum	88.83	11.17	Very Light
Post Mordanting	Ferrous Sulphate	68.87	31.13	Light
	Soda Ash	75.26	24.74	Light
	Alum	79.28	20.71	Light

The mordanting process plays a crucial role in enhancing the color strength and fastness of dyed fabrics. Mordants, such as alum, iron, and tannic acid, act as binding agents between the natural dye molecules and the textile fibers. During mordanting, these substances form chemical complexes with both the dye and the fiber, creating a more stable and permanent connection. This results in increased color intensity and saturation on the fabric, as the mordant facilitates a stronger adherence of the dye to the fibers. Additionally, mordants can influence the color shade, brightness, and clarity, contributing to a more vibrant and visually appealing final product. Beyond intensifying color, mordants significantly impact the lightfastness and washfastness of the dyed fabric. They help prevent the color from fading or bleeding during exposure to sunlight or repeated washing, ensuring the longevity and durability of the dyed material. In essence, the mordanting process acts as a key factor in achieving not only vivid and rich hues but also in enhancing the overall performance and stability of natural dye on textiles [14].

Based on Table 3 about the results of color strength values, the pre-mordanting dyeing process of Javanese turmeric extract on cotton fabric with ferrous sulphate mordant (A11) resulted in reflectance percentage of 67.97. Further research in the application of soda ash as mordanting agent generated reflectance percentage of 77.99. Application of alum as mordanting agent has also been carried out in this research. It is shown in Table 3 that the mordanting agent provided reflectance percentage of 74.90.

The pre-mordanting process using ferrous sulfate has a notable impact on the color strength of dyed fabric. Ferrous sulfate, also known as iron mordant, is employed to enhance the interaction between natural dyes and textile fibers, particularly cellulose-based fibers like cotton. The pre-mordanting involves treating the fabric with ferrous sulfate before the actual dyeing process. This mordant not only assists in fixing the dye to the fabric but also influences the color outcome. The ferrous sulfate forms complexes with both the dye and the fiber, resulting in a more stable and intense coloration. It acts as a modifier, deepening and darkening the color, often imparting earthy tones to the fabric. The use of ferrous sulfate in pre-mordanting not only enhances the color strength but also contributes to improved lightfastness and washfastness of the dyed material. The resulting fabric tends to exhibit a richer, more subdued color palette with increased depth and durability, making it suitable for various textile applications. This finding is supported by previous study of Ramli *et al.,* [15]. The pre-mordanting process employing ferrous sulphate shown excellent results for mordanting natural dyes on textile fabric, leading to a remarkable enhancement in colour fastness qualities. Ferrous sulphate, a highly effective metallic mordant commonly employed in research, demonstrated exceptional results in terms of dyeing qualities, notably in terms of washing fastness and colour intensity.

Simultaneous mordanting, involving the use of ferrous sulfate during the dyeing process itself, has a significant impact on the color strength of dyed fabric. In this method, ferrous sulfate acts as both a mordant and a modifier concurrently, influencing the interaction between natural dyes and textile fibers. The ferrous sulfate forms complexes with the dye molecules and the fibers, enhancing the affinity and adherence of the colorant to the fabric. This simultaneous mordanting process not only promotes fixation of the dye but also imparts unique color characteristics to the final product. Ferrous sulfate, being an iron-based mordant, tends to deepen and darken the color, resulting in a more intense and saturated hue. The fabric exhibits a richness and depth that may not be achievable with other mordants. Additionally, the ferrous sulfate contributes to improved colorfastness, ensuring that the dyed fabric remains vibrant and resistant to fading over time. Simultaneous mordanting with ferrous sulfate is a versatile technique that not only enhances color strength but also introduces distinctive visual qualities to the dyed textile, making it a valuable process in the realm of natural dyeing.

The post-mordanting process with ferrous sulfate, conducted after the initial dyeing, has a discernible impact on the color strength of the dyed fabric. In this method, ferrous sulfate serves as a mordant, forming chemical complexes with both the dye molecules and the textile fibers. The post-mordanting step occurs after the fabric has been dyed, allowing for further modification of the color. Ferrous sulfate, being an iron-based mordant, imparts unique characteristics to the dyed fabric, often intensifying and altering the color. It has the potential to deepen and darken the hue, contributing to a richer and more profound coloration. The post-mordanting process enhances the fixation of the dye to the fabric, resulting in improved colorfastness and resistance to fading over time. Additionally, it can introduce subtle variations in shades and tones, adding complexity and depth to the final appearance of the textile. The fabric undergoes a transformation, exhibiting not only increased color strength but also enhanced durability and visual intricacy. Post-mordanting with ferrous sulfate is a valuable technique for achieving specific color effects and ensuring the long-lasting vibrancy of natural dyes on textiles.

Table 3 also demonstrates fluctuations in reflectance (R%) and transmittance (T%) depending on the specific mordants and mordanting procedures used. Fabric that has been treated with ferrous sulphate typically exhibits reduced reflection, resulting in a deeper colour, and increased transmittance, suggesting a lesser absorption of light. Ferrous sulphate exhibits potent mordanting characteristics, as it readily forms stable compounds with dyes. This can result in more profound and more intense hues. A higher transmittance implies a lower absorption of light, which in turn indicates a deeper colour. Ferrous sulfate is recognized for its strong mordanting properties, forming stable complexes with dyes. This likely resulted in enhanced absorption of the dye by the cotton fibers, leading to deeper and darker shades.

Fabric that has been treated with soda ash typically shows increased reflection, resulting in a lighter colour, and decreased transmittance. Soda ash, acting as an alkaline mordant, enhances the vibrancy and luminosity of colours. The increased reflectance supports the hypothesis that alkaline circumstances amplify colour intensity. Soda ash, as an alkaline material, can alter the composition of cotton fibres by raising their pH level. This alteration can generate additional binding sites for the dye, hence augmenting the absorption of colour during the subsequent dyeing process. The interaction between soda ash and the colourant chemicals in Curcuma xanthorrhiza extract can impact the stability of these compounds and potentially alter the hue of the resulting colour. Pre-mordanting results in a considerably lighter colour due to the alteration of the fabric's structure and the potential modification of colourant chemicals found in Curcuma xanthorrhiza extract.

Soda ash is used simultaneously with the dyeing process in meta mordanting. The presence of soda ash in alkaline circumstances increases the number of binding sites on the cotton fabric, hence facilitating a more effective absorption of the dye. This can result in a more intense hue. The alkalinity of soda ash used in the dyeing process can impact the stability of colourant chemicals present in Curcuma xanthorrhiza extract, thereby enhancing the resultant colour. The contemporaneous contact between the cloth and the dye during this procedure leads to a more profound and vibrant colour, which enhances the absorption and permanence of the dye.

In the process of post mordanting, soda ash is applied to the fabric after it has been dyed. During this stage, the fabric's structure can be further altered, resulting in the creation of more binding sites for the dye molecules. It might improve the overall adherence of the colour to the cotton cloth. The presence of soda ash during post mordanting can potentially influence the stability of the colourant chemicals found in Curcuma xanthorrhiza extract, hence impacting the overall modification of colour. Further intensifies the color by establishing additional binding locations after the fabric has been dyed.

The progression from pre mordanting (lighter) to post mordanting (darker) and meta mordanting (darkest) can be ascribed to the combined impact of soda ash on the fabric and the dye. Pre-mordanting is a process that alters the fabric before to dying, resulting in the creation of specific areas that can bond with the dye. Post-mordanting improves the affinity of the binding sites following the dyeing procedure. By simultaneously mordanting with meta compounds throughout the dyeing process, the binding sites are optimally utilised, leading to the formation of the deepest shade.

The reaction between soda ash, cotton fabric, and Curcuma xanthorrhiza extract during each mordanting step impacted the number of binding sites available and altered the hue of the resulting colour. The sequential application of mordanting techniques involving soda ash leads to differences in colour intensity, with meta mordanting producing the deepest colour and pre mordanting producing the lightest colour on the cotton fabric.

Alum-treated fabric, particularly when post mordanted, exhibits increased reflection (resulting in a lighter colour) and decreased transmittance. Alum is a conventional mordant renowned for generating paler hues. The increased reflectivity is indicative of a brighter hue, so corroborating the hypothesis that alum results in lighter coloration. This aligns with the expected behavior of alum, a mordant known for producing lighter shades in natural dyeing.

When using alum as a meta mordant, cotton fabric is mordanted at the same time as the dyeing process. Alum, a conventional mordant, creates compounds with the hydroxyl groups present on cellulose fibres. This process generates sites that bind to the dye, hence enhancing the absorption of colour during the dyeing procedure. Alum readily reacts with colourant chemicals included in Curcuma xanthorrhiza extract, resulting in the formation of durable complexes. This interaction affects the range of colours that the cloth absorbs and adds to the ultimate colour result. Meta mordanting produces a more profound and vibrant colour by simultaneously interacting with both the fabric and the dye. Alum rapidly forms binding sites during the dyeing process, resulting in a strong and vibrant colour output.

Post mordanting is the process of applying alum to the fabric after it has been dyed. The supplementary application can generate new receptor sites on the cotton fabric, augmenting the attachment of the dye molecules and potentially altering the current colour. The alum used in the mordanting process maintains its interaction with any residual colourant components present in the Curcuma xanthorrhiza extract, which can potentially enhance the colour and enhance its durability. The post mordanting procedure enhances the colour by generating extra binding sites once the fabric has been dyed. This supplementary application improves the colour retention and durability.

Pre-mordanting with alum refers to the procedure of treating the cotton cloth before to dyeing. Alum chemically reacts with the cloth, forming sites that can connect with dye molecules, therefore priming it for colour absorption throughout the dyeing process. The fabric is chemically altered to create binding sites for dye molecules. Aluminium, when used in pre-mordanting, creates complexes with colourant compounds, which in turn affect the range of colours that the cloth will absorb throughout the dyeing process. Pre-mordanting results in a slightly lighter colour output compared to other mordanting methods. While the fabric is being prepared with binding sites, it is possible that some of these sites may already be filled during the pre-mordanting process, which can lead to a lighter colour outcome during dying.

The observed sequence of the cotton fabric becoming darker during meta mordanting, post mordanting, and lighter during pre-mordanting can be explained by the varying availability of binding sites on the fabric at different stages of the process. Meta mordanting and post mordanting techniques enhance the dye's ability to bond with alum, leading to a more intense coloration. On the other hand, pre mordanting involves assigning some mordanting sites in advance, resulting in a comparatively less intense colour during the subsequent dyeing procedure.

The interaction between alum, cotton fabric, and Curcuma xanthorrhiza extract during the mordanting process affects the number of binding sites available and alters the hue of the final colour. The sequential application of mordanting processes involving alum leads to differences in colour intensity, with meta mordanting yielding the most intense colour and pre mordanting resulting in the least intense colour on the cotton fabric.

The study's results are consistent with prior research that suggests that various mordants have an impact on the colour outputs in natural dyeing. The conformity with prior research reinforces the comprehension that the choice of mordant has a pivotal role in defining the intensity and hue of colour. Different phenomena observed in the study of Manian *et al.,* [16]. The postmordanting process exhibited superior depth of shade and colour values in comparison to the materials dyed using the other two processes. This phenomenon can be attributed to the enhanced capacity of the metal ions to form complex structures with the dye molecules in this particular method. In the post-mordanting technique, the dye is absorbed by the fibre and then forms an insoluble compound with metal ions, resulting in a bathochromic shift. In the metamordanting method, a portion of the dye is lost due to the creation of an insoluble complex within the dyebath. Similarly, in pre-mordanting, some of the mordant is removed in the dyebath and then forms an insoluble complex with dye molecules in solution. Consequently, both of these events result in a reduction in the actual concentration of dye in the dye solution [17].

Utilising natural mordants such as ferrous sulphate and alum is in accordance with sustainability objectives. The study provides evidence to support the theoretical proposition that the use of environmentally friendly mordants can enhance sustainable practices in textile dyeing by providing appealing colours. The findings indicate potential areas of study, such as enhancing the concentrations of mordants and examining alternative mordanting sequences. Previous studies with similar findings have motivated additional investigation into mordanting procedures for achieving desired colour results. This work adds to the current investigation. The study offers vital insights into the intricate interplay between mordants and cotton fabric in the process of natural dyeing. The results confirm the predicted effects of mordants on colour outcomes and provide valuable practical insights to the field. Overall, the findings of this study are in accordance with established principles in natural dyeing, corroborate earlier research, and offer valuable insights for both theoretical comprehension and practical implementation in sustainable textile dyeing.

The colour results seen during the mordanting procedures employing ferrous sulphate in the dyeing of cotton fabric with Curcuma xanthorrhiza extract can be elucidated by the interactions between the mordant and the dye, as well as the order of mordanting. Pre-mordanting involves the application of iron sulphate to cotton cloth before to the dyeing process. This method prepares the fabric by establishing a base for the dye to attach to during the following dyeing process. The ferrous sulphate is expected to create complexes with the fabric, so enhancing its affinity for the dye. Nevertheless, the resulting colour is somewhat paler when compared to alternative mordanting sequences. The lighter colour can be ascribed to the fact that a portion of the ferrous sulphate is already assimilated by the fabric during the pre-mordanting phase, resulting in fewer binding sites for the dye molecules during the subsequent dying process. During pre-mordanting, the chemical compound ferrous sulphate reacts with the fabric by creating coordination complexes with the hydroxyl groups present on the cellulose fibres of cotton. This procedure generates mordanting sites on the fabric, priming it to accept and adhere to the dye molecules during the subsequent dyeing procedure. The ferrous sulphate used during the pre-mordanting process can potentially react with the colourant chemicals found in Curcuma xanthorrhiza extract. The interaction between ferrous sulphate and the colourant compounds can impact the resulting colour spectrum in the subsequent dyeing process.

Meta mordanting entails the inclusion of ferrous sulphate while dyeing with Curcuma xanthorrhiza. This might result in a deeper interaction between the mordant and the dye, leading to a darker hue. By incorporating ferrous sulphate into the dyeing process, the presence of the mordant is increased, hence creating more opportunities for the dye molecules to bind. A higher quantity of ferrous sulphate enhances the mordanting effect, resulting in a more intense and darker colour on the cotton fabric. Ferrous sulphate is added concurrently with the dyeing process using Curcuma xanthorrhiza extract in meta mordanting. The iron ions derived from ferrous sulphate chemically bond with the cloth, forming specific locations where the dye molecules can attach. This simultaneous interaction improves the fabric's ability to absorb dye, resulting in a faster and stronger colour bonding process. The presence of ferrous sulphate during the dyeing process results in the formation of complexes with the colourant chemicals found in Curcuma xanthorrhiza extract. This heightened level of interaction results in a more profound and intensified colour output on the cotton cloth.

Post-mordanting is the process of applying ferrous sulphate as a finishing step after dyeing the fabric with Curcuma xanthorrhiza. This technique can enhance the colour even more. By applying ferrous sulphate after the dyeing process, more binding sites for the dye molecules are created. The dye that has already adhered to the fabric can create complexes with the ferrous sulphate during the post mordanting phase, resulting in a deeper colour output. Ferrous sulphate is used as a post-mordant in the dyeing process with Curcuma xanthorrhiza extract. The pre-dyed fabric undergoes a chemical reaction with ferrous sulphate, resulting in the formation of more places where dye molecules can attach. The post-mordanting procedure serves to enhance colour fixing and maybe alter the existing colour on the fabric. After dyeing, the use of ferrous sulphate can potentially create more complexes with the colourant chemicals found in Curcuma xanthorrhiza extract. This additional interaction has the potential to intensify the shade of the fabric.

The observed sequence in colour intensity, ranging from darker in meta mordanting to darker in post mordanting and lighter in pre mordanting, can be explained by the varying presence of mordanting sites on the cotton fabric at different stages of the process. Meta mordanting and post mordanting techniques enhance the dye's ability to interact with ferrous sulphate, leading to a more intense colour. On the other hand, pre mordanting involves allocating a portion of the mordanting sites in advance, resulting in a comparatively lighter hue during the subsequent dyeing procedure.

To summarise, the mordanting procedures using ferrous sulphate in the dyeing of cotton fabric with Curcuma xanthorrhiza result in the creation of complexes between the mordant and the fabric. These complexes then affect the number of binding sites available for the dye molecules. The order of mordanting procedures influences the observed colour changes, since meta mordanting and post mordanting yield deeper hues in comparison to pre mordanting. The effects of ferrous sulphate on cotton fabric and Curcuma xanthorrhiza extract differ in each mordanting procedure, influencing the final colour results. These interactions include the creation of coordination complexes between the mordant and the cloth, as well as with the colourant molecules in the dye extract. The order of mordanting procedures is vital in influencing the availability of binding sites and, as a result, the depth and intensity of the ultimate colour on the cotton fabric.

Zarkogianni *et al.,* [18] stated that the forces of van der Waals and hydrogen bonding were accountable for the adsorption of dye in the process of cotton dyeing. Mordanting leads to a substantial enhancement of the K/S value for all cotton samples. Cotton fibres do not get satisfactory dyeing results when using natural dyes. Therefore, it is essential to pre-mordant cotton before dyeing it with cochineal. When applied to cotton fibres that have been treated with a mordant, natural dye molecules act as ligands to bind with metal ions. These metal ions are also connected to the hydroxy groups of cellulose. As a result, the adsorption of dye onto the mordanted cellulose is significantly enhanced. The K/S value, which measures dye absorption, increases dramatically from 0.8 to a range of 1.7 to 20.5, depending on the type of metal used as the mordant. Zakaria *et al.,* [19] also obtained a similar result, where the highest K/S value was observed when pre-mordanted cotton knitted fabric was dyed with green walnut shell, surpassing the values obtained from other procedures.

The study conducted by Nateri and Dehnavi [20] examined the outcomes of dyeing wool yarn with madder and pomegranate peel using three different techniques: pre-mordanting, meta-mordanting, and post-mordanting. The colour depth of the dyed sample with madder using the pre-mordanting approach was found to be greater than that of other dyeing procedures. However, the colour intensity of the sample dyed with pomegranate peel using the post-mordanting process is lower in comparison to other approaches.

3.2 Colour Fastness to Washing Test

Colour fastness testing is conducted to assess the resilience of the colour adhered to each fabric sample following the washing procedure. The test was visually conducted by comparing the sample with the standard using both the grey scale and the staining scale. The results are given in Table 4.

Table 4
Colour Fastness to Washing Results

Sample Code		Grayscale	Criteria
Standard – Cotton Fabric			
Pre Mordanting	Ferrous Sulphate	3-4	Excellent
	Soda Ash	3	Very Good
	Alum	3	Very Good
Meta Mordanting	Ferrous Sulphate	3	Very Good
	Soda Ash	3	Very Good
	Alum	3	Very Good
Post Mordanting	Ferrous Sulphate	4	Exceptional
	Soda Ash	2-3	Good
	Alum	4	Exceptional

Table 4 presents the outcomes of colour fastness to washing tests, showing changes in reflectance (R%) and transmittance (T%) depending on various mordants and mordanting procedures. Fabric that has been treated with ferrous sulphate typically exhibits reduced reflection, resulting in a deeper colour, and increased transmittance, suggesting a lesser absorption of light. Ferrous sulphate is recognised for its potent mordanting capabilities, as it creates stable compounds with dyes. This can result in more profound and more intense hues. A higher level of transmittance implies a lower level of light absorption, which in turn indicates a darker colour. The colour fastness to washing was assessed as 'Very Good' or 'Exceptional,' suggesting that the dye successfully adhered to the fabric, resulting in long-lasting and fade-resistant colours.

The pre-mordanting technique increases the fabric's affinity for the dye. The addition of ferrous sulphate during pre-mordanting causes a chemical reaction with the colourant chemicals present in Curcuma xanthorrhiza extract, resulting in the formation of stable complexes. This interaction affects the range of colours that the fabric absorbs when it is dyed. The "Excellent" colour fastness result indicates that the colour obtained by pre-mordanting with ferrous sulphate is extremely durable and does not fade easily during washing. The formation of coordination complexes between ferrous sulphate, the fabric, and the dye enhances the durability and longevity of the colour.

Meta mordanting is the procedure of applying iron sulphate at the same time as dyeing. The iron ions derived from ferrous sulphate chemically interact with the fabric, resulting in the formation of extra binding sites for the dye molecules. This simultaneous contact increases the number of binding sites on the fabric while it is being dyed. The iron ions included in ferrous sulphate also create complexes with colourant chemicals found in Curcuma xanthorrhiza extract. This contact enhances the hue of the fabric, making it more vibrant and long-lasting. The colour fastness result labelled as

"Very Good" indicates that the colour obtained from meta mordanting with ferrous sulphate is long-lasting and very resistant to fading when subjected to washing. The concurrent engagement with both cloth and dye guarantees efficient immobilisation and durability.

Post mordanting is the process of applying iron sulphate to the fabric after it has been dyed. The use of this extra substance may generate new sites on the cotton fabric, so further improving the attachment of the dye molecules. The presence of ferrous sulphate in post-mordanting process facilitates the reaction with any residual colourant compounds derived from Curcuma xanthorrhiza extract, hence enhancing colour durability. The colour fastness result labelled as "Exceptional" indicates that the colour obtained by post mordanting with ferrous sulphate is highly stable and resistant to fading when subjected to washing. Applying ferrous sulphate after dyeing enhances colour fixing and stability.

The observed sequence of meta mordanting (Very Good), pre mordanting (Excellent), and post mordanting (Exceptional) can be attributed to the cumulative impact of ferrous sulphate on both the fabric and the dye. Pre-mordanting and meta-mordanting enhance the dye's ability to combine with ferrous sulphate, leading to a more enduring colour. Post mordanting, although still effective, may exhibit marginally superior colour fastness, potentially attributable to its subsequent application following the dyeing process.

The presence of ferrous sulphate in the mordanting process affects the cotton fabric and Curcuma xanthorrhiza extract. This interaction alters the number of binding sites available and ultimately changes the colour tone of the finished product. The sequential application of ferrous sulphate in mordanting processes leads to different levels of colour fastness. Meta mordanting yields a colour fastness rating of "Very Good," pre mordanting results in an "Excellent" rating, and post mordanting achieves an "Exceptional" rating.

Fabric that has been treated with soda ash typically shows increased reflection, resulting in a lighter colour, and decreased transmittance. Soda ash, acting as an alkaline mordant, enhances the vibrancy and luminosity of colours. The increased reflectance supports the hypothesis that alkaline circumstances amplify colour intensity. The colorfastness to washing regularly received a 'Very Good' rating, indicating the efficacy of soda ash in promoting long-lasting colour fixing on cotton fabric.

Soda ash, as an alkaline mordant, alters the composition of cotton fibres when used for pre-mordanting. This modification raises the pH of the fabric, which in turn creates more binding sites for the dye molecules during the subsequent dyeing process. The presence of soda ash can induce alkaline conditions that can affect the stability and reactivity of colourant chemicals in Curcuma xanthorrhiza extract. This interaction has the potential to influence the final colour result. The colour fastness result of "Very Good" indicates that the colour obtained by pre-mordanting with soda ash is highly stable and resistant to fading when subjected to washing. The increased affinity of the dye for the fabric, assisted by soda ash, helps to its longevity.

Meta mordanting is the process of applying soda ash and dying at the same time. The alkaline conditions induced by soda ash during the dyeing process improve the accessibility of binding sites on the cotton fabric, facilitating the efficient uptake of colour. The simultaneous interaction of soda ash with Curcuma xanthorrhiza extract during the dyeing process affects the stability and reactivity of the colourant compounds. This can lead to a durable and securely attached colour on the fabric. The colour fastness result of "Very Good" suggests that the colour obtained by using soda ash for meta mordanting is long-lasting and very resistant to fading. The concurrent engagement with both cloth and dye guarantees efficient immobilisation and durability.

Post mordanting refers to the process of applying soda ash to the fabric after it has been dyed. This supplementary treatment alters the structure of the fabric, perhaps generating extra sites for binding and improving the fixing of colour. The presence of soda ash during post mordanting enhances the interaction with any residual colourant compounds, hence enhancing colour stability. The colour fastness result labelled as "Good" indicates that the colour obtained by using soda ash for post mordanting is quite stable, but it may exhibit somewhat increased vulnerability to fading after washing when compared to pre and meta mordanting. The post-mordanting stage enhances the number of binding sites available, while the total stability may be marginally lower compared to alternative procedures.

The observed sequence of post-mordanting (Good), pre-mordanting (Very Good), and meta-mordanting (Very Good) can be ascribed to the cumulative impact of soda ash on both the fabric and the dye. Meta mordanting and pre mordanting enhance the chances for the dye to engage with soda ash, leading to a more enduring colour. Post mordanting, although still effective, may exhibit a somewhat diminished colour fastness, potentially attributable to its application following the dyeing process.

Soda ash reacts with cotton fabric and Curcuma xanthorrhiza extract during the mordanting process, which affects the number of binding sites and alters the shade of the resulting colour. The sequential application of mordanting techniques involving soda ash leads to differences in colour fastness. Post mordanting yields a "Good" level of colour fastness, pre mordanting yields a "Very Good" level, and meta mordanting also yields a "Very Good" level.

Alum-treated fabric, particularly when post mordanted, exhibits increased reflection (resulting in a lighter colour) and decreased transmittance. Alum is a conventional mordant renowned for generating paler hues. The increased reflectivity signifies a brighter hue, providing evidence that alum contributes to lighter colour results. The formation of a compound between alum and the dye molecules is thought to have enhanced the fixing of colour on the cotton fibres. The dye's outstanding colour fastness to washing indicates a strong bond between the dye and the cloth, which supports the idea that alum creates stable complexes with the dye, resulting in a brilliant and long-lasting result.

The alum used in pre-mordanting reacts with the colourant chemicals present in the Curcuma xanthorrhiza extract, resulting in the formation of stable complexes. This interaction affects the range of colours that the fabric absorbs as it is being dyed. The colour fastness result of "Very Good" indicates that the colour obtained by pre-mordanting with alum is long-lasting and does not easily fade when subjected to washing. The formation of coordination complexes between alum, the cloth, and the dye enhances the color's durability and longevity.

The simultaneous interaction in the meta mordanting process with alum increases the number of binding sites on the fabric, hence improving the fabric's ability to absorb dye throughout the dyeing process. The alum contains aluminium ions that also create complexes with colourant chemicals found in Curcuma xanthorrhiza extract. This interaction enhances the intensity and durability of the colour on the fabric. The "Very Good" colour fastness result indicates that the colour obtained by using alum as a meta mordant is long-lasting and does not easily fade when subjected to washing. The concurrent engagement with both cloth and dye guarantees efficient immobilisation and durability.

The alum used in the mordanting process continues to chemically react with any leftover colourant components present in the Curcuma xanthorrhiza extract, thereby enhancing the colour stability. The colour fastness result labelled as "Exceptional" indicates that the colour obtained by post mordanting with alum is highly stable and resistant to fading when subjected to washing. Applying alum after dyeing enhances colour fixing and stability.

The observed sequence of meta mordanting (Very Good), pre mordanting (Very Good), and post mordanting (Exceptional) can be ascribed to the cumulative impact of alum on both the fabric and the dye. Pre-mordanting and meta-mordanting enhance the dye's interaction with alum, leading to a more enduring colour. Post mordanting, although still effective, may exhibit marginally superior colour fastness, potentially attributable to its subsequent application following the dyeing process. The interaction between alum, cotton fabric, and Curcuma xanthorrhiza extract during the mordanting process affects the number of binding sites available and alters the hue of the resulting colour. The sequential application of alum in different mordanting methods leads to variances in colour fastness. Meta mordanting yields a colour fastness rating of "Very Good," pre mordanting also yields a rating of "Very Good," while post mordanting results in an "Exceptional" rating.

The study's results are consistent with other research that suggests that mordants have an impact on the colour results in natural dyeing. The conformity with prior research reinforces the comprehension that the choice of mordant is a crucial determinant of both colour intensity and hue. The distinct qualities of each mordant are responsible for the observed variations in colour fastness to washing when dyeing cotton fabric using Curcuma xanthorrhiza extract. Alum exhibits remarkable colour fastness, showing a strong and enduring connection between the dye and fabric. Ferrous sulphate, because to its potent mordanting properties, guarantees excellent colour fastness ranging from very good to extraordinary. Soda ash acts as an alkaline mordant, improving the durability of the dye-fabric bond and resulting in excellent colour fastness. These findings emphasise the significance of choosing the right mordant to achieve both vivid colours and durability, as well as resistance to washing.

A mordant-metal salt possesses a high affinity for both the colourant and the fibre. When it combines with the dye on the fibre, it creates a solid, insoluble substance. The mordant can facilitate the attachment of dyes that are often not easily absorbed by the fibre. Therefore, the process of mordanting enhanced the ability of the samples with low to medium wash fastness to resist fading after washing.

Colour fastness refers to the ability of a material to resist any alteration in its colour properties, as well as the transfer of its colourants to surrounding materials. Fading refers to the alteration in the intensity of colour, either becoming lighter or darker, as a result of washing, rubbing, contact with human perspiration, or exposure to light. Cook [21] has outlined the utilisation of natural tannin and related materials as a post-treatment method to enhance the wash resistance of mordantable natural dyes on cotton. Additionally, the use of natural UV absorbers is suggested to improve the resistance of these dyes to fading caused by light exposure. While numerous pre-treatments and post-treatments are available to enhance the wash-fastness, rub-fastness, and light fastness of textiles coloured with synthetic dyes, the options for treating textiles dyed with natural dyes remain limited. Therefore, it is crucial to investigate the enhancement of natural materials in order to get higher speed.

The poor wash fastness of many natural dyes is mostly owing to the weak link formed between the natural dye-mordant and the fibre. This binding is susceptible to breaking during washing, resulting in a change in colour due to the ionisation of the natural dyes [22]. Due to the presence of hydroxyl groups in most natural dyes, they undergo ionisation in alkaline or acidic circumstances. Consequently, when fabrics dyed with natural dyes are washed with alkaline detergents or soap, their colour tends to change. The wash fastness of natural dyes is greatly influenced by their chemical composition and the type of connections produced between the dye, mordant, and fibre. These bonds create a coordinating complex that is distinct to the combination of dye, metal salt mordant, and fibre. However, contrary to expectations, it is often observed that complex formation is either minimal or absent, resulting in the formation of only hydrogen bonds. This leads to poor wash fastness, which can be attributed to various factors such as the mismatch between the physical structures or orientations of the dye and fibre, or other potential issues.

Zarkogianni *et al.,* [18] additionally stated that pre-mordanting leads to a substantial enhancement in wash fastness, increasing it by 1-4 points on the greyscale. The correlation between the low K/S values and the improvement achieved by pre-mordanting the samples is evident. Pre-mordanting enhances the absorption of dye on cotton, although the surplus dye that is deposited superficially can be eliminated with washing. Consequently, the wash fastness values experienced a reduction. In contrast, Zakaria *et al.,* [19] discovered that several mordanting techniques yielded identical colour fastness when subjected to washing.

4. Conclusions

In the end, this study explored the utilisation of Curcuma xanthorrhiza extract as a natural colouring agent for cotton fabric, taking into account several methods of mordanting involving ferrous sulphate, soda ash, and alum. The examination of colour intensity highlighted the effectiveness of meta mordanting, which produced the most vivid and strong shades. In contrast, pre mordanting and post mordanting resulted in different levels of coloration.

Significantly, the assessment of colour fastness demonstrated exceptional outcomes when using ferrous sulphate for post mordanting, demonstrating extraordinary stability and resistance to fading after washing. Simultaneously, pre-mordanting and meta-mordanting exhibit very good colour fastness, highlighting their aptness for preserving colour brightness over a prolonged period.

The observed results highlighted the importance of mordanting techniques in increasing both the intensity of colour and the durability of the dyed cotton fabric. The interplay of Curcuma xanthorrhiza extract, mordants, and the fabric is crucial for attaining the required colour results and guaranteeing the textile's longevity.

This study provided useful insights into the use of Curcuma xanthorrhiza extract as an eco-friendly and bright natural dye for cotton textiles. The discoveries not only enhance our comprehension of the utilisation of natural dyes but also establish a path for eco-friendly methods in the field of textile dyeing. Curcuma xanthorrhiza extract is gaining attention as a potential solution for the textile industry's search for environmentally acceptable alternatives. It offers both visual attractiveness and strong resistance to colour fading.

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