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Exploration of Natural Dyes and Mordanting on Cotton Fabric with Monochromatic Color Combinations

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ABSTRACT

This study explores the use of natural dyes as a sustainable alternative to synthetic dyes in the textile industry, with a focus on creating monochromatic color combinations on cotton fabric. Using a qualitative descriptive experimental approach, this study tested the effectiveness of pigments derived from indigo, secang wood, mangosteen peel, and turmeric through variations in mordanting techniques (pre-mordanting, meta-mordanting, and post-mordanting). The mordants used include alum and tunjung to observe the resulting color shifts and visual intensity. The results indicate that the post-mordanting technique with tunjung mordant produces deeper and more intense color saturation, while alum preserves the original color brightness. A systematic monochromatic effect was successfully achieved through modifications in solution concentration and dyeing duration, without the addition of synthetic dyes. Additionally, it was found that drying in the shade provides better color stability compared to direct sunlight exposure. This study concludes that the optimization of mordanting variables and consistent technical procedures can produce color gradations that are aesthetically pleasing, harmonious, and environmentally friendly. These findings are expected to serve as a reference for the development of textile designs that prioritize the principles of the circular economy and sustainability

INTRODUCTION

The global textile industry currently stands at a critical juncture between demands for productivity and the responsibility to preserve ecosystems (Purnomo, 2024). As one of the most versatile and popular materials for both fashion and household needs, cotton fabric has become a primary focus in the implementation of sustainability concepts due to its skin-friendly fiber properties and high absorbency (Arif Santoso, 2024). However, the dominant use of synthetic dyes in the production process remains a significant contributor to water pollution due to chemical waste that is difficult to break down and damages aquatic life (Sudradjat, n.d.). The shift toward the use of natural dyes has become a collective imperative to mitigate environmental impacts while addressing the growing global consumer awareness of ethical and sustainable textile products (Biji et al., 2015).

Natural dyes extracted from biological sources such as indigo, turmeric, mangosteen peel, and secang wood offer aesthetic advantages through their soft, warm, and unique (distinctive) color characteristics. Although ecologically superior, the application of natural dyes to cellulose fibers such as cotton faces technical challenges related to low dye affinity toward the fibers, which results in inconsistent intensity and susceptibility to external factors such as washing and sunlight (Shintia et al., 2016). Therefore, optimization through mordanting techniques is necessary to form a bond between natural color pigments and fabric fibers in order to achieve a more stable and permanent visual quality.

The effectiveness of natural dyeing depends heavily on the selection of the type of fixing agent (mordant) and its application method (Refina Irbah & Ma'rifatun Nasikhah, 2025), whether through pre-mordanting, simultaneous, or post-mordanting techniques. The use of mordants such as alum and ferrous sulfate not only functions as a color fixative but also plays a role in modifying the resulting color shift (Refina Irbah & Ma'rifatun Nasikhah, 2025). This study specifically explores the potential of natural dyes in creating monochromatic color designs on cotton fabric. The primary focus is on how variations in mordant concentration and dyeing techniques can produce harmonious color gradations within a single tonal range, which represents a novelty in the aesthetics of eco-friendly textile design (Akhyar Ad Dafiq et al., n.d.).

Through an experimental approach combined with qualitative descriptive analysis, this study aims to map the visual characteristics resulting from various mordanting treatments. Given that this study focuses on design exploration, the evaluation was conducted through in-depth visual observation of changes in color intensity and maturity in each fabric sample. The results of this exploration are expected to provide a practical reference framework for designers and artisans in optimizing natural dyes as an innovative solution that balances the aesthetic power of monochromatic design, process efficiency, and the principles of sustainability in the creative industry.

METHODS

This study employs an experimental method with a qualitative descriptive approach to analyze the dyeing process and results on cotton fabric (Setyaningsih et al., 2025). The primary focus of the study is the exploration of natural dyes with monochromatic color combinations through various mordanting techniques. A qualitative descriptive approach was chosen to thoroughly map the visual characteristics, color shifts, and aesthetic values resulting from each treatment without conducting quantitative laboratory tests. Research variables include the type of natural dye (such as indigo and secang wood) as the independent variable, and mordanting techniques (pre-mordanting, meta-mordanting, and post-mordanting) as control variables to observe changes in visual intensity on the fabric.

The research process was supported by technical instruments, including a digital scale for material precision, extraction pots, dyeing vats, and a standardized drying area. The primary material used was 100% cotton fabric as the cellulose fiber medium. Natural color sources were extracted from plant-based materials, including indigo, secang wood, jolawe, mangosteen peel, pomegranate, and turmeric. To optimize the color fixation and maturation process, this study utilized natural mordants and auxiliaries such as alum, tunjung, salt, and brown sugar as natural binding agents. All experimental results were then documented and analyzed through comparative visual observation to determine the effectiveness of each method in creating harmonious monochromatic gradients.

RESULTS AND DISCUSSION

The Process of Exploring Natural Dyes

To conduct this exploration of natural dyes, the author used monochromatic color techniques; these colors are primary colors such as red, blue, yellow, green, purple, and orange. These are single colors that are combined or varied with gray (tone), white (tint), and dark (shade); the differences lie only in brightness (light, dark) and saturation (strong–weak). For example, red mixed with white becomes pink; when mixed with gray, it becomes maroon or darker; similarly, when mixed with dark shades, red becomes darker. Since natural dyes do not contain white, gray, or black (dark) colors, the author explored these hues by conducting light-dark experiments using varying water concentrations (by volume), adjusting the duration of the dyeing process, and mixing colors with one another to produce monochromatic tones.

Ilustration of natural dye solution concentration

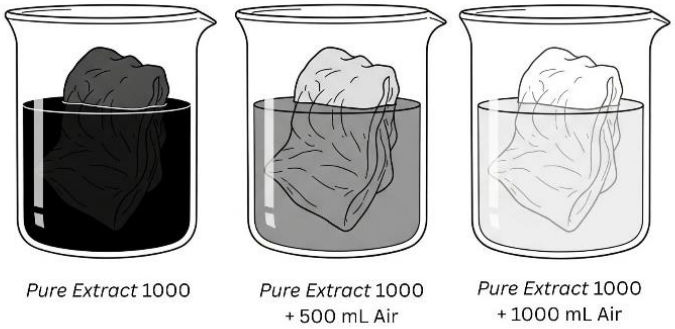


Figure 1. Illustration of Differences in Liquid Concentration
(Source: Nukke Sylvia, 2025)

The exploration of natural dyes and mordanting on cotton fabric with a monochromatic color combination uses 3 mordanting techniques including Pre-Mordanting, Meta-Mordanting and Post-Mordanting. The procedure begins with the extraction process of natural dyes such as indigo, turmeric, sappanwood, mahogany, and jolawe, using a boiling or soaking method according to the characteristics of the material until a thick colored solution is obtained, then filtered to remove solid residue.

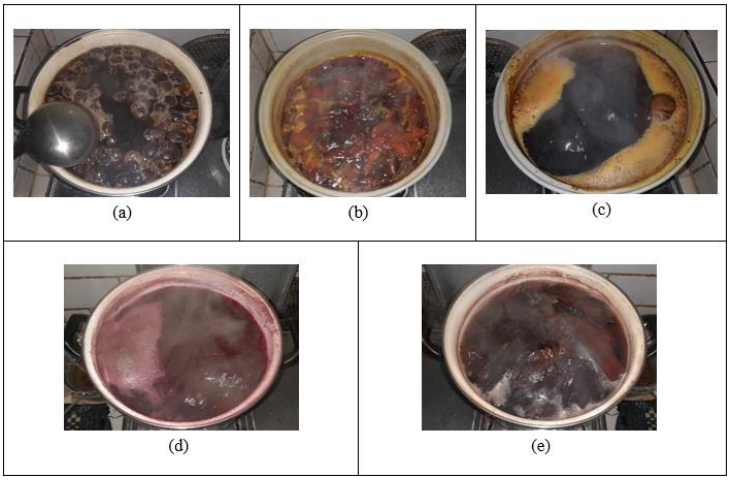


Figure 2. Natural Dye Extraction Process: a. Jolawe, b. Turmeric, c. Mangosteen Peel, d. Secang, e. Mahogany
(Source: Nukke Sylvia, 2025)

Table 1. Composition of Natural Dye Extraction

No	Mordan Type	Weight (gr)	Water Volume (Liters)	Treatment
1	Dried Jolawe	25	1	Boiled until the water volume is reduced by 50%
2	Dried Turmeric Slices	25	1	Boiled until the water volume is reduced by 50%
3	Dried Mangosteen Peel	25	1	Boiled until the water volume is reduced by 50%
4	Secang Powder	25	1	Boiled until the water volume is reduced by 50%
5	Dried Mahogany	25	1	Boiled until the water volume is reduced by 50%

Indigo dye requires special preparation to produce this natural dye. The process of making indigo dye using brown sugar is a natural reduction method that utilizes the sugar content as a reducing agent. Indigo naturally exists in the form of indigotin, which is insoluble in water; therefore, it requires a reduction process to be converted into leuco-indigo (white indigo), which is soluble and can bind to fibers.

Table 2. Composition of Natural Indigo Dye Paste Solution

No	Mordan Type	Total	Treatment
1	Water	1 Liter	Heat the water (by boiling) to around 60-70°C.
2	Betel Lime	10gr	Dissolve the betel lime in a little water until it forms a paste, then add it to the warmed water and stir thoroughly until there are no lumps.
3	Brown Sugar	20gr	Crush the brown sugar and dissolve it in the warm water until completely homogeneous.
4	Indigo Pasta	30gr	Dissolve it in the betel lime and brown sugar solution, then stir until evenly distributed and there are no lumps. Then, ferment for 2 x 24 hours.

Figure 3. Indigo Pasta Dissolving Process
(Source: Nukke Sylvia, 2025)

In this process, brown sugar acts as an electron source under alkaline conditions (achieved by adding soda ash to produce an alkaline solution), causing it to ferment and produce reducing agents. These agents then reduce indigotine to its leuco form, making it soluble in the dye solution and causing the solution to turn green. The next step is weighing the mordant using an analytical balance (previously calibrated with the container) according to the experimental design, namely 20 g of mordant per 1 liter of water (20 g/L), with the following mordant solution composition:

Table 3. Mordant Solution Composition

No	Mordan Type	Wight (gr)	Volume Air (Liter)	Treatment
1	Vinegar	20	1	Stir until evenly distributed and no lumps form
2	Tunjung	20	1	Stir until evenly distributed and no lumps form
3	Alum	20	1	Stir until evenly distributed and no lumps form

(a) (b) (c)

Figure 4. The Process of Measuring Mordant; a. Vinegar, b. Tunjung, c. Alum
(Source: Nukke Sylvia, 2025)

After weighing, the mordant is gradually dissolved in a portion of the process water (approximately 30–50% of the total volume) while stirring continuously until the granules have completely dissolved, then the remaining water is added to reach the final volume

Figure 5. Results of Tunjung, Alum, and Vinegar Mordant Solutions
(Source: Nukke Sylvia, 2025)

Dissolution is carried out at a warm temperature (approximately 40–60 °C) to accelerate the dissolution process without causing adverse effects on the prepared mordants. The homogenized solution is allowed to stand briefly to release bubbles and lower the temperature. Next, each container to be used is labeled (type of mordant, type of dye, soaking time, mordanting technique, and drying technique) before use. Each container is filled with 6 pieces of cotton fabric, following the calculations based on the drying technique and the fabric's soaking duration.

Figure 6. Process of Soaking Cotton Fabric with Natural Dyes
(Source: Nukke Sylvia, 2025)

Test fabrics that have undergone the scouring process are immersed in a mordant solution, a dye solution, or a combination of both, depending on the mordanting technique being tested, namely pre-mordanting, meta-mordanting, post-mordanting, or meta-mordanting with a mixture of natural dyes. Each transparent plastic container in the figure represents a specific treatment, labeled with information on the type of dye, type of mordant, mordanting technique, solution concentration, and soaking duration. Treatment variations are controlled based on soaking time (8, 16, and 24 hours), consistently measured solution volume, and the fabric-to-solution ratio to ensure uniform results. During the soaking process, the solution is stirred periodically to ensure even color distribution across the fabric's surface and prevent the formation of spots or color variations. These containers are neatly arranged in several rows according to treatment categories, facilitating identification and data collection throughout the experiment.

Once the soaking process is complete after the specified duration, the test fabric is removed from the solution and immediately undergoes a light rinsing stage using clean water to remove any remaining mordant solution or dye residues not bound to the fibers. Rinsing is done carefully without excessive squeezing to avoid damage to the fiber structure or changes in color distribution.

Figure 7. Drying without Direct Exposure to Sunlight
(Source: Nukke Sylvia 2025)

Figure 8. Drying in Direct Sunlight
(Source: Nukke Sylvia 2025)

The fabric was dried using two different methods: direct sun-drying to evaluate the color response to exposure to UV radiation and natural heat, and drying without sun exposure (in a ventilated shaded area) to observe hue stability without the influence of photodegradation. These two methods were applied to compare the effects of drying conditions on color intensity, brightness, and fastness. Once the fabric was completely dry, each sample was visually inspected, followed by photographic documentation and data recording. Test results from all treatments were analyzed comparatively to identify trends in hue differences, color stability, potential visual changes due to the drying process, and the relationship between mordanting techniques and the final color performance on the fabric. Thus, the sequence of steps from soaking, rinsing, to drying provides a comprehensive overview of the fabric's response to various mordanting and dyeing treatments. The data obtained from each technique variation will serve as the basis for evaluating the effectiveness of each method, while also providing a scientific reference for determining the treatment combination that yields the most optimal, stable, and aesthetically pleasing colors in fabric dyeing using natural materials.

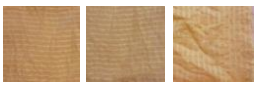
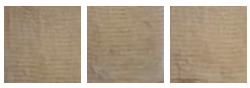
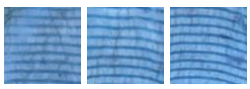
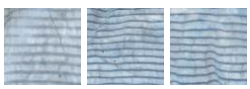
Results of Natural Dyeing on Cotton Fabric

1. The Effect of Water Volume Addition on Fabric Color Intensity with Natural Dyes

The results show that variations in water volume significantly affect the intensity and stability of color on cotton fabric. Under standard conditions (1000 mL of dye extract), the solution has a sufficiently high pigment concentration, resulting in a strong, vivid, and relatively stable color. However, adding 500 mL (1500 mL total) and 1000 mL (2000 mL total) of water caused the solution to become increasingly dilute, lowering the pigment concentration and resulting in fabric colors that tended to be pale and faded. This occurs because as the solvent volume increases, the number of pigment molecules per unit volume decreases, resulting in fewer molecules able to bind to the cellulose fibers in the cotton fabric. Additionally, the concentration gradient between the dye solution and the fabric fibers decreases in the diluted solution, causing the absorption of pigments into the fiber pores to slow down.

Table 4. Results of Natural Dye Exploration with Gradual Addition of Water

No	Type	Color Results on Cotton Fabric	Result Description
1	Turmeric	*Pure Extract* 1000mL 	The results of soaking the fabric with 1000 mL of pure turmeric extract resulted in a very intense turmeric color, ranging from dark yellow to bright yellow.
		Pure Extract 1000 + 500mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 500 mL of water resulted in a slightly faded turmeric color, namely bright yellow with some areas of the fabric tending to be pale and uneven.
		Pure Extract 1000 + 1000mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 1000 mL of water resulted in a very faded turmeric color, namely pale yellow in most areas of the fabric, tending to be white.
2	Mahogany	*Pure Extract* 1000mL 	The results of soaking the fabric with 1000 mL of pure extract resulted in a very intense mahogany color, namely dark red or brick red tending to brownish.
		Pure Extract 1000 + 500mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 500 mL of water resulted in a slightly faded mahogany color, namely bright brown tending to orange, with some areas of the fabric tending to be speckled and uneven.
		Pure Extract 1000 + 1000mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 1000 mL of water resulted in a very faded mahogany color, with most areas of the fabric appearing pale orange, tending towards cream.
3	Secang	*Pure Extract* 1000mL 	The results of soaking the fabric with 1000 mL of pure extract resulted in a very deep sappanwood color, a brick red tending towards brown.
		Pure Extract 1000 + 500mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 500 mL of water resulted in a slightly faded sappanwood color, a bright brown tending towards orange, slightly light brown.
		Pure Extract 1000 + 1000mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 1000 mL of water resulted in a very faded sappanwood color, with most areas appearing pale cream, tending towards white.

4	Jolawe	*Pure Extract* 1000mL 	The results of soaking the fabric with 1000 mL of pure extract resulted in a very deep jolawe color, a dark to light brown.
		Pure Extract 1000 + 500mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 500 mL of water resulted in a slightly faded jolawe color, with a light brown tending to cream, and some areas being uneven.
		Pure Extract 1000 + 1000mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 1000 mL of water resulted in a very faded jolawe color, with most areas being light brown and pale.
5	Mangosteen	*Pure Extract* 1000mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 1000 mL of water resulted in a very deep mangosteen color, with a brownish hue.
		Pure Extract 1000 + 500mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 500 mL of water resulted in a slightly faded mangosteen color, with a bright brown tending to orange, with some areas being uneven.
		Pure Extract 1000 + 1000mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 1000 mL of water resulted in a very faded mangosteen color, with most areas being light brown and orange, and tending to pale.
6	Indigo	*Pure Extract* 1000mL 	The results of soaking the fabric with 1000 mL of pure extract resulted in a very intense indigo color, ranging from dark to light blue.
		Pure Extract 1000 + 500mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 500 mL of water resulted in a slightly faded indigo color, becoming light blue and tending to pale in some areas.
		Pure Extract 1000 + 1000mL 	The results of soaking the fabric with 1000 mL of pure extract and adding 1000 mL of water resulted in a very faded indigo color, with most areas of the fabric turning pale blue, tending to green..

The amount of water used in the natural dyeing process has been shown to be a variable that affects color intensity. The results in the table above indicate that increasing the water volume directly reduces the pigment concentration of dye materials such as turmeric, mahogany, secang, jolawe, mangosteen, and indigo. This process results in a lighter or paler final color, indicating that the water-to-pigment ratio is crucial in determining the vibrancy of the color produced on the fabric. Therefore, controlling the water volume is essential to achieving the desired color intensity. This finding has significant practical implications, particularly in the application of monochromatic concepts. By carefully manipulating the water volume, the dyeing process can create light and dark variations of a single base color. The color gradients resulting from the measurement and determination of water volume not only provide visual distinction but also enhance aesthetic flexibility in the dyeing outcome. Thus, the influence of water volume on color intensity can be utilized as an effective method for producing consistent monochromatic gradations, thereby opening opportunities for more diverse artistic creations. Overall, the relationship between water volume and color intensity in natural dyeing is a fundamental principle. Controlling water volume allows the dyeing process to produce a variety of color intensities and serves as a strategy for creating a uniform monochromatic gradient.

1. The Effect of Mordan Type on Color Variation in Fabrics Dyed with Natural Dyes Tunjung Mordan

The use of tunjung mordan produces a grayish color. This phenomenon can be explained by the chemical interaction between the ferrous ions (Fe^{2+}) contained in tunjung mordan and the natural pigments. Tunjung mordan has a very strong binding affinity for the phenolic groups and tannins in the pigments. The reaction between ferrous ions and tannins forms a complex that optically reflects dark colors, resulting in a shift in the pigment's hue toward gray. Therefore, Tunjung mordant is often used to achieve dark or grayish color effects in the dyeing process.

Table 5. Results of Natural Dye Exploration with Tunjung Mordant

No	Natural Dye	Result	Result Description
1	Turmeric		Soaking cotton fabric using natural turmeric dye with a volume of 1000 mL of Pure Extract for 24 hours produced a pale grayish yellow color with an uneven yellow hue.
2	Mahogany		Soaking cotton fabric using natural mahogany dye with a volume of 1000 mL of Pure Extract for 24 hours produced a reddish-brown color (similar to boiled tea leaves) and a pale grayish color with an uneven hue.
3	Secang		Soaking cotton fabric using natural secang dye with a volume of 1000 mL of Pure Extract for 24 hours produced a reddish-brown color (similar to boiled tea leaves) and a pale grayish color with an uneven hue.
4	Jolawe		Soaking cotton fabric using Jolawe natural dye with a volume of 1000 mL of Pure Extract for 24 hours resulted in dark brown and a grayish-white color, with uneven coloring.

5	Mangosteen		Soaking cotton fabric using mangosteen natural dye with a volume of 1000 mL of Pure Extract for 24 hours resulted in reddish-brown (similar to boiled tea leaves) and a grayish-white color, with uneven coloring.
6	Indigo		Soaking cotton fabric using Indigo natural dye with a volume of 1000 mL of Pure Extract for 24 hours resulted in bottle green and a grayish-white color, with fairly even coloring.

An exploration of natural dyeing processes using various materials such as turmeric, mahogany, secang, jolawe, mangosteen, and indigo shows that the use of tunjung as a mordant consistently produces a grayish hue. This phenomenon is not limited to a single type of dye but occurs in all tested materials, confirming that the chemical interaction between the mordant and the dye pigment plays a crucial role in determining the final result. Chemically, this color-shifting mechanism can be explained by the interaction of ferrous ions (Fe^{2+}) from the tunjung with pigment compounds. This process effectively "shifts" the dye's original hue, causing a visible shift in the color spectrum toward grayish tones. It can be concluded that the results of the tunjung mordant exploration have a dominant effect in altering the color of natural dyes. The resulting color change can also be utilized to achieve a grayish tone in the dyeing process to meet the required aesthetic standards.

Vinegar Mordant

The use of vinegar mordant (acetic acid) in the natural dyeing process consistently produces brighter colors. Chemically, acetic acid functions to lower the pH of the solution, which significantly affects the stability of natural dye pigments. This decrease in pH primarily affects pigments such as anthocyanins, flavonoids, and curcumin, which tend to be more stable and exhibit brighter colors under acidic conditions. Under low pH conditions, the molecular structure of natural dye pigments becomes more stable, preventing degradation or unwanted color changes. This stability allows natural dyes to adhere more effectively to fabric fibers and better retain their original hue, resulting in bright and clear colors.

Table 6. Results of Natural Dye Exploration with Vinegar Mordant

No	Natural Dyes	Result	Result Description
1	Turmeric		Soaking cotton fabric using Turmeric natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a bright yellow color that was evenly distributed throughout the fabric.
2	Mahogany		Soaking cotton fabric using mahogany natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a reddish-brown color that was evenly distributed throughout the fabric.
3	Secang		Soaking cotton fabric using sappanwood natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a reddish-brown color that was evenly distributed throughout the fabric.

4	Jolawe		Soaking cotton fabric using jolawe natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a green-brown color that was evenly distributed throughout the fabric.
5	Mangosteen		Soaking cotton fabric using mangosteen natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced an even reddish-brown color throughout the fabric.
6	Indigo		Soaking cotton fabric using indigo natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced an even bright blue color throughout the fabric.

Based on the experimental results in the table above, it can be concluded that vinegar mordant is effective in producing bright colors with various natural dyes. All dyes tested—including turmeric, secang, mahogany, jolawe, mangosteen, and indigo—exhibited significant brightness. This effectiveness is consistent across all mordanting methods—whether applied before (pre-mordanting), during (meta-mordanting), or after (post-mordanting) the dyeing process—indicating that vinegar is an appropriate fixing agent for enhancing color intensity on fabric. This can serve as a guideline for achieving the true or authentic color of the dyes to be used in future applications.

Alum Mordant

The use of alum produces results similar to those of vinegar, namely bright and stable colors. The Al^{3+} ions in alum act as a mordanting agent capable of forming coordination bonds with the hydroxyl groups of natural pigments, resulting in brightly colored complexes.

Table 7. Results of Natural Dye Exploration with Alum Mordant

No	Natural Dye	Result	Result Description
1	Turmeric		Soaking cotton fabric using turmeric natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a bright yellow color that was fairly even across the fabric.
2	Mahogany		Soaking cotton fabric using mahogany natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a reddish-brown color that was fairly even across the fabric.
3	Secang		Soaking cotton fabric using sappanwood natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a reddish-brown color that was fairly even across the fabric.
4	Jolawe		Soaking cotton fabric using jolawe natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a brownish-green color that was fairly even across the fabric.

5	Mangosteen		Soaking cotton fabric using mangosteen natural dye with a volume of 1000 mL of Pure Extract for 24 hours produced a fairly even reddish-brown color throughout the fabric.
6	Indigo		Soaking cotton fabric using indigo natural dye with a volume of 1000 mL of Pure Extract for 24 hours produces a bright blue color that is evenly distributed throughout the fabric.

The use of alum as a mordant also produces bright and vivid colors from various types of natural dyes, demonstrating its effectiveness as a color-fixing agent. Just like vinegar mordant, alum is able to strongly bind dye pigments to fabric fibers, resulting in a vibrant, bright, and long-lasting color spectrum. These results are consistent across various dyes, proving that alum is a good choice of mordant for enhancing color quality and durability in the natural dyeing process.

Research findings indicate that the type of mordant plays a significant role in determining the color variations of fabric produced from natural dyes. Tunjung imparts a grayish effect due to the formation of Fe^{2+} complexes with the pigment, causing the original hue to be masked by a dark monochromatic tone. Vinegar and alum, conversely, produce brighter and more stable colors, where this brightness is particularly evident in the meta-mordant technique because the chemical conditions of the solution are at the optimum point for pigment stability. Thus, the choice of mordant not only determines colorfastness but also the direction of hue change, whether toward a gray gradient (tunjung) or the enhancement of the original color (vinegar and alum). When considered in relation to the concept of monochromatic color, the use of tunjung produces a single-color gradient leaning toward gray, which, in the context of color art, can be utilized to create variations in light and dark tones without losing color consistency. Meanwhile, the use of vinegar and alum more prominently highlights the monochromatic aspect in terms of color brightness, resulting in a single base color with stronger variations in saturation. This confirms that mordants can be utilized not only for fixation but also as a strategy to control the aesthetic direction of monochromatic dyeing based on natural dyes.

1. The Effect of Mordanting Techniques (Pre, Meta, Post) on Fabric Color with Natural Dyes

Pre-Mordanting

The pre-mordanting technique involves soaking the fabric in a mordant solution before the dyeing process begins. This process allows mordant ions to bind to the fabric fibers first, so that when the color pigments are introduced, their interaction is more limited. The results are generally relatively stable and closely resemble the original color of the dye used. For example, indigo dye, which tends to be blue, will still produce a stable blue hue with little variation in lightness or darkness. The advantage of pre-mordanting is high color stability, especially during washing, because the pigment has already formed an initial bond with the fiber. However, the disadvantage is that the color intensity is often not as strong as with other methods, so the result appears more “subdued” or closer to the dye’s base color.

Meta-Mordanting

The meta-mordan technique involves mixing the mordant solution directly into the dye bath. At this stage, the mordant ions and pigments react simultaneously, forming a color complex that immediately adheres to the fabric fibers. The resulting color is heavily influenced by the nature of the mordant used. For example, using alum tends to produce gray or blackish hues, while alum or vinegar yields brighter colors. This technique offers good flexibility in producing strong color variations, as the reaction occurs simultaneously and is more intense. Additionally, meta-mordan allows for the emergence of rich, natural gradations, making it a frequent choice when researchers or artisans wish to explore the full potential of a specific dye.

Post-Mordanting

The post-mordanting technique is performed after the dyeing process is complete. The fabric, which has already absorbed the pigment, is then soaked in a mordant solution, which serves to strengthen and stabilize the color. This effect tends to produce deeper or darker colors, especially when using tunjung, which can turn the color into a deep gray or black. With mordants such as vinegar or alum, the effect is more about enhancing brightness, so the color appears more stable, though not necessarily darker. This technique is very useful when the primary goal is to extend color fastness and enhance contrast, although there is a risk of significant deviation from the original color.

Table 8. Results of Natural Dye Exploration Using Mordant Techniques (Pre, Meta, and Post)

No	Natural Dyes	Results			Information
		PRE	META	POST	
1	Turmeric	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	With the natural turmeric dye, the pre-mordanting technique produces a fairly deep yellow color on the fabric, whether using vinegar, tunjung or alum mordant. With the natural turmeric dye, the meta-mordanting technique produces a thick yellow color evenly on the fabric, whether using vinegar, tunjung or alum mordant. With the natural turmeric dye, the post-mordanting technique produces a fairly deep yellow color on the fabric, whether using vinegar, tunjung or alum mordant.
2	Mahoni	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum 	vinegar:  Tunjung:  alum 	With natural mahogany dye, the pre-mordanting technique produces a fairly thick reddish brown color on the fabric, whether using vinegar, tunjung or alum mordant. With natural mahogany dye, the meta-mordanting technique produces a thick reddish brown color that is evenly distributed on the fabric, whether using vinegar, tunjung or alum mordant. For mahogany natural dyes, the post-mordanting technique produces a fairly deep reddish-brown color on the fabric, whether using vinegar, tunjung, or alum mordants.
3	Secang	vinegar: 	vinegar: 	vinegar: 	For sappanwood natural dyes, the pre-mordanting technique produces a fairly deep

		Tunjung:  alum 	Tunjung:  alum: 	Tunjung:  alum: 	brick red color on the fabric, whether using vinegar, tunjung, or alum mordants. For sappanwood natural dyes, the meta-mordanting technique produces a deep, even brick red color on the fabric, whether using vinegar, tunjung, or alum mordants. For sappanwood natural dyes, the post-mordanting technique produces a fairly deep brick red color on the fabric, whether using vinegar, tunjung, or alum mordants.
4	Jolawe	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	For Jolawe natural dyes, the pre-mordanting technique produces a fairly deep light brown color on the fabric, whether using vinegar, tunjung, or alum mordants.
5	Mangosteen	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	For Jolawe natural dyes, the meta-mordanting technique produces a deep, even brown color on the fabric, whether using vinegar, tunjung, or alum mordants. For Jolawe natural dyes, the meta-mordanting technique produces a deep, even brown color on the fabric, whether using vinegar, tunjung, or alum mordants. For Jolawe natural dyes, the post-mordanting technique produces a fairly deep brown color on the fabric, whether using vinegar, tunjung, or alum mordants.
6	Indigo	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	vinegar:  Tunjung:  alum: 	Indigo natural dye, the pre-mordanting technique produces a fairly deep blue color on the fabric, whether using vinegar, tunjung, or alum mordants. For indigo natural dye, the meta-mordanting technique produces a deep, even blue color on the fabric, whether using vinegar, tunjung, or alum mordants.

	For indigo natural dye, the post-mordanting technique produces a fairly deep indigo color on the fabric, whether using vinegar, tunjung, or alum mordants.

Of these three methods, each has distinct advantages depending on the specific needs. Pre-mordanting is better suited for producing stable colors that closely resemble the natural hues of the dye material, making it ideal for research emphasizing color authenticity. Meta-mordanting is more suitable for exploring dominant and vivid color variations, and is particularly useful in developing textile designs that require visual diversity. Meanwhile, post-mordan is best used when color intensification or deepening is required, particularly in works that demand a rich or dramatic effect. Thus, there is no single "best" technique; rather, the choice of method must align with the ultimate goal: color authenticity (pre), color exploration (meta), or color durability and deepening (post).

1. The Effect of the Drying Process on Fabric Color with Natural Dyes

The drying process plays a crucial role in determining the durability and final quality of fabric color, as this stage involves the interaction of three primary factors causing pigment degradation: ultraviolet (UV) radiation, oxygen, and temperature increase. Direct sun-drying causes UV photons to be absorbed by the pigment's chromophores, thereby increasing the molecular energy to an excited state. In addition, an increase in surface temperature accelerates the rate of degradation, while the rapid evaporation of water causes pigments to settle on the surface of the fibers (surface fixation), leaving them more exposed to light and oxygen. Conversely, drying in the shade with good air circulation results in a slower and more even rate of evaporation. These conditions allow the pigments to diffuse deeper into the cellulose matrix and form more stable hydrogen or coordination bonds, resulting in a final color that tends to be more intense, homogeneous, and long-lasting.

Table 9. The Effect of the Drying Process on Fabric Color with Natural Dyes

No	Natural Dyes	Color Results on Cotton Fabric		Result Description
		Sun	Non-Sun	
1	Turmeric			For the natural Turmeric dye, the drying process in direct sunlight produces a bright color with slight fading in some areas, while the drying technique indirect sunlight produces an even color.
2	Mahogany			For the natural mahogany dye, the drying process in direct sunlight produces a bright color with slight fading in some areas, while the drying technique indirect sunlight produces an even color.
3	Secang			For the natural secang dye, the drying process in direct sunlight produces a bright color with slight fading in some areas, while the drying technique indirect sunlight produces an even color.
4	Jolawe			For the natural jolawe dye, the drying process in direct sunlight produces a bright color with slight fading in some

				areas, while the drying technique indirect sunlight produces an even color.
5	Mangosteen			For mangosteen natural dye, the sun-drying process produces bright colors with slight fading in some areas, while the sun-drying technique produces an even color.
6	Indigo			For indigo natural dye, the sun-drying process produces bright colors with slight fading in some areas, while the sun-drying technique produces an even color.

When dried in the sun, rapid evaporation creates a sharp moisture gradient from the surface to the interior of the fiber. These conditions can cause pigment back-staining and result in uneven color distribution (tide line). Excessive oxidation of certain pigments, such as leuco-indigo, also occurs more frequently, resulting in a lighter blue color compared to slow drying in the shade. In shaded conditions, the more moderate evaporation rate allows for more even pigment distribution (leveling), enhances pigment binding to cellulose microfibrils, and reduces direct exposure to UV radiation. Consequently, the resulting color is more intense, homogeneous, and exhibits higher lightfastness. Thus, the difference in color results between drying in direct sunlight and in the shade is not solely due to the presence of light, but rather a combination of photochemical, oxidative, and temperature factors, as well as diffusion and evaporation profiles, which simultaneously determine the intensity, stability, and final quality of the color.

CONCLUSION

This study confirms that natural dyes such as indigo, turmeric, mangosteen peel, jolawe, mahogany, and secang wood have great potential for producing monochromatic color designs on cotton fabric through the control of technical variables in the dyeing process. Variations in mordanting techniques (pre-, meta-, and post-) were found to produce significant differences in brightness, fastness, and color tone. Pre-mordanting tends to preserve the color's authenticity, meta-mordanting yields the most dominant color according to the mordant's characteristics, while post-mordanting serves to emphasize darker shades or brighten the final result. Meanwhile, variations in water volume and soaking time affect the pigment concentration in the solution, which is then reflected in the light-to-dark gradation on the fabric. The more concentrated the solution, the stronger the intensity and depth of the resulting color. Additionally, the drying process plays a crucial role in determining the stability and aesthetic quality of the monochromatic result. Direct sunlight exposure accelerates pigment degradation (particularly curcumin and anthocyanins), leading to fading and shifts in color tone, whereas shade drying enhances pigment diffusion into the fibers, resulting in a more durable, stable, and homogeneous hue. The combination of mordant control, concentration, and drying methods enables the formation of systematic monochromatic gradations, ranging from light, bright, to deep hues, thereby providing a rich variety of color tones despite being derived from a single source

Figure 9. Color Tones Resulting from Exploration with Natural Dyes
(Source: Nukke Sylvia, 2025)

Thus, this study not only confirms the effectiveness of natural dyes as an environmentally friendly alternative to synthetic dyes but also offers a new contribution in the form of a scientific approach to producing aesthetic, consistent, and sustainable monochromatic shades. This study is still limited to the duration of the dyeing experiments; therefore, further efforts are needed to maximize dyeing results using larger fabric media and longer durations.

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