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RESEARCH ARTICLE TYPE

Different concentrations and solubility of active lime ($CaCO_3$) on the quality of indigo paste from *Indigofera longiracemosa* Boiv.ex. Baill

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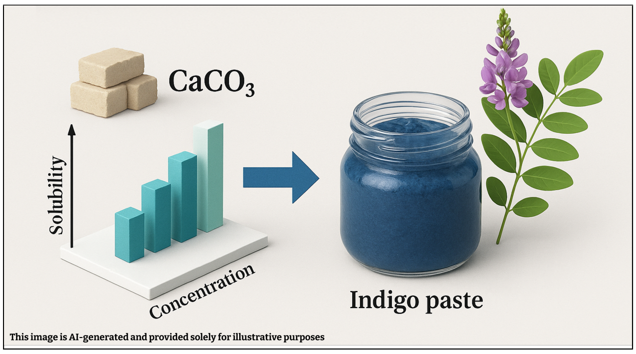

OBJECTIVES This research aims to determine the effect of differences in concentration and solubility of active lime (25% and 35% $CaCO_3$ solution, 25% and 35% $CaCO_3$ supernatant) on the quality of indigo (Indigofera longiracemosa) dye paste. METHODS The method for making indigo dye paste includes the process of soaking fresh leaves and twigs of I. longiracemosa in water, fermentation with an active lime solution of $CaCO_3$ with varying concentrations and solubility, settling, and filtration to obtain indigo paste. Several tests were carried out to evaluate the quality of the color in the fabric and the indican content in the indigo produced. RESULTS The indican content that was successfully tested showed the highest results in the paste treated with 25% $CaCO_3$. Tests show that fabrics dyed with indigo paste and treated with a 35% $CaCO_3$ solution have the best sweat resistance, with an average score of 4. The heat resistance test on fabric dyed with indigo paste in all treatments scored 4-5, showing excellent color fastness, no fading, and no staining on other fabrics. CONCLUSIONS The differences in concentration and solubility of $CaCO_3$ solution result in variations in the physical characteristics of indigo paste, the colors produced on fabric, the indican content, as well as the colorfastness to sweat and heat.

KEYWORDS $CaCO_3$; concentration; Indigofera longiracemosa; natural dyes; solubility

1. INTRODUCTION

Dyes are intensively colored compounds which applied to substrates such as paper, fiber, hair, or cosmetics to impart a certain color (Aggarwal 2021). Blue was the first color to be discovered. The indigo blue dye has been known and used in Hindu culture in India since 2500 BC. *Indigofera* is known by the public Javanese as tom, while Sundanese people call it Tarum. Historically, in 352-395 AD in Pasundan land stood the kingdom with the name Tarumanegara. It is believed that the royal name is related to the tarum plant, which at that time was mostly used as a textile dye (Muzayyinah 2014). According to history in Babat Tanah Jawi (1925) kingdom Tarumanegara in West Java which at that time was led by Ratu Shima, already knows batik and natural colors of *Indigofera* plants. Batik made from *Indigofera* dye is usually given as souvenirs to the Chinese kingdoms that come visit (Muzzazinah et al. 2016).

The *Indigofera* genus consists of shrubs or small trees with upright or spreading branches covered in fine, branching hairs. It has a taproot with white nodules and produces pod-shaped fruit, a characteristic of the Leguminosae family (Fugarasti et al. 2020). *Indigofera* leaves are alternate, usually odd-pinnate, and sometimes have three or more single leaflets. Its stomata are generally paracytic and found on both the upper and lower leaf surfaces, though more abundant on the lower surface (Muzzazinah et al. 2021). The flowers grow in clusters on axillary stalks, with bell-shaped, five-toothed petals and a butterfly-shaped corolla. Its pod-shaped fruit contains 1–20 round seeds. *Indigofera* logeracemosa morphology is shown in Figure 1.

Indigofera longiracemosa Boiv. ex Baill is a species from the *Indigofera* genus found on Java Island. It was identified in Wedomartani Village, Ngemplak District, Sleman Regency, Yogyakarta, Indonesia, in 2014. This species is distinguished by its reddish young stems, unlike other *Indigofera* species, which have green stems, and its zigzag stem growth pattern, whereas other species have straight stems (Muzzazinah et al. 2015)

According to Muzzazinah et al. (2016), *I. longiracemosa* has a high indican content and is being developed as an alternative natural dye. It is now cultivated in several regions in Indonesia. *Indigofera* produces fat-dye pigments, which are absorbed into fibers through a redox process (Putri et al. 2021). Fat dyes have excellent resistance to light and washing, and *Indigofera* dye is typically sold in paste form, made through fermentation.

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Arta et al. (2019) explained that during fermentation, the indican in *Indigofera* leaves is hydrolyzed into indoxyl and glucose by the enzyme β-glucosidase. Indoxyl then oxidizes upon air exposure to form indigo paste. The production of indigo paste requires active lime, which acts as an oxygen binder to intensify the blue color. Active lime, or quicklime, is obtained by heating calcium carbonate ($CaCO_3$) above 825 °C (Arta et al. 2019). Adding active lime to *Indigofera* leaf extract creates an alkaline environment that aids oxidation, breaking down indican into indoxyl and glucose (Muzzazinah et al. 2016), thus helping in the paste precipitation process. The pH neutralization reaction that occurs is as follows.

$$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O \qquad (1)$$

In addition, active lime provides calcium molecules that bind with indigotin molecules in *Indigofera* leaves to form the paste (Arta et al. 2019). This process prevents color degradation and produces a deeper and more stable blue color. The right concentration and solubility of $CaCO_3$ are crucial for achieving good quality and strong blue color intensity. The precipitation and adsorption of indigo onto $CaCO_3$ are illustrated in Figure 2. This research aims to determine the optimal lime concentration for indigo paste production.

2. RESEARCH METHODOLOGY

The equipment used includes a plastic soaking tub for soaking fresh leaves and twigs of *I. longiracemosa* plants, a dipper for dipping *I. longiracemosa* soaking water, mori cloth for filtering indigo paste, an analytical balance for weighing the weight of *I. longiracemosa* and the resulting paste, primis cotton cloth as a coloring medium, and a small container/thinwall to store the resulting paste. Primis cotton cloth was used for the dyeing test.

2.1 Materials

The materials used include fresh leaves and twigs of the *I. longiracemosa* plant as the main ingredient, $CaCO_3$ as an oxygen binder in the drilling process, water to soak the *I. longiracemosa* plant, soda ash as a color-solvent, and hydrosulfite as a color-reducing agent.

2.2 Procedures

2.2.1 Indigo paste dye making

Making indigo paste dye is done by sorting *I. longiracemosa* leaves from the stems and seeds, soaking the leaves and pieces of *I. longiracemosa* twigs in water in a soaking container for 36-48 hours with a ratio of *I. longiracemosa* and water of 1: 5 parts, cleaning the *I. longiracemosa* solution from leaves and twig pieces, adding active lime ($CaCO_3$) with different concentrations and treatments (25% and 35% $CaCO_3$

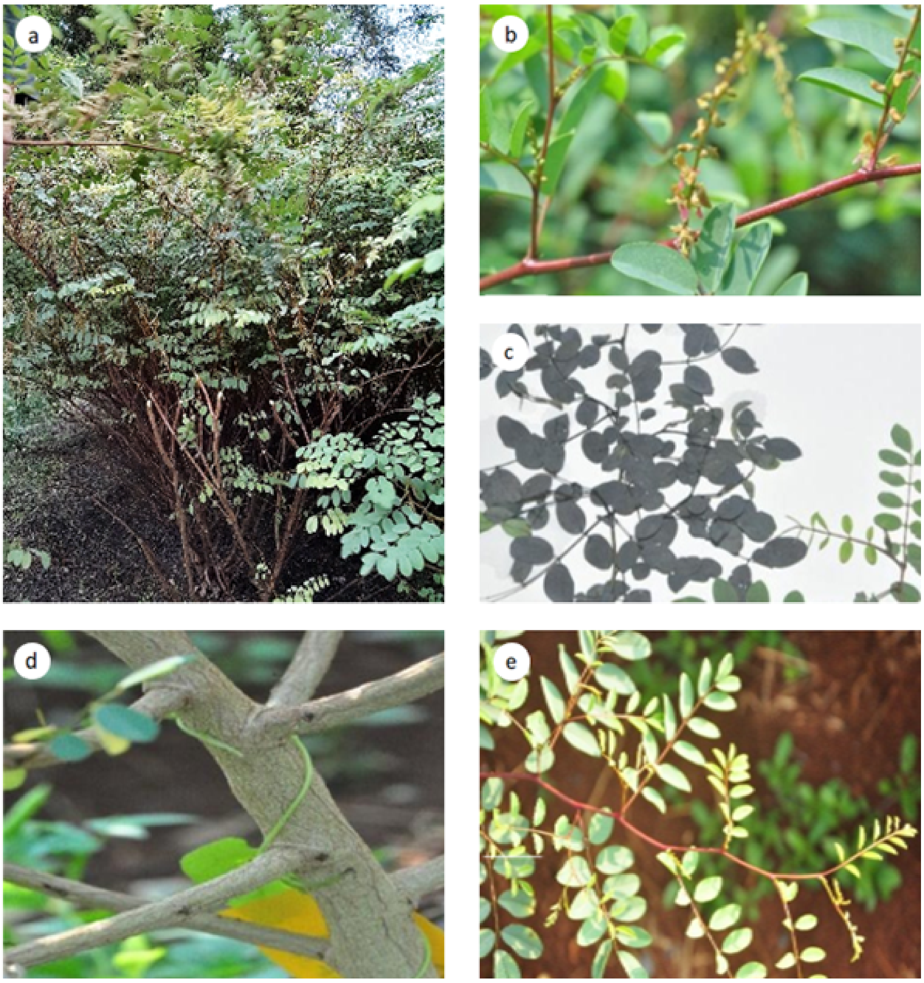


FIGURE 1. Morphology of *Indigofera*, (a) habitus, (b) young stems color, (c) dry leaf and wet leaf color, (d) stem shoot growth form, (e) branching direction (Muzzazinah et al. 2015).

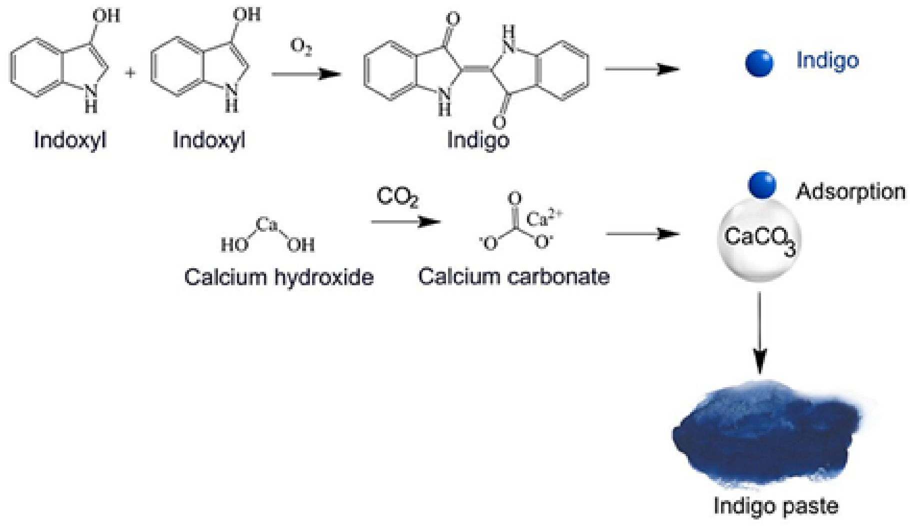


FIGURE 2. Precipitation and adsorption of indigo on $CaCO_3$ surface (Saikhao et al. 2025).

solution, 25% and 35% $CaCO_3$ supernatant), dissolving the *I. longiracemosa* soaking solution for 40-60 minutes or until the color changes to dark blue, settle the *I. longiracemosa* solution which has been dissolved for 36-48 hours until a dark blue precipitate form, filter the clear liquid at the top and take the indigo paste that has settled at the bottom. The process of making indigo paste dye is described in Figure 3.

During the indigo fermentation process, it is important to maintain stable environmental conditions that support color formation. These environmental conditions include basic pH (>7), room temperature (20-25 °C), and interaction with air (oxygen).

2.2.2 Dyeing on fabrics

The process of dissolving indigo paste was carried out using hydrosulfite ($Na_2S_2O_4$) and water as a reducing agent. Adding hydrosulfite helps reduce insoluble indigotin dye into water-soluble leuco indigo, allowing the dye to enter the fabric fibers (Hossain et al. 2017). This leuco indigo compound has better color quality and durability compared to synthetic dyes (Martuti et al. 2019). First, dissolve 75 grams of indigo paste in each treatment with 1 liter of water which has been mixed with 5.5 grams of Natrium Carbonate (Soda Ash). Sodium carbonate (soda ash) is used to raise the pH of the dye solution to a basic level (pH around 10–11.5). This basic condition is needed to reduce indigotin to leuco indigo and help it bind to the fabric fibers (Chavan 2015). Dissolving is

FIGURE 3. Diagram of indigo paste dye making, (a) Sorting *I. longiracemosa* leaves from stems and seeds, (b) Soaking the leaves along with the *I. longiracemosa* twigs in water in a soaking vessel for 36-48 hours, (c) clean the *I. longiracemosa* solution from the leaves and pieces of twigs, (d) aerating soaking solution rinse *I. longiracemosa* for 40-60 minutes, (e) adding activated lime ($CaCO_3$) with different concentrations and solubility, (f) precipitate the *I. longiracemosa* solution which has been aerated for 36-48 hours, (g) filter the clear liquid at the top and take the indigo paste which settles at the bottom, (h) Indigo paste.

carried out using a magnetic stirrer for 30 – 60 minutes until the color of the solution changes and the pH value becomes 11. After a homogeneous solution is formed, let it stand for 30 – 60 minutes before it is used to dye primis cotton cloth (115cm {×} 100cm) which has been scoured using TRO. Fabric dyeing is done 5 times in the order of dyeing, air drying until dry, then proceeding to the next dyeing. After the cloth is stained with indigo paste, the next steps will be fixation using vinegar and data analysis.

Testing Some of the tests that can be done in this research include:

1. Test the color quality of the fabric. Test the color quality of the fabric can be done in various ways, including:
   a) Test for fading resistance to washing In this test, the fabric to be tested is soaked in a detergent solution or special detergent for colored clothes. The fabric is then washed appropriately, such as using a washing machine or hand washing. After washing, the fabric is dried and checked to see how far the color of the fabric is maintained without any signs of fading or significant color change.
   b) Test the fading resistance to heat or light In this test, the fabric is placed under direct sunlight or a heat source such as an incandescent lamp. The fabric is left exposed to heat and light for a certain time. After that, the fabric is checked to see if there are any signs of discoloration or fading caused by exposure to heat and light.
   c) Test for fade resistance to ironing In this test, the fabric is ironed at a suitable temperature for the type of fabric. After ironing, the fabric is checked to see if there is any color change or fading that occurs due to the heat from the iron.
2. Test the indigo content in indigo paste using the HPLC method Indican analysis using the HPLC (High-Performance Liquid Chromatography) method is a common method used to determine indigo levels in samples. The following are the general steps in Indican analysis using the HPLC method:
   a) Sample Preparation: The sample to be analyzed (indigo paste dye) needs to be properly prepared. The sample can be extracted using an organic solvent, such as methanol or acetonitrile, to remove the indigo from the sample. Thereafter, the sample is evaporated to dry and redissolved in a suitable solvent before being filtered to remove unwanted particles.
   b) HPLC Column Preparation: HPLC columns suitable for indican analysis are selected and prepared. This column usually has a stationary phase which separates the indigo from the other components in the sample. HPLC columns need to be conditioned with a suitable mobile phase before use.
   c) Tests and Measurements: The prepared sample is injected into the HPLC system and run through the column using the appropriate mobile phase. Indigo will separate from other components in the sample based on their different affinities for the stationary and mobile phases. HPLC detectors, like UV/Vis detectors, are used to detect indigo as it passes through the detector. The signal generated by indigo is recorded and processed by the HPLC system.
   d) Analysis and Interpretation of Results: The data obtained from the HPLC detector were analyzed and interpreted to determine the indigo content in the sample. Generally, the analysis is carried out by comparing the peak area of indigo with a calibration standard of known concentration. From there, the indigo content in the sample can be calculated using the appropriate quantification method.
   e) Verification and Validation: During indican analysis with the HPLC method, method verification, and validation are carried out to ensure the accuracy and reliability of the results. This involves retesting the sample with the same method or alternative methods to check for repeatability and consistency of results. The HPLC method has been proven effective in indican analysis because it can provide accurate and sensitive results. However, it should be noted that each laboratory and study may have variations in the methods and conditions used, so it is important to refer to the specific protocols and methods followed in a particular study.

3. RESULTS AND DISCUSSION

This study used indigo paste with four treatment groups based on $CaCO_3$ concentration and solubility: 25% $CaCO_3$ solution, 35% $CaCO_3$ solution, 25% $CaCO_3$ supernatant, and 35% $CaCO_3$ supernatant. Each group was tested twice for accuracy. The results include the physical characteristics of the indigo paste, indican analysis using HPLC, fabric dyeing application, and fabric color quality tests.

3.1 Indigo paste physical characteristics

The indigo paste color produced with different concentration and solubility of $CaCO_3$ can be seen in Figure 4.

From these results, it can be seen that the indigo paste at different concentrations and solubility of activated lime produces a paste with almost the same color, namely dark blue with very intense saturation. Data regarding the texture, aroma, color code, and mass of the indigo paste produced from the four treatment groups are presented in the Table 1.

3.2 The texture of indigo pastes produced

Based on the indigo paste texture table, it can be seen that the indigo paste produced from the treatment of 25% and 35% $CaCO_3$ solution produced a paste with a very lumpy texture with a slightly gritty texture, while the indigo paste produced from the treatment of 25% and 35% activated lime supernatant produced a paste with a fairly lumpy texture.

3.3 The aroma of indigo pastes produced

From these data it can be seen that the indigo paste produced from the treatment of 25% and 35% activated lime solution produced a paste with a pungent indigo odor with a slight lime aroma, while the indigo paste produced from the treatment of 25% and 35% activated lime supernatant produced a paste with a pungent indigo odor.

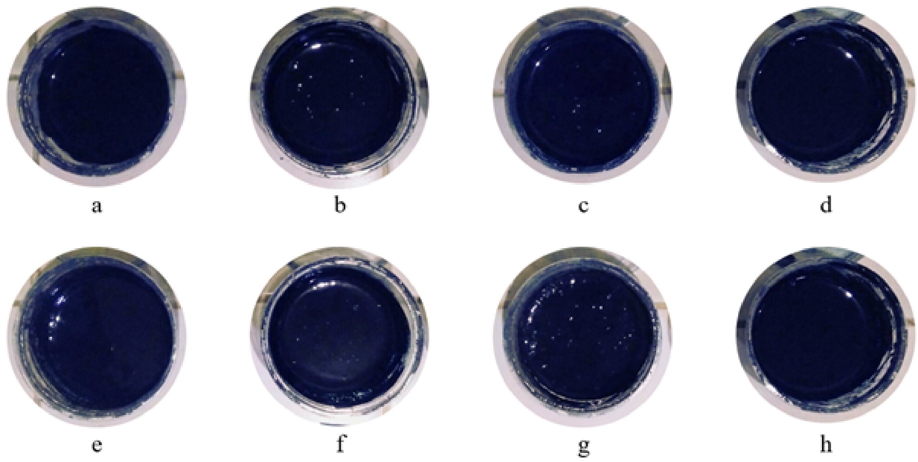


FIGURE 4. The indigo paste color produced, (a) Indigo paste with 25% $CaCO_3$ solution (1st repetition), (b) Indigo paste with 25% $CaCO_3$ supernatant (1st repetition), (c) Indigo paste with 35% $CaCO_3$ solution (1st repetition), (d) Indigo paste with 35% $CaCO_3$ supernatant (1st repetition), (e) Indigo paste with 25% $CaCO_3$ solution (2nd repetition), (f) Indigo paste with 25% $CaCO_3$ supernatant (2nd repetition), (g) Indigo paste with 35% $CaCO_3$ solution (2nd repetition), (h) Indigo paste with 35% $CaCO_3$ supernatant (2nd repetition).

3.4 The mass of indigo pastes produced

Based on the mass table of indigo paste, it can be seen that indigo paste produced from the treatment of giving an activated lime solution with a concentration of 35% lime produced the paste with the most mass followed by indigo paste which was produced from the treatment of giving a solution of 25% activated lime, 35% activated lime supernatant, and 25% activated lime supernatant.

3.5 Indican analysis

The indigo paste produced was then analyzed for its indican content using the HPLC (High-Performance Liquid Chromatography) method. Standard chromatograph of the indican content is presented in Figure 5. The indican content produced in each treatment is presented in Table 2.

The indican content test showed variations in mg/L across treatments. Indigo paste treated with a 25% activated lime solution had the highest indican content (485,974 mg/L), followed by paste treated with a 35% activated lime supernatant (429,057 mg/L), 25% activated lime supernatant (260,812 mg/L), and 35% activated lime solution (120,411 mg/L). The results of the indican content test were then analyzed using statistical tests (ANOVA) to determine whether the differences between treatments were statistically significant. The results of the statistical analysis of the indican test are presented in Figure 6.

Based on the ANOVA analysis of the indican content in the indigo paste produced from different concentrations and solubility of $CaCO_3$, there were significant differences between treatments ($p < 0.05$). The treatment with a 25% $CaCO_3$ solution resulted in the highest average indican content (485.974 mg/L), while the 35% $CaCO_3$ solution resulted in

TABLE 1. The physical characteristics of indigo paste produced.

$CaCO_3$ concentration (%)	Texture	Aroma	Color code	Mass (g)	Repetition
		$CaCO_3$ solution			
25	Very lumpy with a slightly gritty texture	The pungent smell of I. longiracemosa with a hint of $CaCO_3$	#080D2D	66	1st
35	Very lumpy with a slightly gritty texture	The pungent smell of I. longiracemosa with a hint of $CaCO_3$	#0B0F34	87	
25	Very lumpy with a slightly gritty texture	The pungent smell of I. longiracemosa with a hint of $CaCO_3$	#0A0F37	56	2nd
35	Very lumpy with a slightly gritty texture	The pungent smell of I. longiracemosa with a hint of $CaCO_3$	#12163C	75	
		$CaCO_3$ supernatant			
25	Lumpy enough	The pungent smell of I. longiracemosa	#0A0D2E	51	1st
35	Lumpy enough	The pungent smell of I. longiracemosa	#070C2A	53	
25	Lumpy enough	The pungent smell of I. longiracemosa	#0D0E2C	34	2nd
35	Lumpy enough	The pungent smell of I. longiracemosa	#080C29	35	

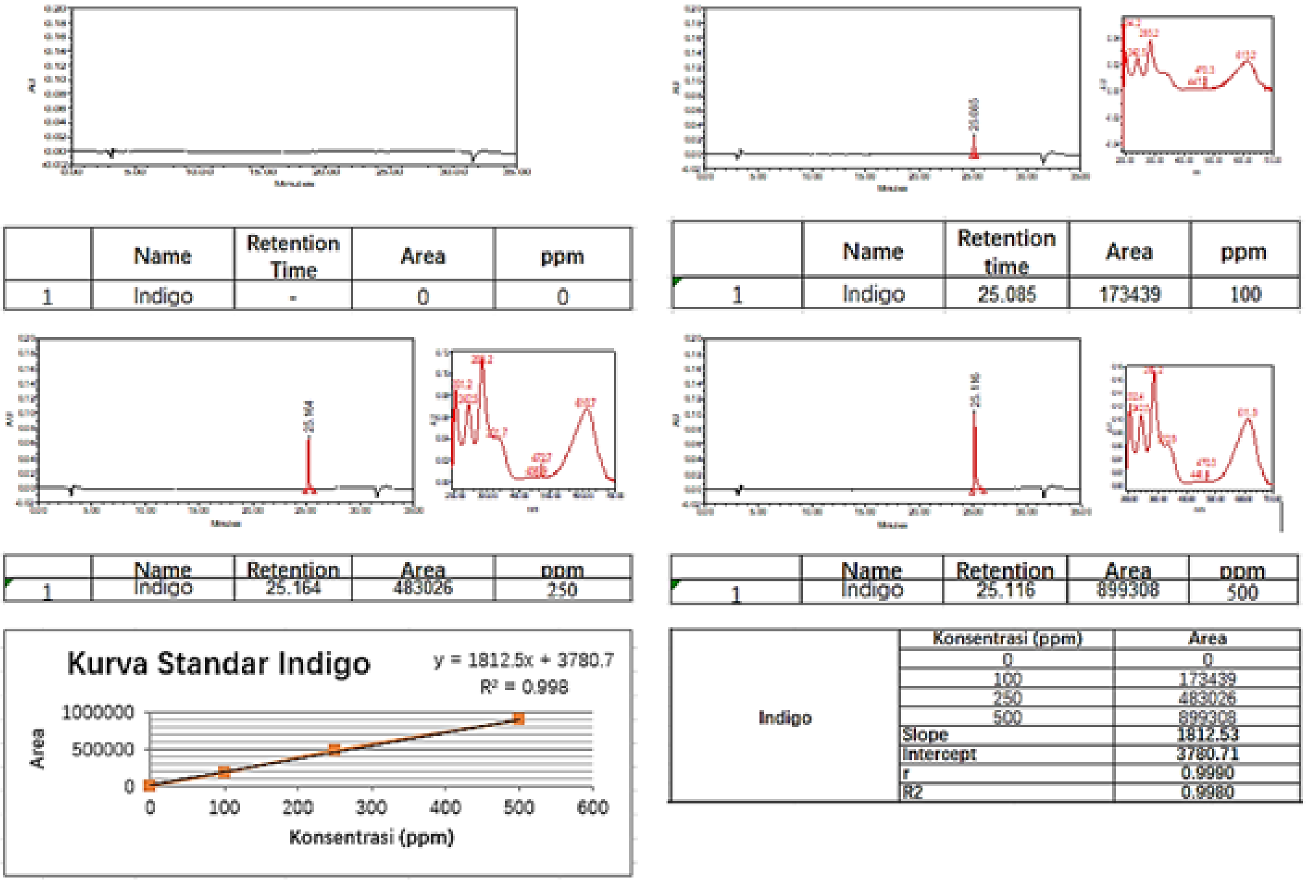


FIGURE 5. Standard cromatograph of the indican content.

the lowest average indican content (120.411 mg/L). This shows that the concentration and form of $CaCO_3$ used significantly affect the indican content produced in the indigo paste production process.

Active lime provides calcium molecules that bind to indigotin molecules in the *Indigofera* leaves to form the paste (Arta et al. 2019). This process prevents color degradation and produces a deeper, more stable blue color. The correct concentration and solubility of $CaCO_3$ are crucial for the quality and intensity of the blue color. Indigo paste with a 25% lime solution produces the highest indican content because this concentration achieves a good redox balance, supported by the optimal pH increase from active lime. On the other hand, the 35% lime solution results in the lowest indican content because, at this high concentration, the $CaCO_3$ solution can cause the pH to increase too much, disrupting the stability of indoxyl, the precursor of indigotin, which reduces the indigo yield. Additionally, increasing the lime concentration makes lime act as a catalyst to speed up the reaction, causing the indigo product to be oxidized by air much faster, so the indigo product cannot be detected because any indigo formed is quickly converted to the indigo dianion (Saikhao et al. 2025).

3.6 Indigo paste dye application on fabric

Indigo paste was then used to dye primis cotton fabrics to determine the effect of different concentrations and solubility of $CaCO_3$ on the resulting color of the fabric. The coloring results are presented in Figure 7.

The data shows that indigo paste treated with a 25% $CaCO_3$ solution (a) produced a very dark blue color on the fabric, with even color distribution but some yellowish-white lime residue on the fabric. Indigo paste treated with a 25%

TABLE 2. Indican content in indigo paste.

$CaCO_3$ concentration (%)	Indican content (g/L)		Mean
	Simplo	Duplo	
$CaCO_3$ solution			
25	497.986	473.962	485.974
35	123.425	117.397	120.411
$CaCO_3$ supernatant			
25	272.723	248.901	260.812
35	451.530	406.584	429.057

Descriptives

Hasil

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Sol25	2	485.97400	16.987533	12.012000	333.34707	638.60093	473.962	497.986
Sol35	2	120.41100	4.262440	3.014000	82.11450	158.70750	117.397	123.425
Sup25	2	260.81200	16.844698	11.911000	109.46840	412.15560	248.901	272.723
Sup35	2	429.05700	31.781621	22.473000	143.51046	714.60354	406.584	451.530
Total	8	324.06350	154.470541	54.613583	194.92290	453.20410	117.397	497.986

ANOVA

Hasil

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	165427.476	3	55142.492	137.808	.000
Within Groups	1600.560	4	400.140		
Total	167028.036	7			

Multiple Comparisons

Dependent Variable: Hasil

Tukey HSD

(I) Perlakuan	(J) Perlakuan	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Sol25	Sol35	365.563000*	20.003500	.000	284.13163	446.99437
	Sup25	225.162000*	20.003500	.001	143.73063	306.59337
	Sup35	56.917000	20.003500	.143	-24.51437	138.34837
Sol35	Sol25	-365.563000*	20.003500	.000	-446.99437	-284.13163
	Sup25	-140.401000*	20.003500	.007	-221.83237	-58.96963
	Sup35	-308.646000*	20.003500	.000	-390.07737	-227.21463
Sup25	Sol25	-225.162000*	20.003500	.001	-306.59337	-143.73063
	Sol35	140.401000*	20.003500	.007	58.96963	221.83237
	Sup35	-168.245000*	20.003500	.004	-249.67637	-86.81363
Sup35	Sol25	-56.917000	20.003500	.143	-138.34837	24.51437
	Sol35	308.646000*	20.003500	.000	227.21463	390.07737
	Sup25	168.245000*	20.003500	.004	86.81363	249.67637

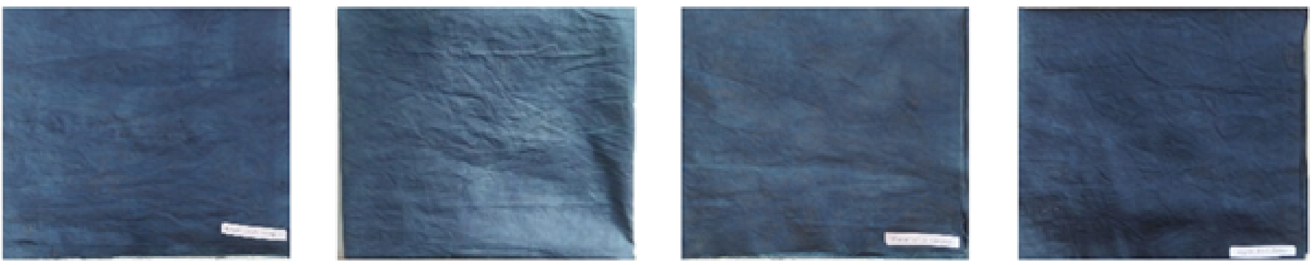
*. The mean difference is significant at the 0.05 level.

FIGURE 6. Statistical analysis table of the indican test.

$CaCO_3$ supernatant (b) resulted in a dark blue color with uneven color spread on the fabric. Indigo paste treated with a 35% $CaCO_3$ solution (c) produced a slightly faded dark blue color with even distribution, but there was a brownish-white lime residue. Indigo paste treated with a 35% $CaCO_3$ supernatant (d) resulted in a very dark blue color on the fabric, evenly spread, and without any lime residue. We recommend *I. longiracemosa* natural dye with the 35% $CaCO_3$ supernatant treatment as the best option, as it produces an intense dark blue color without lime residue, reducing the risk of skin allergies. Adding too little active lime will result in incomplete dye extraction, while using too much lime will cause the paste to contain lime, making the color appear faded (Haryanto and Sasmita 2019). This can happen because adding excessive active lime can actually prevent the indigo pigment from properly bonding to the fabric fibers. A study by Saikhao et al. (2025) also showed that using too much active lime on fabric significantly reduces the indigo content and results in poor dye quality.

3.7 Color quality test on fabric

The fabric that has been dyed with indigo paste is then tested for color quality using a color fastness test to sweat, and a color fastness test to heat. The test results are presented in



a b c d

FIGURE 7. The coloring results on fabric. (a) fabric dyed with indigo paste with 25% $CaCO_3$ solution, (b) fabric dyed with indigo paste with 25% $CaCO_3$ supernatant, (c) fabric dyed with indigo paste with 35% $CaCO_3$ solution, (d) fabric dyed with indigo paste with 35% $CaCO_3$ supernatant.

Table 3.

3.7.1 Color fastness to sweat

Based on Table 3, the sweat fastness test shows that fabrics treated with a 25% $CaCO_3$ solution, a 25% $CaCO_3$ supernatant, and a 35% $CaCO_3$ supernatant all had a color change value of 4, indicating good color fastness and no staining on other fabrics. Meanwhile, fabric treated with a 35% $CaCO_3$ solution had a color change value of 4–5. The high value in this treatment shows a strong bond between the *Indigofera* dye and fabric fibers, preventing color fading even when exposed to sweat or acid (Muzzazinah et al. 2016).

The sweat fastness test also measures color staining on acetate, cotton, polyamide, polyester, acrylate, and wool. The fabrics treated with a 25% $CaCO_3$ solution, 25% $CaCO_3$ supernatant, and 35% $CaCO_3$ supernatant all had the same staining values: 4 on acetate, 3–4 on cotton, 3–4 on polyamide, 4 on polyester, 4 on acrylate, and 3–4 on wool, indicating good color fastness. Meanwhile, fabric treated with a 35% $CaCO_3$ solution showed higher staining values: 4–5 on acetate, 4 on cotton, 4 on polyamide, 4–5 on polyester, 4–5 on acrylate, and 4 on wool, indicating very good color fastness.

3.7.2 Color fastness to heat

The heat fastness test using dry ironing showed the same color change and staining values for all fabrics treated with 25% $CaCO_3$ solution, 25% $CaCO_3$ supernatant, 35% $CaCO_3$ supernatant, and 35% $CaCO_3$ solution. All fabrics had color change and staining values of 4–5, indicating excellent heat resistance. The high color change and staining values show a strong bond between indigotin and fabric fibers, preventing dehydration even under high heat in dry and wet conditions (Muzzazinah et al. 2016).

The color stability of *Indigofera* dye in fabric fibers is due to indigo's ability to bond without a fixation stage. Instead, indigotin tightly adheres to the fibers, making them resistant to color changes during oxidation. Color balance depends on the material type, dyeing process, immersion temperature, solution concentration, pH, and dye affinity (Muzayyinah 2016).

The results of this study can be used as a consideration and reference for creating commercial textile dyes, particularly indigo dyes. This idea is supported by research from (Martuti et al. 2019), which shows that natural dye artisans want to keep innovating but lack the knowledge and skills to create high-quality natural textile dyes. In fact, high-quality natural textile dyes have advantages over synthetic dyes, especially because they are more environmentally friendly.

Natural textile dyes have emerged as an eco-friendly solution for the textile industry (Fried et al. 2022; Singh et al. 2020). Environmentally friendly dyes are non-toxic during production and processing, don't leave toxic residues on the final product, and their waste is easily degradable by nature. For example, waste from leaves, when not used for natural dyes, can be used for compost or animal feed, so it doesn't harm the environment (Eskak and Salma 2020). Natural dyes are non-carcinogenic, making their products safe and comfortable to wear, unlike synthetic textile dyes, which often contain toxic, carcinogenic materials and pollute the environment (Siregar 2017). Eco-friendly products like natural textile dyes align with global market trends for green products (Purwanto 2018) and suit modern consumers who are more concerned about environmental sustainability (Purnama et al. 2017).

Despite their safety and environmental benefits, the natural textile dye industry, especially from *I. longiracemosa*, faces several challenges in production. These challenges include the long dyeing process, which is labor-intensive and needs to be repeated several times (Ariyanti and Asbur 2018; Pujilestari 2017), limited and less vibrant color variations (Alamsyah 2018), and higher costs compared to synthetic dyes due to the more complex production process (Martuti et al. 2019).

The study on the effect of different concentrations and solubility of active lime on the quality of indigo paste has some potential limitations to consider. First, there is poten-

TABLE 3. Color quality test result of indigo paste on fabric.

Type Test	Test Result			
	$CaCO_3$ solution		$CaCO_3$ supernatant	
	25%	35%	25%	35%
Color fastness to sweat				
a. Acid				
Color Change Value	4	4 – 5	4	4
Color Staining Value				
- Acetate	4	4 – 5	4	4
- Cotton	3 – 4	4	3 – 4	3 – 4
- Polyamide	3 – 4	4	3 – 4	3 – 4
- Polyester	4	4 – 5	4	4
- Acrylate	4	4 – 5	4	4
- Wool	3 – 4	4	3 – 4	3 – 4
Color fastness to heat				
Dry Ironing				
- Color Change Value	4 – 5	4 – 5	4 – 5	4 – 5
- Color Staining Value	4 – 5	4 – 5	4 – 5	4 – 5

tial natural variability in the *I. longiracemosa* species used. This study used 9-month-old *I. longiracemosa* plants, with leaves and twigs taken from the third branch from the top and harvested from the same field in Klaten, Central Java. Additionally, all harvesting was done in the morning. Another limitation is the effect of environmental conditions during fermentation and oxidation. The environmental conditions kept in check include a basic pH (>7), room temperature (20-25 °C), and oxygen exposure through aeration. However, factors such as humidity levels and dissolved oxygen variations were not strictly controlled. These factors could affect the effectiveness of the biochemical process, impacting the color quality and the amount of indigo paste produced. With these limitations in mind, the results of this study still provide an important initial overview, but further studies with more controlled environmental conditions and greater repetition are recommended to improve the accuracy and consistency of the results.

4. CONCLUSIONS

Different concentrations and solubility of $CaCO_3$ treatments affected the color, texture, aroma, and mass of the indigo paste. The tested indican content varied across treatments: 25% $CaCO_3$ solution (485.974 g/L), 35% $CaCO_3$ supernatant (429.057 g/L), 25% $CaCO_3$ supernatant (260.812 g/L), and 35% $CaCO_3$ solution (120.411 g/L). Color quality tests showed that fabrics dyed with indigo paste treated with 35% $CaCO_3$ solution had the best sweat fastness, with an average score of 4, indicating good durability, no fading, and no staining. Heat fastness tests for all treatments scored 4–5, showing excellent resistance to fading and staining. Both results meet ISO color fastness standards.

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