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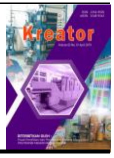

Optimization of Pre-Treatment Methods in Reactive Dye Printing on Handloom Kenaf Fabrics

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A B S T R A K

Pemanfaatan serat kenaf sebagai material tekstil ramah lingkungan menghadapi tantangan dalam proses pencapan, khususnya karena daya serap warnanya yang terbatas. Penelitian ini bertujuan untuk mengkaji dan mengoptimalkan berbagai metode pra-perlakuan pada kain kenaf tenun ATBM dalam proses pencapan menggunakan zat warna reaktif. Desain faktorial berbasis laboratorium digunakan dengan empat variasi pra-perlakuan: tanpa perlakuan, scouring, bleaching, serta kombinasi scouring–bleaching. Evaluasi difokuskan pada uji ketahanan luntur terhadap pencucian, gosokan, dan keringat sesuai standar nasional dan internasional. Uji pencucian menunjukkan nilai 4 hingga 4–5 pada semua perlakuan, menandakan stabilitas yang baik hingga sangat baik. Pada uji gosokan, kain tanpa perlakuan menunjukkan hasil buruk pada kondisi basah (nilai 2), sedangkan perlakuan scouring, bleaching, dan kombinasi meningkat menjadi 2–3 dengan performa tetap kuat pada gosokan kering (4–5). Uji keringat menunjukkan nilai stabil 3 hingga 3–4 baik dalam kondisi asam maupun alkali, yang mengindikasikan pengaruh pra-perlakuan relatif kecil dan lebih dipengaruhi oleh sifat kimia zat warna–serat. Di antara perlakuan yang diuji, bleaching tunggal menghasilkan warna paling cerah, merata, serta ketahanan luntur yang unggul, sementara kombinasi scouring–bleaching menyebabkan inkonsistensi akibat paparan kimia berlebih. Dengan demikian, bleaching tunggal direkomendasikan sebagai pra-perlakuan paling efektif untuk mendukung pemanfaatan serat kenaf alami dalam tekstil berkelanjutan.

A B S T R A C T

The use of kenaf fiber as an eco-friendly textile material faces challenges in the dye printing process, particularly due to its limited dye absorption. This study aims to investigate and optimize various pre-treatment methods on handloom kenaf fabrics for reactive dye printing. A laboratory-based factorial design was employed, testing four pre-treatment variations: untreated, scouring, bleaching, and a combination of scouring and bleaching. Evaluations focused on color fastness to washing, rubbing, and perspiration, following national and international testing standards. The washing fastness test showed ratings of 4 to 4–5 across all treatments, indicating good to very good stability. Rubbing fastness revealed that untreated fabric performed poorly under wet conditions (score 2), while scouring, bleaching, and combined treatments improved results to 2–3, maintaining strong performance under dry rubbing (4–5). Perspiration fastness showed relatively stable ratings of 3 to 3–4 in both acidic and alkaline conditions, suggesting minimal influence of pre-treatment and stronger dependence on dye–fiber chemistry. Among the treatments, bleaching alone produced the brightest, most uniform prints with superior overall fastness, whereas combined scouring-bleaching caused fiber inconsistency due to chemical overexposure. In conclusion, single-step bleaching is the most effective pre-treatment, supporting the sustainable use of natural kenaf fibers in textile applications.
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1. INTRODUCTION

The textile industry continues to evolve with various innovations focused on sustainability, including the increased use of natural fibers as eco-friendly alternatives to synthetic materials. One such natural fiber that has garnered significant attention is kenaf (*Hibiscus cannabinus*), valued for its high tensile strength, durability, and natural biodegradability (Nurhasanah et al., 2024). In Indonesia, the largest kenaf plantations are located in Laren, Lamongan, East Java (Irawati et al., 2022).

In small-scale textile industries, *Alat Tenun Bukan Mesin* (ATBM), or handlooms (HL), remain a vital component of traditional weaving practices (Teowarang et al., 2023). The integration of kenaf fiber in handloom production offers a promising opportunity to support sustainable practices in the textile sector (Hapidh, 2017). However, one of the key challenges in utilizing kenaf fabric is its limited dye absorption capacity, particularly when using reactive dyes, which are commonly employed in textile printing (Masykur & Puspitasari, 2019).

Kenaf fibers have a distinct cellulose structure compared to cotton, which impacts their interaction with dyes. To enhance dye uptake and overall printing performance, appropriate pre-treatment processes are essential. These treatments aim to improve dye penetration, color brightness, wash and rub fastness, and the overall stability of the printed output (Sannapapamma et al., 2022). Common pre-treatment methods include desizing, scouring, bleaching, and chemical modifications that alter fiber surface properties (Kuntari, 2006).

Despite the potential of kenaf as a sustainable textile material, there is a lack of comprehensive studies that examine the optimal pre-treatment variations specifically for reactive dye printing on handloom-woven kenaf fabrics. Previous research has also noted that kenaf fibers are too stiff to be spun using Machine Looms (ML), although they can be blended with cotton fibers, as practiced in Tunisia, to produce yarns (Yosr et al., 2023). Beyond textiles, high-quality kenaf fibers are also used in the automotive, pulp and paper, and geotextile industries due to their mechanical properties and renewability (Ciptandi & Puspitasari, 2023).

The novelty of this research lies in the optimization of various pre-treatment methods on kenaf fibers woven with HL to achieve the best possible outcomes suitable for textile interiors or batik applications. Therefore, this research aims to investigate and optimize various pre-treatment methods on handloom kenaf fabrics for reactive dye printing. By determining the most effective treatment conditions, the study seeks to improve color quality, colorfastness, and contribute to the advancement of eco-conscious textile manufacturing.

2. METHOD

Research Variables

This study employs a laboratory experimental method with a factorial design to examine the effect of different pre-treatment variations (Table 1) on the results of reactive dye printing. The independent variable in this research is the pre-treatment method, while the dependent variables include the quality of the printing outcomes, specifically color fastness, dye absorption, and motif sharpness. The controlled variable is the use of reactive dyes. Data will be analyzed using the Concurrent Triangulation method, in which quantitative and qualitative data are collected simultaneously and compared to obtain more accurate and comprehensive conclusions.

Table 1. Variable Variations in Research Method

No	Pre-Treatment Variations	Description
1	Initial condition	Ic
2	Scouring process	Sc
3	Bleaching process	Bl
4	Scouring-bleaching process	Sc-Bl

Research Flow

The research flow diagram is presented in Figure 1. The handloom kenaf fabric was treated with variations of pre-treatment processes, including scouring, bleaching, and combined scouring-bleaching. Following the pre-treatment, the fabric was subjected to a printing process using reactive dyes (Haris, Sasongko, & Ramadhani, 2025). The final stage involved evaluating the color fastness properties of the printed fabric.

Preparation of Pre-Treatment Variations

The pre-treatment preparation stage was divided into three treatment paths: scouring, bleaching, and a combined scouring-bleaching process including sodium hydroxide (NaOH, 38°Bé, technical grade), sodium carbonate (Na_2CO_3, analytical grade, Merck), and teepol detergent (local market) for scouring (Luciana & Salamah, 2023). While bleaching employed hydrogen peroxide (H_2O_2, 50% solution, analytical grade, Merck) and sodium silicate (Na_2SiO_3, waterglass, local market) (Schreiber et al., 2021) . The combined scouring-bleaching treatment is expected to offer the most comprehensive effect, both in terms of physical impurity removal and lignin degradation (Jiang et al., 2024).

Preparation of Printing Paste

In this study, the printing paste was prepared using a two-stage reactive dye printing method to enhance color yield and fixation on cellulose-based fabric (Haris, Lestari, et al., 2025). In the first stage, the paste formulation included a reactive dye, 2% Manutex as a thickener, and water, which served both as a solvent and a balancing medium to ensure proper viscosity and even dye distribution. In the second stage, a separate chemical solution composed of sodium hydroxide (NaOH), sodium silicate (waterglass), and water was applied to initiate the dye–fiber reaction and promote color development.

Printing Process

The printing process was carried out following standard textile printing procedures. The handloom kenaf fabric was placed on a printing table, and a screen was positioned on top of it. The first-stage printing paste was then applied and evenly spread across the screen using a squeegee. The printed fabric was subsequently dried under sunlight. In the second stage, after the printed fabric had completely dried, a waterglass paste was applied directly onto the printed areas. The fabric was left to rest for approximately two hours to allow fixation, followed by thorough rinsing with running water and final drying (Haris, Sasongko, Murty, et al., 2025).

Color Fastness Test

The washing fastness test was carried out in accordance with the SNI ISO C06:2010 standard, while the rubbing fastness test followed the SNI ISO 105-X12:2013 method. In addition, the color fastness to perspiration was assessed using the AATCC Test Method 15 to simulate the effects of exposure to sweat on the printed fabric. These evaluations provide a comprehensive assessment of the printed fabric's resistance to common physical and chemical stresses during use (Maghfiroh et al., 2025).

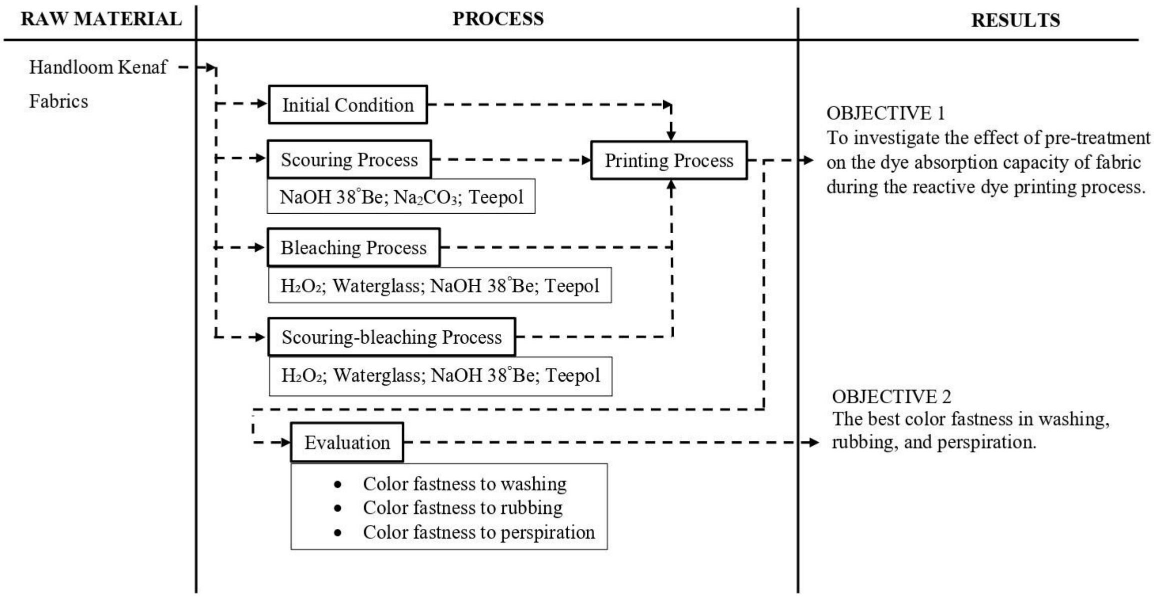


Figure 1. Research Flow Chart

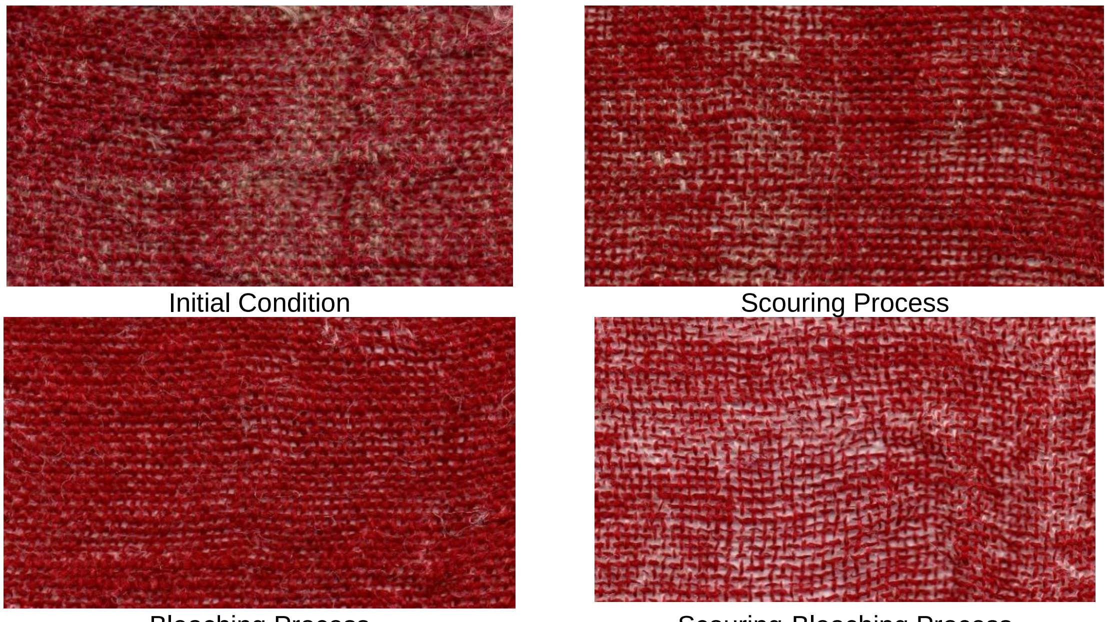
3. RESULT AND DISCUSSION

This study systematically presents the methodological flow of reactive dye printing on handloom kenaf fabric, beginning with variations in pre-treatment and concluding with an evaluation of print quality. The process begins with the selection of kenaf fabric as the primary substrate, chosen for its natural, cellulose-based composition. However, due to its high lignocellulosic content, kenaf poses specific challenges in dye absorption, making pre-treatment a critical phase. The fabric was subjected to four pre-treatment conditions: untreated (control), scouring, bleaching, and a combination of scouring and bleaching. Each method employed standardized chemicals—scouring used NaOH 38°Bé, Na_2CO_3, and Teepol to remove surface impurities and waxes, while bleaching utilized H_2O_2 and waterglass to degrade lignin and brighten the substrate.

The untreated fabric displayed dull surface coloration, stiffness, and non-uniformity—visual and tactile indicators of the presence of natural contaminants. These contaminants obstruct dye penetration and limit covalent bonding between reactive dye molecules and the fiber surface. In contrast, scoured fabric showed improved softness and surface cleanliness, which facilitated greater dye receptivity. Bleached fabric exhibited a brighter and cleaner appearance, enhancing the visual brilliance of the final print. Interestingly, the combined scouring-bleaching treatment produced inconsistent results; while it theoretically offered comprehensive cleaning, it also appeared to compromise fiber integrity, likely due to overexposure to aggressive chemicals. This resulted in uneven dye uptake and visible areas of incomplete coloration.

After pre-treatment, the fabrics were printed using reactive dyes, selected for their ability to form strong covalent bonds with cellulose fibers, thus offering excellent wash fastness and color retention. The printed outcomes, as shown in Figure 2, clearly demonstrate the direct influence of pre-treatment on print quality. Fabrics without pre-treatment yielded prints that were dull, faded easily upon washing, and lacked uniformity, highlighting the ineffectiveness of dye-fiber interaction in the presence of natural barriers. In contrast, scoured and bleached samples exhibited enhanced sharpness, brightness, and color distribution, with bleaching alone producing the most uniform and vivid results. However, the combined treatment, despite expectations, led to a reduction in print definition suggesting that excessive chemical exposure may disrupt the fiber's physical structure and dye-binding sites.

This study confirms that pre-treatment plays a decisive role in determining the success of reactive dye printing on kenaf fabric. Among the tested methods, bleaching alone produced the most optimal outcomes in terms of both visual quality and durability. These findings underscore the importance of fiber surface activation and controlled chemical treatment to maximize dye affinity and overall print performance. The structural state of the fabric before printing, which is largely influenced by the pre-treatment stage, plays a crucial role in determining the efficiency of the dyeing process and the overall quality of the resulting textile.



Initial Condition | Scouring Process

Bleaching Process | Scouring-Bleaching Process

Figure 2. Results of the Resist Printing Process with Pigment Dyes

The results of the color fastness to washing test, as presented in Table 2, indicate that all treatments whether untreated or subjected to scouring, bleaching, and scouring-bleaching achieved ratings ranging from 4 to 4–5 for both color change and staining on cotton and silk fabrics. These values correspond to good to very good fastness levels. Although there were no striking numerical differences among the treatments, the scouring (Sc), bleaching (Bl), and combined scouring-bleaching (Sc-Bl) consistently achieved uniform ratings of 4–5. In contrast, the untreated control (Ic) showed a slight reduction in staining on the cotton fabric.

This finding suggests that pre-treatment enhances the bonding between the reactive dyes and kenaf fibers, thereby improving color stability and reducing the likelihood of fading during washing. Therefore, the application of pre-treatment plays a crucial role in preserving the visual quality of the textile throughout usage and laundering cycles.

Table 2. Results of Color Fastness Tests to Washing

Color Fastness to Washing			
Pre-Treatment Variations	Color Change	Staining on Cotton Fabric	Staining on Silk Fabric
Ic	4-5	4	4-5
Sc	4-5	4-5	4-5
Bl	4-5	4-5	4-5
Sc-Bl	4-5	4-5	4-5

The rubbing fastness (Table 3) results revealed a clear distinction between untreated and pretreated fabrics. Quantitatively, the untreated fabric (Ic) showed good stability in dry rubbing, with scores of 4–5 on cotton and 4 on silk, but a marked weakness in wet rubbing, where the score dropped to only 2 on both substrates. In contrast, fabrics subjected to scouring (Sc), bleaching (Bl), and combined scouring-bleaching (Sc-Bl) exhibited improved wet rubbing fastness, increasing to 2–3, while maintaining stable performance in dry rubbing. Qualitatively, this improvement can be attributed to the removal of impurities such as waxes, pectin, and lignin during pretreatment, which enhanced fiber hydrophilicity and promoted stronger dye–fiber interaction. Through concurrent triangulation of the quantitative scores and qualitative interpretation, it can be concluded that pretreatment, particularly the combined scouring-bleaching process, positively contributes to better color fastness under wet conditions without compromising dry rubbing performance, thereby confirming its effectiveness in enhancing the overall dyeability of kenaf fabrics.

These findings indicate that pre-treatment effectively enhances the dye–fiber affinity and fixation, thereby preventing color loss caused by friction under moist conditions. Among the treatments, bleaching and the combined scouring-bleaching processes emerged as the most effective, showing superior color stability under both dry and wet rubbing conditions. Color fastness in wet conditions is a critical quality parameter, especially for apparel products, which are frequently exposed to moisture and friction during wear and care.

Table 3. Results of Color Fastness Tests to Rubbing

Color Fastness to Rubbing				
Pre-Treatment Variations	Dry Rubbing (Cotton Fabric)	Dry Rubbing (Silk Fabric)	Wet Rubbing (Cotton Fabric)	Wet Rubbing (Silk Fabric)
Ic	4-5	4	2	2
Sc	4-5	4-5	2	2
Bl	4-5	4-5	2-3	2-3
Sc-Bl	4-5	4-5	2-3	2-3

The effect of perspiration, both acidic and alkaline, reflects a critical parameter in assessing textile performance for daily use. Quantitative results (Table 4) showed that the untreated fabric (Ic) had moderate resistance to acidic synthetic sweat, with a rating of 3 for both cotton and silk substrates, while slightly better performance was noted under alkaline conditions with scores of 3–4. Similar tendencies were observed in fabrics treated with scouring (Sc) and bleaching (Bl), indicating that these individual pretreatments did not substantially alter the perspiration fastness properties. Moreover, the combined scouring-bleaching treatment (Sc-Bl) did not provide any significant enhancement, as the ratings remained within the same range of 3 to 3–4. Qualitatively, this suggests that perspiration fastness in kenaf fabrics is less influenced by surface impurities or lignin removal, but more closely related to the intrinsic chemical interaction between dyestuffs and the fiber matrix under acidic or alkaline conditions. Through concurrent triangulation of quantitative scores and qualitative interpretation, it can be inferred that pre-treatment processes primarily improve wet rubbing performance, whereas their effect on perspiration fastness remains limited, highlighting the need for additional finishing strategies to achieve better durability under sweat exposure.

In comparison, the evaluation of handloom kenaf fabrics shows results that are generally similar to those of handloom silk fabrics in terms of washing and dry rubbing fastness, as reported by (Maghfiroh et al., 2025). However, a notable difference lies in the wet rubbing fastness, where handloom kenaf fabrics performed less favorably. This indicates that the fundamental characteristics of handloom kenaf and silk fabrics are comparable in terms of resistance to washing and dry rubbing, suggesting that the fixation and retention of dyes are relatively similar. However, the lower wet rubbing fastness observed in handloom kenaf implies that the dye–fiber bonding is less stable under moist conditions, which may be attributed to the chemical differences between kenaf (cellulose-based) and silk (protein-based fibroin) fibers.

Table 4. Results of Color Fastness Tests to Perspiration

	Color Fastness to Perspiration			
Pre-Treatment Variations	Acid Perspiration (Cotton Fabric)	Acid Perspiration (Silk Fabric)	Alkaline Perspiration (Cotton Fabric)	Alkaline Perspiration (Silk Fabric)
Ic	3	3	3-4	3-4
Sc	3	3	3-4	3-4
Bl	3	3	3-4	3-4
Sc-Bl	3	3	3-4	3-4

Although the differences among treatments were not substantial, the relatively stable ratings across all conditions suggest that pre-treatment has no dramatic effect on perspiration fastness, unlike its influence on washing or rubbing fastness. This can be attributed to the nature of the interaction between reactive dyes and the ions present in sweat solutions, which is less dependent on surface cleanliness and more influenced by the chemical type and structure of the dye itself. Nonetheless, pre-treatment still plays a supportive role in maintaining optimal performance and preventing a sharp decline in the textile's resistance to human body conditions. In short, the data suggest that perspiration fastness is mainly governed by dye–fiber chemistry, while pre-treatment functions more as a stabilizing factor rather than a decisive one.

4. CONCLUSION

This study successfully demonstrates that variations in pre-treatment significantly influence the quality of reactive dye printing on handloom kenaf fabric (ATBM). Experimental findings reveal that each pre-treatment type imparts distinct functional and visual characteristics to the fabric, particularly in terms of dye uptake, color fixation stability, and fastness to washing, rubbing, and perspiration. Scouring effectively enhances fiber porosity and removes non-cellulosic substances, improving dye affinity, while bleaching improves substrate brightness, resulting in sharper and more uniform coloration. Although the combined scouring-bleaching treatment theoretically offers synergistic benefits, it tends to cause uneven dye distribution and potential fiber degradation due to over-treatment. Color fastness tests show that all pre-treatment methods enhance performance compared to untreated fabric, with bleaching and combined treatments yielding the best results in wet rubbing, whereas perspiration fastness showed minimal variation, indicating a stronger dependence on dye chemistry. Overall, single-step bleaching emerges as the most effective pre-treatment for kenaf fabric, providing optimal color clarity, uniformity, and durability without compromising fiber integrity. These findings contribute valuable insights into sustainable textile processing and support the industrial adoption of kenaf-based materials as eco-friendly alternatives.

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