TEKNOBUGA Vol. 14 No.1 (2026)

p-ISSN 2085 4056
e-ISSN 2528 7087

JURNAL TEKNOLOGI BUSANA DAN BOGA

https://journal.unnes.ac.id/journals/teknobuga/index

Improving Color Fastness of Natural Dyes from *Siwalan* Fruit Skin (*Borassus flabellifer L.*) on Cotton and Shantung Fabrics Using Various Fixing Agents

Husnun Hanifah and Sugiyem*

Department of Fashion Education, Faculty of Engineering, Universitas Negeri Yogyakarta, Indonesia
*Corresponding author: sugiyem@uny.ac.id

ABSTRACT - This study aims to determine the effect of using alum powder, iron sulfate (*tunjung*) solution, and pure lime (quicklime) as fixing agents on the color fastness of dyeing using *Siwalan* fruit peel extract on *primissima* cotton and shantung fabric in terms of washing and ironing. The research design was a 3×2 factorial experiment using natural dyes from *Siwalan* fruit peel obtained from traders on Jalan Imogiri Timur, Yogyakarta. The samples consisted of *primissima* cotton and shantung fabric, while the fixing agents used included quicklime, alum powder, and iron sulfate solution. Data were collected through color fastness tests against washing and heat from ironing conducted by the UII Textile Manufacturing and Testing Laboratory. Results were analyzed using the Kruskal-Wallis test. The findings demonstrated that using different fixing agents significantly affected color fastness. Specifically, alum powder produced superior color fastness to washing on *primissima* cotton fabric (average score of 4.0), while all three fixing agents showed equivalent performance on shantung fabric (average score of 4.0). For heat resistance during ironing, alum powder and iron sulfate solution achieved the highest scores (4.5 on average) on both fabric types, representing a 12.5% improvement over the quicklime treatment (4.0). These results indicate that the selection of fixing agents is crucial for optimizing the color fastness properties of natural dyes from *Siwalan* fruit peel.

Keywords: Fixing agent, color fastness, *Siwalan* fruit skin, natural dyes, *primissima* cotton, shantung fabric.

INTRODUCTION

Indonesia is a country with abundant natural resources. Initially, textiles were dyed with natural dyes, but over time, synthetic dyes replaced them because they were more practical. Natural dyes were abandoned due to the difficulty of obtaining raw materials, the complexity of the processes, and the limited color variations. In the fashion industry, during the dyeing process, around 10-15% of the synthetic textile dyes used end up as waste, which then has the potential to damage the surrounding ecosystem (Ayu & Putu, 2023). Increasingly fierce competition in the textile industry has driven demand for a wider variety of colors. Currently, various types of synthetic textile dyes are available, offering a wide range of color options. However, waste from these synthetic dyes can pollute the environment.

The environmental impact of synthetic dye waste presents a significant challenge for sustainable textile production. Recognizing this problem, the potential of locally available natural materials, such as *Siwalan* fruit peel, offers a promising solution that aligns with environmental preservation and waste reduction objectives. By utilizing abundant agricultural byproducts as natural dye sources, textile producers can reduce environmental pollution while maintaining product quality and sustainability standards.

Indonesia has a rich natural environment that can serve as a safe source of dyes with beneficial compounds for the body. In addition, Indonesia's natural wealth and biodiversity provide raw materials for the production of natural dyes.

This made Indonesia the world's leading producer of natural blue indigo dye during the Dutch colonial period, from 1602 to 1942. Currently, around 150 types of natural dyes have been identified in Indonesia.

The growing fashion industry in Indonesia certainly poses a challenge for businesses, which must continuously innovate, including in textile colors. The dyeing process can use natural and synthetic dyes. Currently, many textile craftsmen prefer synthetic dyes because they are more practical, offer a wide range of colors, and are readily available. Data from the Central Statistics Agency (2021) shows that over the past five years, the average annual import of synthetic dyes has exceeded 42,000 tons. Synthetic dye waste can cause significant environmental pollution if not treated properly. However, the continuous use of synthetic dyes will have a negative impact on the environment; therefore, it is necessary to explore natural dyes (Yanuar, 2023). Synthetic dye waste can cause significant environmental pollution if not treated properly (Che & Yang, 2022). However, the continuous use of synthetic dyes will have a negative impact on the environment; therefore, it is necessary to explore natural dyes.

The use of natural dyes has various advantages. Among other things, natural dyes not only add a distinctive touch but also create a unique character with an aesthetic distinct from that of chemical dyes. In addition, their use is more environmentally friendly and sustainable (Afiatna et al., 2024). Natural colors are often the choice for lovers of tradition and sustainability in textile art. Natural dyes can be sourced from plants and animals. The exploration of natural dye sources can be carried out from Indonesia's abundant natural resources. Natural colors can be obtained from various plant sources. Some of these color pigments are formed through heating, processing, or storage, while others are naturally present in plant tissues. Some common types of natural coloring pigments include chlorophyll, which produces green colors and is generally found in leaves; carotenoids, which produce yellow to orange colors, such as in carrots; tannins, which produce brown colors and are commonly found in bark; and anthocyanins, which produce purple to red colors and are commonly found in flowers and fruits.

The skin of the *Siwalan* fruit (Borassus flabellifer) is a type of plant waste that can be used as a natural dye. As a palm tree species, the *Siwalan* tree is widely distributed in Tuban Regency and can only thrive in tropical climates. *Siwalan* grows optimally in dry, open areas at an altitude of 0-500 meters above sea level. In Indonesia, this plant is found in coastal areas, such as East Java (Lamongan, Gresik, and Tuban), Central Java, Madura, Bali, NTT, NTB, Southeast Maluku, and South Sulawesi. *Siwalan* trees grow abundantly in lowlands, coastal areas, and dry lands. *Siwalan* grows optimally in dry, open areas at an altitude of 0-500 meters above sea level. In Indonesia, this plant is found in coastal areas, such as East Java (Lamongan, Gresik, and Tuban), Central Java, Madura, Bali, NTT, NTB, Southeast Maluku, and South Sulawesi(Rohalida et al., 2022). *Siwalan* trees grow abundantly in lowlands, coastal areas, and dry lands. Planting *Siwalan* trees is also beneficial for increasing the water table through their taproot system (Sivasankar et al., 2023). *Siwalan* fruit *(Borassus flabellifer)* is widely distributed in the southern part of the Indian subcontinent for the consumption of its fruit and water (Narayanankutty et al., 2023). The *Siwalan* fruit *(Borassus flabellifer*) contains about 40% undiluted dark yellow pulp with a distinctive taste and bitterness, and the pulp is extracted manually or mechanically with water (Sangeetha et al., 2023) In addition, ripe *Siwalan* fruit is a potentially important source of nutrients, especially antioxidants and carotenoids, which are promising for health (Sathyaruban et al., 2024).

Based on observations and interviews with three *Siwalan* fruit sellers in the Yogyakarta region, significant quantities of peel waste are generated daily. A seller on Solo–Yogyakarta Street reported average daily sales of 30 pieces, generating approximately 15 kg of *Siwalan* fruit peel waste. A seller on Imogiri Timur Street reported selling 40 fruits daily, producing approximately 20 kg of waste. A third vendor in Panjatan Kulon Progo reported selling 30 fruits daily, with approximately 15 kg of waste. Based on data from all three sources, approximately 17 kg of *Siwalan* fruit peel waste is produced per day. This accumulation can reach 119 kg per week if left unattended. Currently, the *Siwalan* fruit peel is usually just discarded because no one has found a practical use for it. The public perception that this material is merely waste suggests that its potential has not been optimally explored. In fact, the *Siwalan* fruit peel has the potential to be reprocessed, thereby adding value and creating environmental benefits.

Several studies have explored various applications of palm tree components, such as the use of palm fiber waste as a base material for handicrafts (Apriyanti, 2018). The use of palm shell waste as activated carbon with $ZnCl_2$ and $NaCO_3$ activators in an effort to purify used cooking oil (Ihsan, 2022). Utilization in the culinary field, namely innovation in processed food products in the form of dodol *Siwalan* (Hayati et al., 2023) And *lontar* fruit is used as a raw material for pudding, which is developed into a functional food to support physical health (Dewi & Yanuarto, 2024). Ethanol extract of palm fruit skin was used to test antibacterial activity against the growth of Streptococcus mutans (Aprilia et al., 2021). Utilization of palm frond waste as a planting medium for briquettes (Hardiyanti et al., 2021) The skin of the *Siwalan* fruit produces light brown to dark brown colors, depending on the length of immersion, when used as a natural dye for mastectomy bra products. In this study, the textile material used was Tencel (Rohalida et al., 2022). Recent research has demonstrated that *Siwalan* fruit peel produces light to dark brown colors, depending on extraction and dyeing parameters, making it a viable natural dye source. However, previous research has been limited to specific textile materials such as Tencel. To date, the use of *Siwalan* fruit peel as a natural dye on *primissima* cotton and shantung fabrics has not been widely explored, presenting a significant research opportunity.

LITERATURE REVIEW

Natural Dye

Natural dyes used as coloring agents can be sourced from animals, minerals, or plants, and can be used directly or after processing. Natural dyes can be found widely both on land and in the sea, and can be obtained from sources such as plants, animals, microorganisms, minerals, and other materials have been explored (Li et al., 2022). The use of natural dyes is well known; for example, indigo from plants has been used for thousands of years. Natural dyes are divided into several main categories based on their chemical structure, such as indole derivatives, alkaloids, polyenes, macrolides, peptides, or terpenoids.

The use of natural dyes for textiles requires the addition of substances that serve as binders or fixatives in the dyeing or coloring process to produce bright, long-lasting colors. Natural dyes are obtained through extraction from certain parts of plants, such as wood stems, roots, seeds, leaves, and flowers.

Siwalan Fruit Peel as a Natural Dye

Siwalan, or *lontar* (*Borassus flabellifer L.*), belongs to the *Arecaceae* family and is a dioecious monocotyledonous palm tree. This plant can grow to a height of up to 30 meters, with fan-shaped leaves measuring 1-3 meters in diameter. This palm tree is found in a number of regions in Indonesia, including Central Java, East Java, Madura, Bali, West Nusa Tenggara, East Nusa Tenggara, South Sulawesi, and Southeast Maluku (Rokhania et al., 2025). The plant has a distinctive morphology, with a single cylindrical stem that can grow up to 30 meters, a stem diameter of about 40-50 cm, and large fan-shaped leaves.

Siwalan is widely distributed across tropical regions, including Indonesia and India, and is known as a versatile plant with many benefits. In addition to its fruit being beneficial for health due to its nutrient content, the skin of the *Siwalan* fruit is also useful as a natural textile dye. Ripe *Siwalan* fruit contains approximately 40% dark yellow pulp with high levels of antioxidants and carotenoids, which are promising compounds for both health and dyeing applications.

Textile Materials

Textile materials are all types of materials derived from fibers or threads that are processed through techniques such as weaving, knitting, or other methods of joining to form sheets of fabric. These materials are widely used in the manufacture of clothing, household items, and industrial and technical applications (Hadi et al., 2022). Each type of textile fiber has unique characteristics that require different dyeing methods.

Cotton is one of the most commonly used fibers because it is highly absorbent, comfortable, readily available, and affordable. Despite undergoing various processes, cotton retains its physical properties, is water-absorbent (hydrophilic), and is resistant to alkalis, making it ideal for use as a colored textile material. In Indonesia, textile products made from cotton fiber are better known as katun (Kusrianto, 2020). Types of cotton fabric include prima cotton, *primissima* cotton, poplin cotton, and Japanese cotton. Cotton fabric is generally characterized by its soft and smooth texture, making it comfortable and non-irritating to the skin. Cotton fabric has excellent absorbency for sweat and water, making it ideal for use in hot and humid weather.

One type of cotton- or rayon-based fabric that resembles cotton is shantung fabric. Shantung fabric is a lightweight, slightly textured fabric with characteristics that make it drape well, feel soft, and stay cool when worn. The main base material for shantung fabric is generally viscose rayon, although some types use *primissima* cotton. Because rayon and cotton absorb color well, shantung fabric is well-suited to hand-drawn or stamped dyeing. The colors on shantung fabric tend to be sharp and durable if fixed properly.

Fixing Agent

Fixation is the process of strengthening colors so they do not fade quickly, binding natural dyes, and creating color variations according to the type of fixation material used (Ardhea et al., 2023). To make the colors from natural substances more stable and less prone to fading, a fixation process is carried out to strengthen the bond between the dye and the fabric fibers, using solutions such as alum, iron sulfate ($FeSO_4$), and quicklime (CaO) (Khoiron Nisa et al., 2022).

Fixation is an important stage in fabric dyeing, locking in the color so it does not fade easily. The use of alum helps strengthen the bond between natural dyes and fabric fibers, thereby increasing color fastness to washing and rubbing (Yuniati et al., 2021). The final color is greatly influenced by the amount and technique of dyeing used, as well as the type of fixative applied. According to research, fixation is performed after the fabric is dyed with natural dyes, and there are three fixation methods, each producing different results.

Generally, the use of different binding agents has a specific effect on the fabric's color. The use of alum as a binding agent produces a brighter fabric color closer to the original dye color. Conversely, the use of iron sulfate darkens and mutes the fabric color. Meanwhile, the use of quicklime produces a lighter, more distinct color variant. The selection of the fixing agent is therefore critical for achieving desired color outcomes.

Color Fastness

Color fastness is the ability of a textile material to retain its original color despite undergoing certain treatments, such as washing, rubbing, perspiration, exposure to light, and everyday use. According to Kartikasari & Enggar (2021) Color fastness is an important property in fabrics because colors that fade easily reduce the product's aesthetic value and quality. Color fastness to rubbing is an important parameter in fabric quality testing. This parameter indicates the extent to which the color on the fabric remains intact after experiencing friction during use.

Color fastness remains a major challenge in dyeing with natural dyes. To overcome this, dye extraction with solvents and the application of appropriate dyeing methods are carried out to improve fastness. Today, natural dyes are once again popular as environmentally friendly dyeing options and leading alternatives. The use of a fixing solution helps improve color fastness to rubbing and washing. Al^{3+} ions in fixatives bind with tannin compounds, forming larger natural dye molecules that are difficult to remove from the fiber gaps, thereby increasing color fastness against fading.

METHOD

This study used a purely experimental approach to observe changes in the fabric after dyeing. This study applied a 3×2 factorial experimental design, with two factors being tested.

Experimental Design

The first factor was the type of fabric, consisting of *primissima* cotton fabric (A) and shantung fabric (B). The second factor was the type of fixing agent, consisting of alum powder at 5% concentration (a), iron sulfate solution at 3% concentration (b), and pure lime (quicklime) at 2% concentration (c). The combination of these two factors resulted in six treatments (A×a, A×b, A×c, B×a, B×b, B×c).

TABLE 1. Experimental design.

Fabric Type	**Alum Powder (5%)**	**Iron Sulfate (3%)**	**Quicklime (2%)**
Primissima Cotton	A×a	A×b	A×c
Shantung Fabric	B×a	B×b	B×c

Each treatment was carried out in three replicates, resulting in a total of 18 samples for testing color fastness to washing and 18 samples for testing color fastness to dry ironing. This approach allows for a systematic and measurable interaction between fabric type and fixation type on color fastness.

Data collection in this study was conducted through a series of laboratory experiments. Fabric samples that had undergone dyeing were further tested to assess the quality of the dyeing results. The tests conducted included color fastness to washing and heat fastness through ironing. These tests were carried out by a team of testers from the Textile Manufacturing and Testing Laboratory, Textile Engineering Study Program, Faculty of Industrial Engineering, Islamic University of Indonesia (UII). Test procedures followed standard ISO protocols. After the samples were tested, the test results were reported as numerical color fastness values on the Grey Scale (1-5 rating).

The data analysis technique used in this study is descriptive statistical analysis. Prior to hypothesis testing, normality and homogeneity tests were conducted using the Shapiro-Wilk and Levene tests, respectively. Following these preliminary tests, the Kruskal-Wallis nonparametric test was used to analyze differences among treatment groups. Data analysis was conducted using IBM SPSS 25. A significance level of $\alpha = 0.05$ was used throughout the analysis. If the significance results showed $p < 0.05$, it indicated a significant effect, and the hypothesis was accepted. If the significance results showed $p > 0.05$, it indicated no significant effect, and the hypothesis was not accepted.

RESULTS AND DISCUSSION

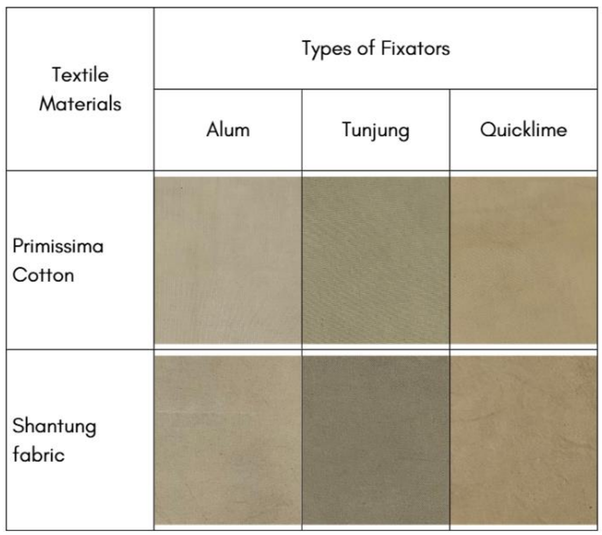

FIGURE 1. Dyeing result.

TABLE 3. Color fastness test results to washing and ironing.

Treatment	Fabric Type	Fixing Agent	Washing (n=3)	Ironing (n=3)
A×a	*Primissima* Cotton	Alum Powder (5%)	4.0	4.5
A×b	*Primissima* Cotton	Iron Sulfate (3%)	3.5	4.5
A×c	*Primissima* Cotton	Quicklime (2%)	3.6	4.0
B×a	Shantung Fabric	Alum Powder (5%)	4.0	4.5
B×b	Shantung Fabric	Iron Sulfate (3%)	4.0	4.5
B×c	Shantung Fabric	Quicklime (2%)	4.0	4.0

Note: Values represent average scores from three replicate samples (n=3). Fastness rated on a 1-5 Grey Scale per ISO standards.

TABLE 4. Kruskal-Wallis statistical test results.

Test Parameter	H Statistic	Degrees of Freedom	p-value (Asymp. Sig.)
Washing Fastness	17.000	5	0.017*
Ironing Fastness	13.862	5	0.004*

* $p < 0.05$, indicating statistically significant differences between treatment groups

The statistical analysis revealed significant effects of fixing agent type on color fastness. Because the asymptotic significance values were less than 0.05 ($p = 0.017$ for washing; $p = 0.004$ for ironing), the null hypothesis was rejected. This confirms that there is a statistically significant effect of fixing agent type on the color fastness of fabric dyed with natural dyes from *Siwalan* fruit peel, as measured by both washing and ironing fastness tests.

Color Fastness to Washing

The results demonstrated that the selection of fixing agent significantly influenced color retention during washing. *Primissima* cotton fabric showed differentiated performance based on fixing agent: alum powder produced superior fastness (average 4.0, "good" category), while iron sulfate and quicklime produced slightly lower fastness (3.5 and 3.6, respectively, "fairly good" category). In contrast, shantung fabric demonstrated consistently good fastness across all three fixing agents (averaging 4.0), indicating superior dye-retention properties of this fabric type. These findings align with earlier research showing that alum fixatives enhance color stability on natural fibers and that Shantung's chemical composition provides better dye adhesion.

Color Fastness to Ironing Heat

Results for heat resistance showed a different pattern from those for washing fastness. Both *primissima* cotton and shantung fabrics achieved their highest fastness scores (4.5, "good" category) when treated with alum powder or iron sulfate, representing a 12.5% improvement over quicklime treatment (4.0). This suggests that iron sulfate, which showed inferior performance in washing fastness, provides superior performance against heat stress. This unexpected finding contradicts conventional assumptions about these fixatives and suggests that their mechanisms of action vary with the type of stress applied to the fabric.

The superior performance of alum powder and iron sulfate against heat stress compared to quicklime may be attributed to the chemical bonding mechanisms specific to these metal compounds. Alum (aluminum potassium sulfate) and iron sulfate form coordinate complexes with tannins and other dye molecules, creating structures more resistant to thermal degradation. Conversely, quicklime's mechanism involves pH modification, which may be less effective at preventing dye migration during high-temperature exposure.

The divergent performance of fixing agents between washing and ironing tests demonstrates that dye fixation mechanisms are stress-specific. Practitioners must therefore select fixing agents based on the intended use of the dyed fabric, balancing washing durability with heat resistance according to application requirements.

Color fastness to soap washing. In this study, the results of the color fastness test to washing showed that the best fastness values were obtained from *primissima* cotton fabric using alum as a fixing agent, and shantung fabric with variations of alum, *tunjung*, and pure lime as fixing agents, each of which achieved an average value of 4 in the good category. Statistical analysis also showed significant differences in color fastness to washing between treatment groups, particularly in *primissima* cotton and shantung fabric with variations in alum, iron, and pure lime fixatives. These findings indicate that variations in the types of fixatives used play a role in producing differences in colorfastness to washing in *primissima* cotton and shantung fabrics. The results obtained in this study are in line with Pujilestari (2014) view that alum fixatives on natural textile fibers can produce more stable and fade-resistant colors. In addition, the results of the study by Nur & Sugiyem (2021) also support this finding, which shows that the use of alum, tawas, and lime fixatives in dyeing fabrics with natural dyes is highly effective in improving color fastness to washing and rubbing. Similarly, research by Sukmawati et al (2022) confirms that variations in the type of fixative can produce differences in color intensity and fastness, with alum and *tunjung* proven to yield more durable colors on natural fiber-based fabrics such as *primissima* cotton and shantung.

Color fastness to ironing heat. In this study, the results of the color fastness test to ironing heat showed that the best fastness values were obtained with *primissima* cotton and shantung fabrics using alum and *tunjung* fixing agents, each achieving an average value of 4.5 in the good category. Statistical analysis also showed a noticeable difference in color fastness to ironing heat between treatment groups, particularly in *primissima* cotton and shantung fabric with variations in alum and alum-tungstic acid fixatives. These findings indicate that variations in the types of fixing agents used play a role in producing differences in color fastness to ironing heat in *primissima* cotton and shantung fabrics. The results of this study are in line with the research of Ardhea et al. (2023), which shows that the best color fastness to dry rubbing is achieved in natural fiber fabrics such as *primissima* cotton and shantung, using alum and *tunjung* as fixatives. In addition, the study by Widian et al. (2022) explains that alum fixation solutions have better color fastness in dyeing natural fiber fabrics, such as *primissima* cotton and shantung fabric. Similarly, the results of Fauziah et al (2023) Research show that the use of alum fixatives in dyeing natural fiber fabrics has a good effect on color fastness. Thus, it can be shown that fixation can increase color fastness because the natural dyes become locked in and are more difficult to escape through the pores of the fibers.

Based on the test results, the effect of using different types of fixing agents on dyeing with natural dyes from *Siwalan* fruit peel on *primissima* cotton and shantung fabric shows that the use of alum fixing agent produces the same color as dyeing with natural dyes extracted from *Siwalan* fruit peel. Before dyeing, the fixing agent is cream-colored. The *Tunjung* fixative produced a darker color than before dyeing, resulting in a gray color. Meanwhile, pure lime fixative produced a sharper color than dyeing with fixative alone, resulting in a light brown color.

Based on color determination using the Encycolorpedia website, the effect of the alum fixative produces a light goldenrod yellow color on *primissima* cotton fabric and a lemon meringue color on shantung fabric. The effect of *tunjung* fixative on *primissima* cotton fabric produces a pale spring bud color, while on shantung fabric it produces a pearl color. The effect of pure lime fixative produces a Blond color on *primissima* cotton fabric and a Medium champagne color on shantung fabric. This is in line with Pujilestari (2014) The opinion states that fixation is essentially an effort to lock in the absorbed dye so that it can react with the textile material and the fixative used. The fixation stage is also an important part of the dyeing process, binding and strengthening the color.

Based on the research conducted, it is recommended that textile craftsmen who wish to utilize *Siwalan* fruit peel waste as a source of natural dyes consider several types of fixing agents suitable for their color fastness objectives. To obtain colors that are resistant to washing, it is recommended to use shantung fabric rather than cotton fabric because it has better absorbency for natural dyes with alum, alum, and quicklime fixing agents, which have been proven to produce good results in washing tests. Meanwhile, to produce colors resistant to ironing heat, it is recommended to use cotton and shantung fabrics with alum and alum-based fixing agents, as this has been proven to yield superior results. The selection of fabric and the type of fixing agent is expected to help textile craftsmen determine the right fabric and fixing agent so that coloring from *Siwalan* fruit waste achieves optimal color fastness and is useful in natural textile crafts and the batik industry.

CONCLUSION

This research demonstrates that the selection of fixing agents significantly impacts the color fastness of textiles dyed with *Siwalan* fruit peel extract. For washing fastness, alum powder proved most effective on *primissima* cotton (4.0), while all three agents performed equivalently on shantung (4.0). For ironing fastness, both alum powder and iron sulfate achieved superior results (4.5) on both fabric types, compared to quicklime (4.0).

These results have significant implications for both textile craftsmen and the sustainable dyeing industry. By utilizing *Siwalan* fruit peel as a natural dye source, combined with optimized selection of fixing agents, textile manufacturers can produce durable, eco-friendly fabrics while reducing reliance on synthetic dyes and minimizing environmental waste. The superior performance of shantung fabric across all treatments suggests it is the preferred choice for natural dyeing applications, prioritizing washing durability.

Future research should explore the following directions: investigation of long-term color stability beyond current testing parameters; exploration of additional natural fiber types (silk, wool); evaluation of combined fixation methods; and scaling the process for industrial production. Additionally, the mechanism underlying iron sulfate's superior heat resistance requires further investigation, as these finding challenges conventional understanding of fixative chemistry and may lead to optimized fixation protocols for heat-resistant applications.

The sustainable potential of this approach is significant. Given the current daily waste of approximately 17 kg of *Siwalan* fruit peel across the Yogyakarta region alone, scaling this process could simultaneously address waste management challenges and provide textile producers with an economically viable, environmentally responsible natural dye source. This research contributes to the growing global movement toward sustainable textile practices and circular economy principles in the fashion industry.

REFERENCES

Afiatna, F. A. N. F., Muflihah, N., & Mayasari, A. (2024). Meningkatkan Nilai Produk Batik yang Ramah Lingkungan dengan Pewarnaan Menggunakan Sumber Daya Alam Tumbuhan. *Jurnal Abdinus : Jurnal Pengabdian Nusantara*, *8*(1), 184–191. https://doi.org/10.29407/ja.v8i1.21336

Aprilia, M., Sulistyaningtyas, A. R., & Prastiyanto, M. E. (2021). *Uji Aktivitas Antibakteri Ekstrak Etanol Kulit Daging Buah Siwalan (Borassus flabellifer) Terhadap Pertumbuhan Streptococcus mutans*. https://prosiding.unimus.ac.id/index.php/semnas/article/view/952/959

Apriyanti, I. R. (2018). Studi Potensi Pemanfaatan Limbah Serat Batok *Siwalan* (Borassus flabellifer L) sebagai Bahan Baku Kerajianan Lokal (Benang) Gresik. In *Jurnal Teknologia Aliansi Perguruan Tinggi (APERTI) BUMN* (Vol. 1, Issue 1). https://www.neliti.com/id/publications/266098/studi-potensi-pemanfaatan-limbah-serat-batok-*Siwalan*-borassus-flabellifer-l-seba

Ardhea, M., Rois, F., & Agus, H. (2023). Pengaruh Variasi Konsentrasi dan Jenis Fiksasi pada Zat Warna Alam Daun Sirsak Terhadap Ketajaman dan Ketahanan Luntur Warna pada Kain Batik. *Jurnal Riset Rumpun Ilmu Teknik*, *2*(2), 148–157. https://doi.org/10.55606/jurritek.v2i2.2078

Ayu, K., & Putu, N. (2023). *Pemanfaatan Pewarna Alam dalam Menghasilkan Karya Fesyen (Studi Kasus Produk Busana Casual Pria dan Wanita)* (Vol. 4, Issue 2). Online. https://jurnal.std-bali.ac.id/index.php/damoda

Che, J., & Yang, X. (2022). A Recent (2009–2021) Perspective on Sustainable Color and Textile Coloration Using Natural Plant Resources. In *Heliyon* (Vol. 8, Issue 10). Elsevier Ltd. https://doi.org/10.1016/j.heliyon.2022.e10979

Dewi, B., & Yanuarto, T. (2024). *Pemanfaatan Buah Lontar (Borassus Flabellifer) pada Olahan Puding Sebagai Pangan Fungsional Untuk Kesehatan Tubuh*. *3 Nomor 1*. https://doi.org/doi.org/10.58222/jp.v3i1.367

Fauziah, M., Haerudin, A., & Fuadi, A. M. (2023). *Pengaruh Komposisi Zat Fiksasi (Kapur-Tunjung) dan Waktu Fiksasi Terhadap Kualitas Warna Kain Batik Menggunakan Pewarna Alami dari Kayu Tingi*. *40*(2), 165–174. https://doi.org/10.22322/dkb.v40i2.8165.g6307

Hadi, S., Jatmika, W., Negeri, S., & Trenggalek, P. (2022). Peningkatan Kreativitas Berkarya Seni Rupa Materi Penerapan Ragam Hias pada Bahan Tekstil Melalui Praktik Membatik dengan Teknik Lukis Siswa Kelas VII A SMP Negeri 2 Panggul. *Jurnal Simki Pedagogia*, *5*(2), 179–191. https://doi.org/doi.org/10.29407/jsp.v5i2.136

Hardiyanti, S., Chofifa, Z. N., Aries, M., Sumarna, E., Rizki Utama, A., Broto, W., Pemanfaatan, [, Kulit, L., Sebagai, S., Media, B., Di, T., Kembangbilo, D., & Tuban, K. (2021). *Pemanfaatan Limbah Kulit Siwalan sebagai Briket Media Tanam di Desa Kembangbilo Kabupaten Tuban*. https://doi.org/doi.org/10.14710/jpv.2021.12165

Hayati, N., Ainurrizqoh, H., Rosa Indah, A., Selvi, E., Waiil Al-Wajieh, M., & Teknik Institut Sains dan Teknologi Annuqayah, F. (2023). Inovasi Olahan Produk Pangan Berupa *Siwalan* Menjadi Dodol *Siwalan* (Sticky Palm). In *Jurnal PkM ABDHINAH* (Vol. 1, Issue 2). https://doi.org/doi.org/10.59005/j-abdisuci.v1i2.53

Ihsan, F. (2022). *Pemanfaatan Limbah Tempurung Siwalan (Borassus flabellifer L) sebagai Karbon Aktif dengan Aktivator Zncl2 dan Na2CO3 untuk Penjernihan Minyak Jelantah*. http://etheses.uin-malang.ac.id/37294/

Kartikasari, & Enggar. (2021). Pengaruh Fiksator pada Zat Pewarna Alam Ekstrak Daun Kopi Terhadap Ketahanan Luntur Warna Jumputan. *Jurnal Keluarga*, *07*(02). https://doi.org/doi.org/10.30738/keluarga.v7i2.9100

Khoiron Nisa, A., Wiji Hidayati, C., & Khomsatin, S. (2022). Spin Jurnal Kimia & Pendidikan Kimia Analisis Pemordanan Tawas Pada Pencelupan Ekstrak Kulit Rambutan Sebagai Motif Batik Jumputan Analysis Of Alum Mordanting Process On Dyeing Rambutan Skin Extracts As Motifs For Jumputan Batik. *Spin*, *4*(1), 37–47. https://doi.org/10.20414/spin.v4i1.4852

Kusrianto, A. (2020). *Pengetahuan tentang Tekstil dan Produk Tekstil untuk Desain Fashion* (C. Mitak, Ed.). Penerbit Andi Offset.

Li, N., Wang, Q., Zhou, J., Li, S., Liu, J., & Chen, H. (2022). Insight into the Progress on Natural Dyes: Sources, Structural Features, Health Effects, Challenges, and Potential. In *Molecules* (Vol. 27, Issue 10). MDPI. https://doi.org/10.3390/molecules27103291

Narayanankutty, A., Job, J. T., Moothakoottil Kuttithodi, A., Sasidharan, A., Benil, P. B., Ramesh, V., Farouk Elsadek, M., Rizwana, H., & Essam El-Din, M. M. (2023). Proximate composition, antioxidant, anti-inflammatory, and anti-diabetic properties of the haustorium from Coconut (Cocos nucifera L.) and Palmyra palm (*Borassus flabellifer L.*). *Journal of King Saud University - Science*, *35*(1). https://doi.org/10.1016/j.jksus.2022.102404

Nur, W. L., & Sugiyem. (2021). Pengaruh Jenis Fiksator Terhadap Ketahanan Luntur Warna pada Kain Sutera dengan Pewarna Alam Buah Ranti (Solanum nigrum L). *Prosiding Pendidikan Teknik Boga Busana*. https://jurnal.uny.ac.id/index.php/ptbb/article/view/44690

Pujilestari, T. (2014). *Pengaruh Ekstraksi Zat Warna Alam dan Fiksasi Terhadap Ketahanan Luntur Warna pada Kain Batik Katun*. *31*(1). https://media.neliti.com/media/publications/60451-ID-pengaruh-ekstraksi-zat-warna-alam-dan-fi.pdf

Rohalida, A. P., Kahdar, K., & Sunarya, Y. Y. (2022). Pemanfaatan Limbah Kulit *Siwalan* (Borassus Flabellifer) Sebagai Pewarna Alami untuk Produk Intimates (Bra Mastektomi). *Syntax Idea*, *4*(1), 9. https://doi.org/10.36418/syntax-idea.v4i1.1735

Rokhania, A., Budiandari, R. U., Ningrum, L. W., & Hudi, L. (2025). *Karakteristik Fisik Minuman Serbuk Buah Siwalan(Borassus flabelliferL.) Kajian Konsentrasi Tween 80 dan Lama Pengeringan*. *16(1)*. https://doi.org/doi.org/10.35891/tp.v16i1.4860

Sangeetha, S., Thuraisingam, S., Jayawardane, J. A. E. C., & Srivijeindran, S. (2023). A novel approach to the formulation of an encapsulated bioactive powder from palmyrah (Borassus flabellifer L) fruit pulp for nutraceutical applications. *Food Chemistry Advances*, *3*. https://doi.org/10.1016/j.focha.2023.100405

Sathyaruban, S., Perera, G. S. C., Amarasinghe, D. H. J. M., Uluwaduge, D. I., & Kuganathan, S. (2024). Efficiency of the experimental diet enriched with palmyrah (*Borassus flabellifer L.*) fruit pulp on growth, pigmentation, immune challenge, and breeding performance in the guppy (Poecilia reticulata). *Aquaculture Reports*, *38*. https://doi.org/10.1016/j.aqrep.2024.102285

Sivasankar, G. A., Moorthy, C. B., Kaliappan, S., Sathyamurthy, R., Sathish, T., Saravanan, R., & Ağbulut, Ü. (2023). Sustainable nano-added biofuel production from Borassus flabellifer oil for conventional internal combustion engines. *Energy*, *282*. https://doi.org/10.1016/j.energy.2023.128381

Sukmawati, D. A., Fuadi, A. M., & Haerudin, A. (2022). *Pengaruh Jenis dan Konsentrasi Fiksasi Terhadap Kualitas Warna Kain Batik Dengan Pewarna Alam Sabut Kelapa*. *2*(1), 7–14. https://doi.org/10.46964/jimsi.v2i1.1472

Widian, O. A., Widayatno, T., & Haerudin, A. (2022). *Pengaruh Jenis dan Konsentrasi Zat Fiksasi Pada Ekstrak Daun Mangga Dalam Pewarnaan Kain Batik (Effect of Type and Fixation Concentration on Mango Leaf Extract in Batik Fabric Dyeing)* (Vol. 12, Issue 1). https://doi.org/10.26418/jt.v12i1.53613

Yanuar, H. (2023). GamaWarni, Alat Pewarna Alami untuk Kain dan Benang Karya Peneliti UGM. *Liputan 6*. https://www.liputan6.com/regional/read/5451526/gamawarni-alat-pewarna-alami-untuk-kain-dan-benang-karya-peneliti-ugm

Yuniati, Y., Cahyani, M. D., Novidayasa, I., Prihatini, P., & Mahfud, M. (2021). *Ekstraksi Zat Warna Alami dari Kayu Bakau (Rhizophora mucronata) dengan Metode Microwave-Assisted Extraction*. https://doi.org/doi.org/10.18860/al.v9i1.11038