Development and characterization of mangosteen rind *(Garcinia mangostana)* as a natural dye for batik

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Abstract. *Garcinia mangostana* contains xanthones and anthocyanins that can produce stable pigments while utilizing organic waste. This finding supports the use of natural dyes in batik, while also serving as a tangible response to the growing demand for more ethical and environmentally responsible clothing. The research was conducted at Batik Kebon Indah in Klaten to examine the extraction process, application technique, and performance of mangosteen-rind dye on cotton fabric. The study involved direct engagement in the dyeing process through cycles of extraction, mordanting, dyeing, and fixation using alum, lime, and tunjung (iron) to evaluate how different mordants influence colour outcomes and durability. Laboratory tests were conducted to evaluate colorfastness to washing and rubbing. This study employs a qualitative action research approach, supported by descriptive quantitative data, to explore and describe the process, effectiveness, and practical application of mangosteen-rind natural dye in batik production, including the use of three fixatives. That is alum, lime, and iron (tunjung) to examine how different mordanting treatments influence the resulting colour quality and durability. This research offers a practical, tested alternative to synthetic dyes, providing further insights into natural-pigment innovation, circular design, and sustainable textile production that can enhance product differentiation and support eco-friendly branding.

1 Background

Batik, as one of Indonesia's most treasured cultural heritages, embodies a deep connection between art, identity, and tradition. However, behind its vibrant patterns lies an urgent environmental concern. Based on data from 16 MSMEs in Yogyakarta, Solo, and Pekalongan in one month with the production of 2,624 pieces of batik, they can consume 350,000 L/month [1]. The industry's dependence on synthetic dyes, composed of chemical substances that contaminate water and harm ecosystems, poses a significant sustainability challenge. Batik industrial wastewater contains BOD, COD, TSS, and heavy metals [2].

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The use of water, energy, and chemicals in the textile production chain is increasing significantly, which in turn is growing its environmental impact [3]. Growing environmental concerns and a shift toward sustainable consumption have revitalized interest in the textile sector. The concept of ZDHC (Zero Discharge of Hazardous Chemicals) in the textile industry emphasizes fundamental criteria for ensuring the sustainability of the textile dyeing industry [4]. These criteria generally include environmentally friendly dyeing practices, the use of clean technologies, non-toxic dyestuffs, the avoidance of heavy metals and ecologically sensitive colouring agents, and a focus on achieving minimal or zero wastewater discharge. The Adoption of natural dye plants signals a broader transition toward eco-friendly practices in the textile sector. Economically, the production of natural dyes supports local communities and contributes to rural development [5]. Recently, the development and cultivation of natural plant dyeing have been considered as an ecological dyeing technology in the textiles industry [6].

Indonesia is renowned for its rich biodiversity, which yields a diverse range of natural colors, from the vibrant hues of tropical plants to the rich tones of forest fruits, offering a palette of pigments that reflect the country's exotic beauty. One of the fruits that contains intense natural pigments is mangosteen (Garcinia mangostana). Its rind is rich in xanthones and anthocyanins, compounds capable of producing stable and eco-friendly hues. besides its vibrant color potential, the use of mangosteen rind can also promote the utilization of organic waste as an alternative to synthetic dyes.

This study aims to evaluate the process of extraction of mangosteen peel pigment, analyze its application to batik fabric, and assess its color fastness through laboratory testing and direct application in Batik Kebon Indah, Klaten. The novelty of this study lies in the integration of the use of mangosteen peel organic waste as an alternative to batik dye, combined with laboratory-based technical analysis and real-world dyeing practices at the artisanal level.

2 Theoretical Study

2.1 Natural dyeing

Natural dyeing is a process that utilizes dye materials derived from plants, animals, or minerals to colour textiles and other products. Natural dyeing is more environmentally friendly because it does not contain hazardous chemical substances that synthetic dyeing often does, which significantly contributes to environmental pollution. Natural dyes have been used since prehistoric times to colour natural fibers, including cotton, wool, and silk, as well as fur and leather. The use of natural dyes declined since 1856 due to the discovery of synthetic dyes [7]. Natural dyeing can provide an alternative color, making the product unique due to the result of different color characteristics that depend on the extraction, dyeing, and fixation processes applied. Moreover, the use of local materials offers benefits in reducing dependence on synthetic dyeing, which can be highly detrimental to the environment. The utilization of various natural materials, which are locally available, such as java-teak leaf, mangosteen rind, sappan wood (also known as Indian redwood), and turmeric, is used for batik dyeing. According to Widiawati, Products that are considered environmentally friendly for their sustainability have attracted the interest of many consumers, one of which includes naturally dyed textile products [8].

2.2 The Potential of Mangosteen as a Natural Dye

Mangosteen trees are widely planted in communities for fruit production and as a means of greening, due to their large leaves [9]. This makes the mangosteen rind an interesting alternative for batik crafters who want to produce an environmentally friendly product. The mangosteen rind is rich in xanthone compounds, which can result in colors ranging from purple to red brown, with good color retention on clothes [10]. According to Asra et al., the mangosteen rind contains anthocyanin substances that function as a natural dye, providing stability and preventing fading [11]. The use of mangosteen-rind as a natural dye can also provide economic benefits to batik craftsmen. The study conducted by Oryzanty demonstrates that the development of the mangosteen agroindustry is a strategic move. The benefits & utilization of mangosteen rind can be processed into various products, such as juice, xanthone juice, fruit syrup, cocktails, capsules, or xanthone tablets, for health purposes, anticancer drugs, diet supplements, or coloring materials [12]. The utilization of mangosteen rind waste not only reduces total organic waste but also provides economic value to the material that would otherwise be discarded. The product that uses natural dye tends to sell better because it fulfills the consumer's preference who wants an environmentally friendly product.

2.3 The Awareness of Natural Products

The increasing awareness of products made from natural materials and those that are environmentally friendly, in this case, the batik product with natural dyeing using mangosteen rind, has a promising market perspective, both domestically and internationally. Martuti states that textile products with natural dyeing materials have a great opportunity to risen. The manufacture of eco-friendly products through the application of organic materials, including batik dyes, represents a cleaner production method that prioritizes sustainability. The awareness of global consumer demand for environmentally friendly (eco-friendly) products emerged as a response to the green lifestyle and environmental awareness movement. The use of these types of materials is a universal consumption trend adopted as an effort to create a harmonious life between nature (green lifestyle) and the batik industry [13]. The utilization of mangosteen rind as a natural dye gives batik craftsmen a competitive advantage.

3 Research Method

3.1 Research Type

The research is conducted using a qualitative method with an Action Research Approach, supported by descriptive quantitative data from laboratory colorfastness tests. The focus of the research is to understand the process of applying natural dyes from mangosteen rind in batik production. The reason it employs qualitative research with an action research approach is that the researchers are involved and familiar with the research that will be conducted. The study will employ a single instrumental case study that was conducted in a specific location, namely Batik Kebon Indah. According to Oranga [14] Qualitative research is highly effective for exploring and providing a deeper, more comprehensive, and detailed description of phenomena. Qualitative research describes and explains relationships, individual experiences, and group norms.

Quantitative data, in the form of color fastness tests conducted in the laboratory, were used as supporting evidence to assess the effectiveness of the action in each cycle. However, this did not alter the focus of the research, which was centered on the process and practical experience. This research will contribute to the description of the utilization of mangosteen-rind waste, the process of mangosteen-rind extraction for dyeing, the laboratory test color results related to color fading, and the visualization of dyeing applications on batik clothes.

3.2 Data Analysis

This research is conducted through an action research approach. The data analysis uses as a systematic arrangement and organization of collected information to create meaningful patterns, categories, and descriptive units [15]. Qualitative data in this research were analysed using thematic analysis and reflective cycles of action research. Meanwhile, the quantitative laboratory data presented as a result of the action research on creating batik using mangosteen rind were analyzed descriptively to support the evaluation of dye performance.

4 Result and Discussion

4.1 The Extraction Process of Manggis-rind used as a natural *Batik* dye

The mangosteen rind (Garcinia mangostana L.) is one of the materials that can be used for natural batik dyeing, as it contains a pigment content like anthocyanin, which can produce color. In every mangosteen season, Batik Kebon Indah does not forget to capitalize on the potential of manggis rind, which can be used to create a natural batik dye. The mangosteen rind is considered environmentally friendly, which can help reduce dependence on synthetic dyes. The textile artisan at Batik Kebon Indah prefers using this natural dye due to the safety of the extraction process, which does not cause itchiness or heat on the skin, and is easy to decompose. In the process of extraction, of course, there will be some phases, among others are:

4.1.1 Mordanting Process

Mordanting is the first process done before dying. The aim is to remove all kinds of dirt from the clothes, making it easier for the dyeing substance to penetrate the fibers of the clothes. The challenge in using natural dyeing, which can be identified as one of them, is the stability and the color fade maintenance on the clothes; therefore, Kebon Indah uses natural mordants such as alum or uses detergent to help strengthen the color binding on the clothes' fiber and increase the color resilience from the sunlight and washing.

4.1.2 Mangosteen-rind Extraction Process

The natural dyeing of mangosteen rind can be applied in printed batik, where Kebon Indah offers a variety of batik motifs for printing, both in terms of style and size. One of the dominant motives is a combination of plant or animal motives. Before being made into dye, the mangosteen rind is extracted for dyeing. Extraction is a process that results in a dyeing substance; the more the material is used, the more intense the result will be. This is in accordance with the statement of Budiyono and friends (2000:69)," The dyeing substance gained from nature or plant, both directly and indirectly". The dyeing substance extracted from mangosteen rind must be dried first, and then it is boiled in 5 litres of water for every 1 kg of mangosteen rind.

4.1.3 Dyeing Process

The dyeing process involves immersing clothes in a solution of dye after the dye has been extracted through a specific extraction process. This dyeing process will result in various colors depending on the total dyeing. The more dyeing done, the darker (thicker) the color will be.

4.1.4 Fixation Process

The fixation process is a method to achieve perfection by applying solutions of lime, alum, and lotus to set the color, ensuring that the resulting color from fixation dyeing does not fade easily. The giving solution will result in the final color on the batik. For example, giving a lime solution will result in a slightly dark (thick) color. The alum fixation will give a darker color compared to lime fixation, while the lotus solution will give the darkest color.

4.2 The Stability Grade or Fade Resilience Resulted in the Laboratory Test on Mangosteen Rind Dyeing.

This research aims to investigate and evaluate the extent to which the process of dyeing and printing yields satisfactory results, thereby assessing the quality of natural dyeing using manggis-rind (Gracinia Mangostana) on cotton clothes. The primary aspect is testing for color fading, considering that natural dyeing is generally prone to fading compared to synthetic dyeing. Batik Kebon Indah has never conducted any laboratory tests related to the color resulting from manggis-rind. By doing so, it can be used to evaluate whether the dyeing obtained from manggis-rind exhibits good color resilience when used as a dye on batik clothes.

Grey Scale for color changing and staining scale is used to evaluate the staining. The standard used is the standartd which has been known, and it is made by the Society of Dyeis and Colourists (SDC) in England and the United States, e,g, Association of Chemistsand Colourist (AATCC). The evaluation described by Grey Scale can be stated in the value (mark) formulae chromatic Adam, which is in the following table:

Table 1. Grey Scale

Mark of Color Fade Resilience	Color Difference (in CD Scale)	Tolerance for Work Standard (in C.D Scale)
5	0	±0.0
4-5	2.2	±0.2
4	4.3	±0.3
3-4	6.0	±0.4
3	8.5	±0.5
2-3	12.0	±0.7
2	16.9	±1.0
1-2	24.0	±1.5
1	34.1	±2.0

*Mark in the parentheses is used only in 9 grades in Grey Scale Marks

The standard grey colour and color in *Grey Scale*, it is calculated from the formulae of chromatic Adam in the C.DC.D (Colour Difference). Mark 5 shows that it does not result a color changing, mark under 5 shows that it results a color changing. Next, in the Staining Scale, it is stated in the Chromatic Adam Scale as in Grey Scale, the statement is as follow:

Table 2. Mark of Color Staining in Staining Scale

Mark of Color Fade Resilience	Color Difference (in CD Scale)	Tolerance for Work Standard (in C.D. Scale)
5	0	±0.0
4-5	2.0	±0.3
4	4.0	±0.3
3-4	3.6	±0.4
3	8.0	±0.5
2-3	11.3	±0.7

Mark 5 will only be given when the colour difference of the originally white clothes has been tested. The result evaluation Grey Scale and Staining Scale is similar, but there is a little difference in a piece of clothes that is not stained and the one that is stained. The following is the description of the Staining Scale:

Table 3. Evaluation of the Staining Scale Mark

Mark of Color Fade Resilience	Color Difference (in CD Scale)
5	Very Good
4-5	Good
4	Good
3-4	Good Enough
3	Fair
2-3	Minus

Manggis-rind has been tested in the Laboratory of Balai Batik, which was conducted to assess its color fading resilience to washing at 40° C and its color fading resilience to rubbing on the color-staining mark. The following is the result of the Lab test on Alum Fixation:

Table 4. Test on Alum Fixation

No	Test Type	Test Result	Tes Method
1.	Color Fading Resilience toward Washing 40°C	3-4	SNI ISO105-C 06:2010 SNI ISO 105-A02:2010 SNI ISO105-A03:2010
	Mark of Color Changing		
	-Acetate	4-5	
	-cotton	4	
	-Polya mide	4-5	
	-Acrylate	4-5	
	-Wool	4-5	
2.	Color Fading Resilience toward Rubbing Mark of Color Staining		SNI ISO 105-X12:2016 SNI ISO 105-A03:2010
	-Dry cotton	4-5	
	-Wet cotton	45	

In the Alum Fixation, the lab test results show marks from the washing test at 40° C, with a color-changing mark of 3–4. Additionally, in the color staining, the results are 4-5. While in the test of fading resilience on the dry clothes and wet clothes is 4-5. The following is the result of lab test using Lime Fixation:

Table 5. Test on Lime Fixation

No	Test Type	Test Result	Tes Method
1.	Color Fading Resilience toward Washing 40°C Mark of Color Changing -Acetate -cotton -Polya mide -Acrylate -Wool	4 4-5 4 4-5 4-5 4-5	SNI ISO105-C 06:2010 SNI ISO 105-A02:2010 SNI ISO105-A03:2010
2.	Color Fading Resilience toward Rubbing Mark of Color Staining -Dry cotton -Wet cotton	 4-5 4-5	SNI ISO 105-X12:2016 SNI ISO 105-A03:2010

In the Lime Fixation, the lab test results indicate marks from a washing test at 40° C, with a color-changing mark of 4, followed by a color staining mark of 4-5. Meanwhile, the fading resilience (rubbing) test yielded a color staining mark of 4-5 for dry samples and 4 for wet samples. following is the result of a lab test using *Tunjung* Fixation:

Table 6. Test on *Tujung* Fixation

No	Test Type	Test Result	Tes Method
1.	Color Fading Resilience toward Washing 40°C Mark of Color Changing -Acetate -cotton -Polya mide -Acrylate -Wool	3-4 4-5 4 4-5 4-5 4-5	SNI ISO105-C 06:2010 SNI ISO 105-A02:2010 SNI ISO105-A03:2010
2.	Color Fading Resilience toward Rubbing Mark of Color Staining -Dry cotton -Wet cotton	 4-5 4-5	SNI ISO 105-X12:2016 SNI ISO 105-A03:2010

For the *Tunjung* Fixation, the lab test results show that the washing test at 40° C has a color-changing mark of 4, followed by a color staining mark of 4-5. The color fading resilience (rubbing) test scored 4-5 for dry clothes and 4 for wet clothes.

5 Conclusion

The batik motif design, which utilizes mangosteen-rind waste, is an effort to enrich natural dyeing. The natural dye extracted from *mangosteen rind waste aims* to add natural enrichment in Indonesia. It is underutilized and has never been extensively utilized in the development of batik products. The dyeing of clothes using *mangosteen rind throughout 10 dyeing processes results in* good color quality. The process of color fixing is performed in three phases of fixation, using lime, alum, and *Tunjung*. Using the dye extracted from *mangosteen rind will result in a brownish color or light brown with a slight reddish tint*. The natural dye extracted from *mangosteen* is applied as a natural dye for batik.

This research confirms that the natural colorant extracted from mangosteen rind waste, which is currently highly underutilized, holds strong potential for extensive application in the development of batik products. The dyeing process on cotton fabric, involving ten dipping stages and sequential fixation (using lime, alum, and Tunjung), yields stable color quality, specifically a brownish or light brown spectrum with a slight reddish tint. This success not only expands the variety of natural colors available but also offers an environmentally friendly solution to waste management, aligning perfectly with the principles of sustainable textile production.

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