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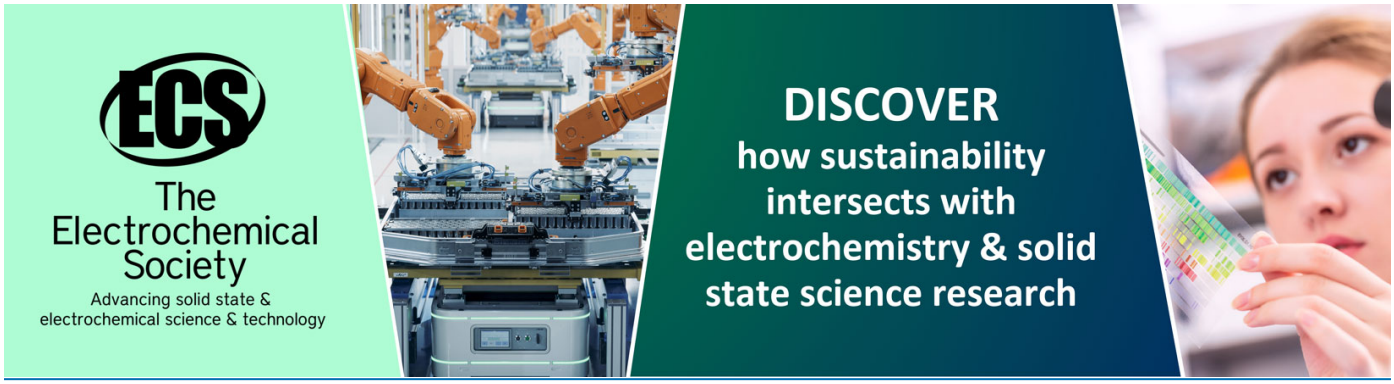

Sustainability of the use of natural dyes in the textile industry

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Abstract. The waste of synthetic dyes from the textile industry causes environmental problems, and it is categorized as hazardous wastes. In contrast, the use of natural dyes is reported to produce fewer pollutants. However, the use of mordant for improving the quality of the dyeing process may release hazardous pollutants because mordant that is commonly used contains heavy metals. In order to claim that the use of natural dyes promotes the sustainable textile industry, it is challenging to find alternative sources of mordant-like materials that are environmental-friendly. It has been reported that tannins could replace mordant for dyeing process using natural dyes. This paper discussed the sustainability of the use of natural dyes in the textile industry based on economic, environmental and social aspects.

Keywords: *natural dyes, textile industry, sustainability*

1. Introduction

The textile dye industry is classified as an industry that uses and produces hazardous and toxic waste, in which 95% of the textile industry wastewater comes from the coloring process and 5% from the rinsing process [1]. The use of chemicals in the textile production process will produce waste containing BOD (*Biochemical Oxygen Demand*), COD (*Chemical Oxygen Demand*), TSS (*Total Suspended Solid*), and pH values that are below the standard. Metal contents such as chromium, lead, and zinc are found in textile wastes which will be carcinogenic if it accumulates in the human body [2]. Stakeholders such as society, the textile industry, fashion designers, art workers, and the government have realized the dangers posed by the use of these synthetic dyes. Thus, there is a ban on AZO compounds that is the main chemical component in synthetic dyes in Europe, USA and India, slow fashion movements and sustainable living principles to switch using natural products in the textile industry [3].

The available supply of natural dyes is still 1% of world demand (10.000 tons) [4]. This figure indicates a high load of wastes from the use of synthetic dyes in the textile industry. The potential for developing natural dyes to replace synthetic dyes is still very wide. Businesses in the field of natural dyes are growing, but not the same as textile natural dyes. This is because the characteristics of the colors produced cannot match the quality of synthetic dyes and are not economical in the production process [5]. This is a challenge for the natural textile dye industry to be developed. One of the textile products that use natural dyes in Indonesia is the batik industry. Batik industry as one of the important industries that contribute greatly to economic growth in Indonesia.

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2. Natural Dyes Technology

2.1. The Commodity of natural dyes

Based on research conducted by Indrianingsih and Darsih (2013) [6], there are 41 dyeing plants commonly used as natural textile dyes in Indonesia. Type of dye can be classified based on chemical structure, dye source, and application method. Dyes based on chemical structures consist of indigoids (blue), pyridine based (yellow), carotenoids (yellow, orange, and red), quinonoid (yellow to red range), flavonoids (pale yellow ranges to dark yellow, orange, and blue), dihydropyran based (Brazilian colors CI 75280 and haematoxylin CI 75290), betalains (betaxanthin yellow and purple betacyanin), and tannins (as mordant and when mixed with other sources produce yellow, brown, gray, and black). Colouring based on its source consists of dyes from plants (flowers, fruit, seeds, leaves, wood, skin, roots, and other parts), animals (insecticides that produce red and purple), mineral (metal salts and metal oxides and red ocher). While colouring based on the application method consists of mordant, vat dyes (the process of using buckets, for example indigo, wood, and Tyrian purple), direct dyes (turmeric, annatto, pomegranate, and safflower on cotton cloth), acid dyes (to dye polyamide materials such as wool, silk and nylon), basic dyes/cationic dyes, and disperse dyes (for colouring polyester fibre and acetate) [7].

Natural dyes can be obtained directly from agriculture, waste/by-product from agriculture or forestry (example: bark from industrial timber), as well as waste from food and beverage industries (pressed berry, residual distillation, pomade, skin, shells, etc.) [8]. Natural dyes in textiles not only function to provide color but also have other functions. Other functions of natural dyes include antimicrobial, UV protection, antibacterial, and anti-inflammatory and anti-insects [4].

Natural textile dyes as antimicrobials can prevent the growth of microbes that cause odor, loss of color, the formation of fungi, degradation of clothing, skin infections, allergies, and various related diseases. Natural fibers such as cotton and wool required finishing stages in their production, due to very susceptible to microbes growth [7] [9]. Examples of natural antimicrobial dyes are tannins, flavonoids, alkaloids, curcumin, naphthoquinones, juglone, lapachol, and catechins. The method for increasing antimicrobial activity can be done by plasma treatment, chitosan treat, enzymatic, cationic, microencapsulation, and cross-linking method [8].

Natural dyes as protection from UV light can prevent darkening of the skin to cancer, examples of natural dyes are rheum embodies, gardenia yellow and curcumin [7]. According to Shahid *et al.* [8], natural dyes from orange peel extract applied to wool fiber have a UV protective effect six times higher than wool factories with synthetic dyes. Natural dyes as anti-insects can prevent insects from attacking textile products such as carpets, garments, furniture, towel and more. It becomes a big problem in terms of storage and many losses that occur. Some effective natural dyes as anti-insect are lac dye, gallnut, catechu, red cabbage, cochineal, indigo, and cork tree extract. Cochineal and Madder are proven effective for anti-insects on carpet beetles [8].

2.2. Natural dyes extraction

Natural textile dyes production has been very much carried out the research, which can be from plants and biotechnology processes. The way to find out a plant has a color that can dye textiles is to crush the parts of the flower/ leaf with the finger and then pay attention to the color formed. If the color resistant from removing and washing, it has the potential to be a natural dye that will not be lost due to washing. Then if the dye imprints on the paper and does not fade after being placed on the lamp for 304 hours, the dye will be resistant to light [4].

Things that need to be considered before extraction are material preparation, selecting solvents, and optimal extraction methods. Material preparation consists of the process of collecting, drying, and minimizing the size to enlarge the surface of the material to contact with solvents [7]. Industrial-scale methods to maximize color yield are found in the preparation process of the ingredients. Sources of natural dyes are dried until the moisture content reaches 40-80%, then milled to form a powder. Extraction is done to take color components through physical and chemical by adding solvents. The

optimum condition in extraction is to do a variety of solvent tests and measure optical density using a spectrophotometer. While gravimetric yield can be measured by filtering extraction liquid through a standard filtration process followed by solvent evaporation, washing, and drying to obtain pure dyes [2].

The type of solvent depends on the type of compound to be extracted. Hydrophilic compounds dissolve in polar solvents such as methanol, ethanol, or ethyl esters. While lipophilic compounds dissolve in dichloromethane solvents or a mix between dichloromethane and methanol [7]. The extraction process in natural dyes can be done in various ways, including percolation, dilution methods, acid and base processes, supercritical fluid extraction, microwave extraction, and ultrasonic extraction [6]. The purification process used thin-layer chromatography (TLC) or high-performance chromatography (HPLC). Among these extraction methods, which are very often used are percolation and dilution processes because easier and more economical but have a low yield and dye quality. Microwave extraction technology is a very fast extraction process with high yield and dye quality. However, its use is still very limited because of the constrained investment costs of expensive equipment [7].

Along with the development of biotechnology, the use of microorganisms to produce dyes has also been developed. The advantages of utilizing these microorganisms are growing rapidly, resulting in variations in nature and color produced and cost-effective. The addition of DNA to E. coli bacteria has succeeded in creating red, yellow, green, and blue or purple that can be applied to textiles. It has the possibility of using biotechnology as an alternative to the shortage of natural dyes production [10].

2.3. Textile dyeing process

Mordant is commonly used for the dyeing process using natural dyes. Mordant is a substance that binds dyes to fabric fiber so it makes the color resistant for washing and sunlight [6]. Mordants that are often used in the textile industry include alum (low acid), tunjung (strong acid) and lime (base) [11][12][13]. Differences in mordant will produce color differences [14]. The higher of concentration of mordant, the higher the intensity of the color obtained [4][3]. In the dyeing process, things to consider are dyeing time, temperature, solvent ratio, dose and type of mordant, preparation of raw materials and selection of appropriate fabrics [11] [5].

The dyeing process using mordant can be categorized in three ways, namely pre-mordant, meta-mordant/ simultaneous mordant and post-mordant. Pre-mordant is to do layering of dyeing by soaking the cloth in mordant solution before staining [11]. Meta-mordant/ simultaneous mordant by dissolving mordant and dye simultaneously. Post-mordant is the use of mordant after dyeing [7] and followed by rinsing.

Mordant is not environmental friendly chemicals, contains heavy metal and its use in high concentration for producing stable and good quality of the dyeing process. The use of mordant such as alum and iron is very effective [3], but is very dangerous for human health and the environment [5].

However, there have been reported that develop natural mordant from tannins for textile natural dyes. Research related to natural mordant has been carried out by Prabhu and Teli (2011) [9] with materials derived from tamarind skin. Tamarind skin contains tannins which can also function as antibacterial in textiles. Tests were carried out on *Staphylococcus aureus* (gram-positive) and *Escherichia coli* (gram-negative) and washing tests. The treatment was 15% tamarind concentration and 15% tamarind mixing with 1% synthetic mordant (CuSO4). The type of mordanting process that is done is pre-mordanting. The use of mordant is only effective as an antibacterial up to 5 times washing, while synthetic use is 20 times washing. The disadvantage of this study is not comparing the use of tamarind skin mordant with synthetic mordant as a whole. Thus, not being able to compare whether the mixing of synthetic mordant and natural mordant will help reduce using synthetic mordant with the same resistance and antibacterial activity as synthetic mordant.

Subsequent research has also been carried out by Teli *et al.* (2013) [3] stating that the making of mordant from chitosan has been carried out and compared with CuSO4 (blue vitriol) mordant produces higher resistance to washing than chitosan mordant. However, chitosan has antibacterial

properties and can be claimed to be an antibacterial finishing agent for cotton. The concentration of chitosan used was 10% and 20% and the concentration of blue vitriol was 1% and 2%. The color quality with natural dyes has fastness from washing, light, perspiration, and rubbing natural dyes that are the same as synthetic dyes. This quality can be achieved if the treatment of synthetic dyes is 2% and natural dyes are 10% with the help of mordant alum at 10% [15].

3. Sustainability of the use of natural dyes in the textile industry

Sustainability consists of three aspects, namely economic, environmental and social aspects. Based on the analysis of cleaner production carried out on natural color batik by Sirait (2018) [1], the factors that influence the selection of dyes in the textile industry are the production process. The production process considers the dyeing process time, the level of complexity and knowledge about dyeing techniques. Mardinawati *et al.* (2017) [16] also added that in increasing the competitiveness and economic improvement of batik-making communities in Indonesia, it is necessary to consider the sustainability aspects, for example The Group of Natural Colour Batik Laras Tirto Pinilih and Batik Tlodas Temanggung, Indonesia, have been able to increase turnover by increasing the quality and amount of production while considering social and environmental aspect on production. Sustainable of the use of natural dyes in the textile industry achieved through connecting economic, social, and environmental aspects by increasing creativity in technology, increasing capacity and productivity, ensuring supply chain sustainability and enhancing the entrepreneurial spirit. Figure 1 shows the element of sustainability natural-dyes used textile industry along with the driving forces and their goals.

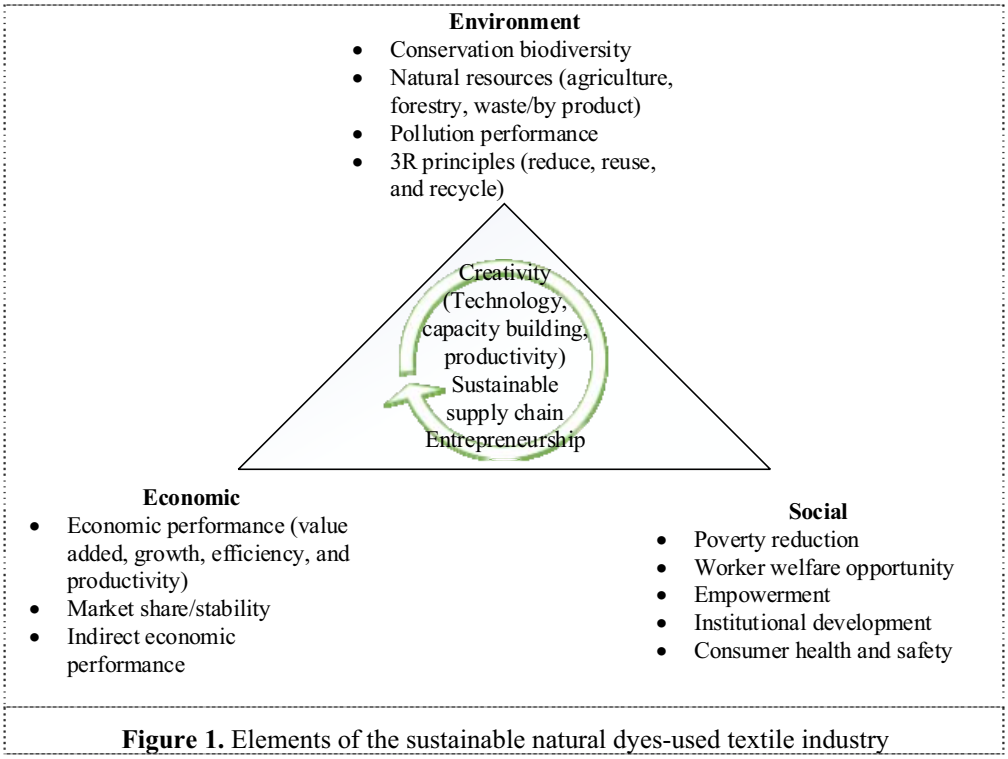

Figure 1. Elements of the sustainable natural dyes-used textile industry

3.1. Economic aspects of the use of natural dyes in the textile industry

Sustainability indicators from economic aspects consist of economic performance, market share, and indirect economic impacts [17]. In terms of market share, the demand for natural dyes is getting higher

[18], it can be an opportunity to get the market in the textile industry through increasing value-added and productivity. Production of natural dyes from indigo, madder, and weld plants were declared economically feasible to be cultivated with modern cultivation techniques and used as raw materials for natural dye. This can be seen in terms of raw materials, production costs and waste handling costs [1]. Availability of raw material and cheap technology needed for producing low-cost natural dyes in the fulfillment textile industry. The low price of natural dyes produced the competitive price of textile products. If this potential continues to be developed, it will create new SMEs that will increase economic growth in the Indonesian textile sector.

Indirect economic of using natural dyes in the textile industry can be seen on the finishing-stage of textile products. The textile industry needed the finishing-stage in textile production to make comfortable, fresh, hygienic and odor-free characteristics and it takes several hours to produce hygienic fabrics [4]. However, the advantages of using natural dyes, the industry can shorten production time and have an impact on reducing production costs. Optimization of natural dye production can be by combining extraction from cultivated plants with the utilization of natural color-producing waste [8].

3.2. Environment aspects of the use of natural dyes in the textile industry

Industrial sustainability indicators in terms of the environment can be seen from aspects of resource use, pollution caused and human behavior activities. Sustainability indicators based on pollution generated involve biodiversity, emissions and waste produced [17]. Natural dye plants can be obtained through planting or taking wild plants directly while doing conservation biodiversity and degraded naturally because of using renewable material. In this case, there has been an industry that applies its cultivation system in collaboration with farmer groups to produce indigo blue dyes from *Indigofera tinctoria* [13].

Emissions and wastes produced natural dyes and dyeing processes in the textile industry greatly influence the sustainability system. There is one source of waste streams during the production process of natural dyes that is biomass waste after doing the extraction process. But, biomass waste from the production of natural dyes can be reused again into derivative products such as compost, biogas, and animal feed to support the 3R principle (Reduce, Reuse, Recycle). In order to claim that the use of natural dyes promotes the environmental friendly textile industry, mordant-like material in dyeing processing will be sustainable at the entire cycle of production and dyeing process textile industry.

Industry challenges 4.0 demands productivity, revenue growth, and increased competitiveness. The aspect of sustainability from an ecologically positive side is evaluated from material and energy efficiency, implementation of easily renewable energy capacity, and adoption of environmental standards and strategies [21]. The value chain improvement in the textile industry, especially in the dyeing process, Angelis *et al.* have examined the level of eco-efficiency for a greener textile industry and achieving a sustainable environment. The results obtained in the case study in Biella, Italy reported that the use of natural dyes will reduce 50% additives and 15% energy. Plasma technology reported by Stegmaeir *et al.* (2009) [20] able to eliminate the drying process in textile products and reduced energy on finishing-stage.

3.3. Social aspects of the use of natural dyes in the textile industry

Social sustainability indicators are conditions of adequate work practices, equality opportunities, community relations, compliance with social policies, consumer health and safety, and human rights [17]. Increasing the need for natural textile dyes will form a new SME and develop entrepreneurship spirit that will increase employment as well as poverty reduction. The natural dye industry builds cooperation with farmers to develop and increase land productivity. This will increase farmer empowerment and local wisdom. On the other hand, the textile industry will be helped by the existence of this natural dye industry to be able to maintain the cultural heritage and competitiveness of regional superior products. The use of natural raw materials will guarantee consumer health and safety and security from industrial workers because they do not use dangerous and toxic raw materials.

This will also improve the institutional nature of the natural textile dye industry that has been developed.

The textile industry is faced with the challenge of simultaneously integrating economic, political, social impacts [5], culture, community, environment, environmentally friendly technology, and sustainable materials. Globalization causes a high flow of information and an accelerating trend which has led to the fast-fashion tragedy which has resulted in the textile industry is the industry that produces the most waste dyes and water. However, the high awareness of stakeholders (fashion designers and brand fashion owners) led to sustainable strategies being adopted by using natural dyes and natural fibers such as wool, silk, and cotton [2] and upholding local wisdom to maintain consistency with the brand image. Collaboration between researchers, designers, and consumers are also needed to build a green strategy in producing a sustainable textile industry [10].

4. Conclusions

Sustainable use of natural dyes in textile industry may be achieved through low-cost production of natural dyes while conserving biodiversity from biomass that is not damaging the environment, application of mordant-like material from the renewable product such as tannin, and promoting new entrepreneur in natural dyes producer, traders, and textile industry.

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