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Natural Dye Production from Beetroot Using Vinegar and Non-Solvent : pH and Colorfastness Testing on White Fabric

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ABSTRACT

Natural dyes derived from plants are increasingly attractive due to their safety and environmental friendliness. This study aimed to investigate the effect of vinegar as a natural solvent on the colorfastness of beetroot (Beta vulgaris L.) dye applied to white fabric. The research involved extracting pigments from beetroot, applying them to fabric, and testing the solution's pH, drying time, and wash fastness. The results showed that pure beetroot extract had a pH of 5.2, while the addition of vinegar reduced the pH to 2.5–3.1. Fabric dyed with beetroot + vinegar exhibited higher initial color intensity (score 11) compared to pure beetroot (score 9), but its colorfastness dropped sharply after washing (score 4 vs. 7). Vinegar addition also prolonged fabric drying time from 12 minutes (without vinegar) to 17.5 minutes (with 20 mL vinegar). These findings indicate that vinegar enhances initial dye brightness but reduces colorfastness after washing. Nevertheless, beetroot dye remains a safer and eco-friendly alternative to synthetic dyes, although further optimization is required to improve its durability.

Keywords: natural dye, beetroot, vinegar, colorfastness, drying time

1. INTRODUCTION

Dyes are a crucial element in the textile industry, providing aesthetic value and enhancing product appeal. In the fabric dyeing process, the industry widely utilizes synthetic dyes due to their high capacity to produce bright, stable, and diverse colors. However, the use of synthetic dyes has raised various serious issues concerning both human health and the environment. Synthetic dyes are known to contain chemicals such as azo compounds and heavy metals that can cause skin irritation, allergies, and even be carcinogenic.[8]

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Furthermore, wastewater from the textile industry that uses synthetic dyes is difficult to decompose (non-biodegradable), thus polluting aquatic environments and degrading ecosystem quality.[12]

In line with increasing public awareness regarding the importance of health and environmental preservation, a trend has emerged towards utilizing natural dyes as a safer and more environmentally friendly alternative solution.[17] The use of natural dyes in textile coloring is increasingly in demand because they are environmentally friendly and safer compared to synthetic dyes, which have the potential to pollute the environment and pose health risks.[1] Natural dyes originate from biological materials such as plants, insects, and minerals, which are biodegradable and do not contain toxic substances. Additionally, natural dyes support the principles of sustainable development as they come from renewable resources.[17] One potential natural material for use as a fabric dye is beetroot (Beta vulgaris L.).[15] Beetroot contains betacyanin pigments that give it a reddish-purple color, making it a potential natural dye for textiles. However, natural dyes generally have weaknesses in terms of color fastness. This fruit is known for its strong purplish-red color due to its betalain pigment content, particularly betacyanin. Beetroot contains betalain pigments, especially betacyanin, which give a bright and attractive red-pink to deep red color. These pigments are water-soluble, making them easy to use as natural dyes for textiles.[9] Betacyanin is water-soluble and stable in acidic environments, making it highly suitable for use as a natural colorant.[15]

Beetroot is not only appealing in terms of color but is also easily obtainable, safe to use, and does not cause toxic effects. In previous research, processed beetroot into dye powder using a tray dryer method with the addition of citric acid to enhance its color stability. Extracted pigments from beetroot peel and demonstrated that the solvent and temperature significantly influence the intensity and stability of the resulting color.[3] The antioxidant content of red beet is also influenced by temperature and pH. The effectiveness of the extraction process depends on the solvent's ability to dissolve the target components. The dissolution of a substance occurs due to interactions between the solvent and the dissolved material.[13] However, the use of simple natural solvents such as vinegar (acetic acid) in the extraction process still needs further investigation.[14] Dyeing with beetroot extract is usually carried out using the wet dyeing (immersion) method. To improve color adhesion to the fabric fibers, fixatives such as alum (aluminum sulfate), iron sulfate, or tannins are often used.[11] Several studies show that the color from beetroot tends to be less durable if fixatives are not used, especially against washing and UV exposure. However, with the right fixatives, color fastness increases significantly, particularly resistance to washing and rubbing.[3] Vinegar is known as a natural acidic solvent with a low pH, which can maintain the stability of betalain pigments while also strengthening the colorfastness on fabric fibers. Vinegar is also safe, readily available, and does not require the addition of other chemicals, making it ideal for simple and environmentally friendly natural dye research.[14]

Nevertheless, the effectiveness of using beetroot as a natural dye with vinegar solvent on the colorfastness of white fabric remains a question. Color bleeding is an important indicator in assessing dyeing quality, as it determines whether the color will remain attached after washing or wearing.[12] Testing the color fastness of mori fabric dyed with natural dyes is crucial to ensure the quality of natural textile products, while also supporting the development of a sustainable and eco-friendly textile industry.[2] Excessive use of retarders can reduce the absorption ability of basic dyes, resulting in a lighter dyeing outcome. Therefore, to determine the optimal dyeing result, tests were conducted on color depth, color evenness, and wash fastness.[5] Furthermore, it is also important to know the characteristics of the dye solution, such as its pH, as well as the drying time of the fabric after dyeing, as these factors also influence color absorption and durability. Therefore, this research was conducted to determine the extent of colorfastness (bleeding), the pH value of the solution, and the drying time of white fabric dyed with natural dye from beetroot using vinegar solvent without any additional mixtures. This study focuses on the use of beetroot extract as a natural dye for cotton fabric (similar to mori fabric). The use of alum and iron sulfate fixatives was also tested to improve color fastness against washing and rubbing. The fastness tests showed that the use of fixatives significantly increased color durability, especially against washing.[4] The results of this study are expected to serve as a reference in the development of natural dyes based on simple, efficient, and environmentally friendly local materials.[7]

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The main chemicals used in this study were fresh beetroot (Beta vulgaris L.) as the source of natural dye, vinegar (acetic acid, CH_3COOH) 5% (Indofood, food grade) as a natural solvent to help stabilize the pigment, and distilled water as an additional solvent. The fabric used as the research object was white mori cloth measuring 15 × 15 cm, which is known for its good absorbency and medium thickness, making it suitable for dyeing experiments. All chemicals used were of food or laboratory grade. The equipment employed in this research consisted of a glass as the extraction and dyeing container, additional containers for holding the extracted solution, a cloth strainer or cheesecloth to separate the pulp from the liquid extract, and a spoon as a stirring and sampling tool. The pH of the dye solution was measured using a pH meter (Eutech pH 700, accuracy ±0.01). Weighing of materials was performed with an analytical balance (Ohaus PA214, readability 0.0001 g). The drying process of the fabric was carried out using a drying rack, and the drying time was measured with a stopwatch (Casio HS-70W, accuracy 0.01 s).

2.2. Research Procedure

The research began by washing and peeling fresh beetroot, which was then grated using a spoon or grater until smooth. The extraction of beetroot was carried out using two methods, namely maceration (cold method) and digestion (hot method).[16] The grated beetroot was squeezed using a cloth strainer or cheesecloth to obtain the liquid extract, which was then filtered again to ensure it was free from pulp. The beetroot extract obtained was mixed with vinegar as needed and stirred with a spoon until homogeneous, resulting in a dye solution with an appropriate pH. Variation of extraction pH was carried out to determine its effect on the extract results.[6] The pre-washed white mori cloth measuring 15 × 15 cm was then immersed in the beetroot dye solution mixed with vinegar for 30 minutes at room temperature. During the dyeing process, the cloth was gently stirred every five minutes to ensure even color absorption across the fabric surface. After the dyeing process was complete, the cloth was removed, excess solution was gently squeezed out, and the fabric was dried on a drying rack at room temperature. The drying time was recorded from the moment the cloth was placed on the rack until it was completely dry to the touch.

The pH of each dye solution was measured before use for dyeing, using a calibrated pH meter. Once the mori cloth was dry, the color intensity was visually observed and scored according to the level of color brightness. To test colorfastness, the dyed fabric was washed under running water for two minutes, then dried again and observed for changes in color intensity. All data—including pH values, drying times, and color

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intensity scores before and after washing—were recorded and analyzed to determine the effect of vinegar addition on the quality of beetroot natural dye on white mori cloth.

3. RESULTS AND DISCUSSION

3.1 Characterization Analysis

Tests were conducted to determine the effect of vinegar addition to beet extract on several parameters, namely fabric drying time, pH value of the dye solution, and color intensity of the fabric before and after washing. Each treatment was observed, and the results are presented in the following graphs. These results were then analyzed to understand the relationship between the variations in treatment and the outcomes obtained.

1. pH Value Chart of Beet Dye Solution

As shown in Figure 1, the pH of beet extract without vinegar was around 5.2. The addition of 10 mL vinegar drastically reduced the pH to 2.5. Further addition of 15 mL and 20 mL vinegar slightly increased the pH to 2.7 and 3.1, respectively

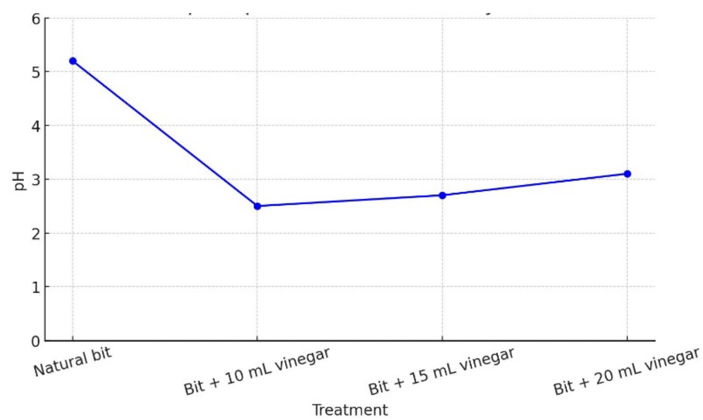

Figure 1. Change in pH of natural beet dye and beet + vinegar solution

The addition of acidic vinegar significantly lowers the pH of the beet dye solution. The sharp drop in pH with the addition of 10 mL vinegar shows that acetic acid is very effective in lowering pH at small volumes. However, adding more vinegar does not decrease the pH linearly; instead, there is a slight increase. This may be due to buffering effects from components in the beet extract that resist further pH reduction. This pH change is important as it can affect the stability of the beet pigment (betacyanin), where at very acidic pH, the pigment may be more stable against oxidation, but color or pigment solubility changes can also occur. The higher the pH used, the darker the resulting color.[10]

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2. Comparison Chart of Color Intensity Before and After Washing

As shown in Figure 2, before washing, the fabric dyed with beet + vinegar showed a higher color intensity score (11) compared to pure beet extract (9). After washing, the intensity of beet + vinegar fabric decreased sharply to 4, while that of pure beet extract decreased slightly to 7, indicating better wash fastness.

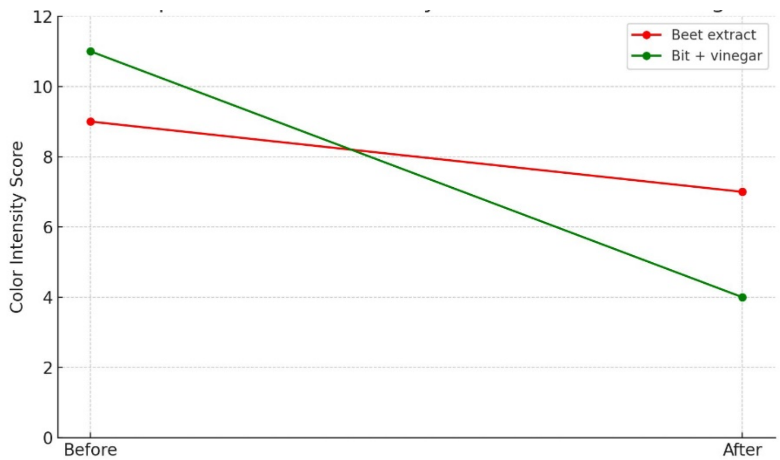

Figure 2. Comparison graph of color intensity before and after washing

Adding vinegar to beet extract increases the initial color absorption on the fabric, so the color appears more intense before washing. However, after washing, the color on fabric with beet + vinegar fades significantly, as shown by the sharp decrease in score. Meanwhile, fabric dyed with pure beet extract, although not as intense initially, is more stable and does not fade as much after washing.This likely occurs because acetic acid from vinegar increases the initial affinity of the dye to the fabric fibers but does not form strong enough bonds, making the color easy to wash away. In pure beet extract, even though initial color absorption is lower, the dye adheres better to the fibers, resulting in more wash-resistant color.

3. Fabric Drying Time Chart

As shown in Figure 3, fabric dyed with natural beet extract without vinegar had the fastest drying time (≈12 minutes). Increasing vinegar volume to 10, 15, and 20 mL progressively lengthened the drying time to 14.5, 16.8, and 17.5 minutes, respectively. This indicates that vinegar addition slows down the evaporation process of water from fabric fibers.

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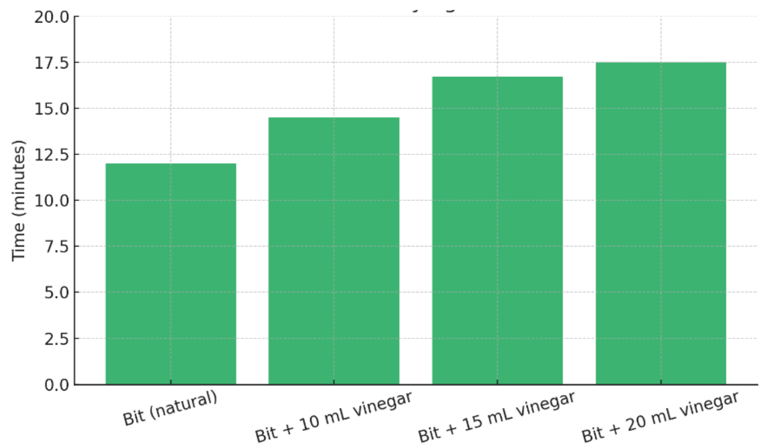

Figure 3. Figure 3. Effect of vinegar addition on fabric drying time.

Increasing the volume of vinegar in the dye solution causes the fabric drying time to be longer. This is likely because vinegar (containing acetic acid) increases the moisture content of the solution and slows down the evaporation of water from the fabric surface. Additionally, acetic acid can affect the structure of the fabric fibers, making it harder for water to evaporate. This effect becomes more pronounced as more vinegar is added.

In addition to pH and drying time, the wash fastness test was carried out to assess the durability of beetroot dye on fabric. The comparison of color intensity before and after washing, along with the calculated colorfastness values, is summarized in **Table 1**.

Table 1. Colorfastness of beetroot dye on mori fabric.

Treatment	Color Intensity Score Before Washing	Color Intensity Score After Washing	Colorfastness Value	Colorfastness Description
Beetroot only	9	7	2	Stable, slightly faded
Beetroot + vinegar	11	2	7	Highly faded

The numerical data in Table 1 are supported by visual observations. The appearance of the dyed fabric samples before and after washing is presented in **Figure 5**.

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(a) (b)

Figure 5. Colorfastness of beetroot dye on mori fabric: (a) before washing, (b) after washing.

4. CONCLUSION

This study demonstrated that vinegar increased the initial color intensity of beetroot dye but reduced its colorfastness after washing. Vinegar also lowered the pH of the dye solution and prolonged fabric drying time. Although beetroot dye is safer and more environmentally friendly than synthetic dyes, further research is needed to enhance its durability to ensure competitiveness in the textile industry.

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