

Natural Dyeing of Cotton Fabric Using *Amaranthus tricolor* Extract: Influence of Extraction Method on Colorimetric, Fastness, and Antioxidant Properties

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Abstract:

Natural dyes have emerged as promising alternatives to synthetic colorants owing to their biodegradability and environmental compatibility. The present study investigates the dyeing performance of **Red Amaranth** (*Amaranthus tricolor*) leaves on **cotton fabric** and evaluates the resulting colorimetric, fastness, comfort, and antioxidant properties. Dye extracts were prepared through both hot and cold aqueous extraction techniques and applied to alum-mordanted cotton fabrics using an exhaust dyeing method. The dyed fabrics were assessed for color characteristics, wash and rubbing fastness, air permeability, and **antioxidant** activity using the DPPH free-radical scavenging assay. Results revealed that extraction conditions significantly influenced pigment stability and shade development. Alum-mordanted samples exhibited bright pink shades with improved color retention, while ferrous sulphate mordant produced darker greyish-brown tones. The fabrics demonstrated good dry rubbing fastness (Grade 4-5), moderate wet rubbing fastness (Grade 3-4), and an air permeability value of 147 mm/s, indicating satisfactory comfort performance. The **DPPH assay** showed 47% antioxidant activity, confirming the retention of bioactive compounds from the natural dye source. The study establishes *Amaranthus tricolor* as a viable natural dye source for **sustainable textile coloration** and highlights its potential for developing value-added functional textiles.

INTRODUCTION:

The increasing environmental concerns associated with synthetic dyes have created a growing demand for sustainable and eco-friendly alternatives in the textile industry. Natural dyes obtained from plant sources are biodegradable, renewable, and less harmful to the environment. Red Amaranth, a pigment-rich leafy plant, has the potential to serve as a natural dye source for textile applications due to the presence of natural colorants such as betalains and anthocyanins.

Bundle dyeing, also known as eco-printing, is a natural dyeing technique in which plant materials are directly placed on fabric and steamed to transfer their pigments and create unique patterns. This study explores the use of red amaranth leaves for dyeing cotton fabric through bundle dyeing and evaluates its dyeing efficiency and fabric properties. The research aims to promote sustainable textile processing while enhancing the aesthetic and functional value of naturally dyed cotton fabrics.

Synthetic dyes contribute significantly to environmental pollution due to the discharge of colored effluents containing toxic aromatic compounds, heavy metals, and non-biodegradable auxiliaries. Approximately 10-15% of textile dyes are lost during processing and discharged into aquatic ecosystems. Consequently, increasing attention has been directed toward renewable plant-based colorants that offer reduced ecological impact.

Amaranthus tricolor is a leafy vegetable rich in betalain pigments, including betacyanins and betaxanthins, which possess strong antioxidant activity and attractive red-violet coloration. Unlike anthocyanins, betalains exhibit unique nitrogen-containing structures that contribute to their biofunctional properties. Although Red Amaranth has been extensively studied in food and pharmaceutical applications, its utilization as a textile dye remains largely unexplored.

OBJECTIVES

1. To investigate the dyeing potential of Red Amaranth leaves on cotton fabric.
2. To evaluate the effect of extraction conditions on shade development.
3. To assess fastness, comfort, and antioxidant properties.
4. To explore the applicability of naturally dyed cotton in functional apparel.

MATERIALS AND METHODS:

Raw Materials and Chemicals

Fabric: 100% cotton plain weave fabric (125 ± 5 GSM).

Scouring: Soapnut extract treatment at 80°C for 60 min.

Mordanting: Alum (15% wof) at M:L ratio 1:30.

Extraction: Hot extraction ($80\text{--}90^{\circ}\text{C}$, 60 min) and cold extraction (24-48 h soaking).

Dyeing: Laboratory winch dyeing machine, M:L ratio 1:20, temperature $50 \pm 2^{\circ}\text{C}$, duration 60 min.

Scouring Process

Scouring was performed using a natural soapnut (*Sapindus mukorossi*) extract containing saponins. Cotton fabrics were treated at a liquor ratio of 1:20 at 80°C for 60 min, followed by thorough rinsing and air drying. The treatment removed hydrophobic impurities and enhanced fabric wettability, facilitating improved dye absorption.

Extraction of Betalain Pigment:

The extraction was conducted using two specific methods to observe pigment stability:

1. HOT EXTRACTION PROCESS

Fresh Red Amaranth leaves were collected, washed thoroughly, and cut into small pieces. The leaves were immersed in distilled water at a material-to-liquor ratio of 1:10 and heated at $80\text{--}90^{\circ}\text{C}$ for 45-60 minutes. The heat facilitated the release of natural pigments from the leaves into the solution. After extraction, the dye liquor was cooled and filtered through muslin cloth and filter paper to remove leaf residues. The filtered extract was collected and used for the bundle dyeing of cotton fabric.

2. COLD EXTRACTION PROCESS

Fresh Red Amaranth leaves were washed, chopped into small pieces, and soaked in distilled water at a material-to-liquor ratio of 1:10. The mixture was kept at room temperature for 24-48 hours to allow the gradual release of pigments into the water without the application of heat. After the soaking period, the extract was filtered through muslin cloth and filter paper to separate the liquid dye from the plant material. The filtered dye extract was then used for bundle dyeing of cotton fabric.

ECO-PRINTING PROCESS

- Collect fresh Red Amaranth leaves.
- Wash the leaves thoroughly to remove dirt and impurities.
- Cut the leaves into small pieces.
- Weigh the leaves and add distilled water at a 1:10 material-to-liquor ratio.
- Soak the mixture at room temperature for 24-48 hours.
- Stir the mixture occasionally to enhance pigment extraction.
- Filter the extract using muslin cloth and filter paper.
- Collect the filtered dye solution for bundle dyeing of cotton fabric.



Figure 1 Extracted Dye



Figure 2 Dyed Fabric

Mordanting

Pre-mordanting of the fabric was carried out using Alum at 15% (owf). The fabric was treated in a mordant bath with a suitable material-to-liquor ratio of 1:30 and the temperature gradually rose from room temperature to 80°C, maintained for 60 minutes. The fabric was stirred intermittently to ensure uniform absorption of the mordant. After completion, the fabric was removed, rinsed with water to eliminate excess mordant, and air-dried before dyeing.

Dyeing Process

Dyeing of the mordanted cotton fabric was carried out using the dye extract from Red Amaranth in a mini winch dyeing machine with an average capacity of 5 liters. The dye bath was prepared, and the fabric was introduced into the machine. The dyeing process was carried out at a controlled temperature of 45–50°C for 60 minutes, with continuous movement to ensure uniform dye penetration and shade development.

RESULTS AND DISCUSSION:

Color Characteristics and Hue Analysis:

The extraction temperature and choice of mordant played a definitive role in the final shade achieved:

1. Thermal Impact: It was observed that temperatures exceeding 60°C caused the betalains to degrade, shifting the color from red violet to peach and pale orange.

2. Alum Mordant: Produced the clearest and bright pastel pink shades, showing good consistency across the fabric surface.

3. Ferrous Sulphate: Acted as a saddening agent, reacting with the pigment to produce muted greyish brown tones.

4. Silk vs. Cotton: Silk fibers showed a significantly higher dye exhaustion rate compared to cotton, resulting in deeper and more saturated colors.

Color Fastness Evaluation:

The samples were tested for wash fastness according to ISO standards.

1. Wash Fastness: The dyed fabric showed poor washing fastness, with significant color loss observed after laundering, resulting in a nearly undyed appearance, caused due to the water dissolving characteristic of the betalain pigment.

2. Rubbing Fastness: The rubbing fastness of the dyed fabric was evaluated using the standard grey scale for staining. The sample exhibited a rating of 4–5 for dry rubbing and 3–4 for wet rubbing, indicating good resistance to color transfer in dry conditions and moderate to good resistance under wet conditions.

3. Air permeability: The fabric exhibited an average air permeability of 147, indicating good breathability suitable for comfort applications.

4. Color Retention: The use of Alum slightly improved the retention of the pink hue, whereas non-mordant and other samples turned yellowish after washing, indicating the loss of betacyanin and the retention of more stable betaxanthins.

Functional Aspect: Antioxidant Properties

A key finding of this research is the retention of bio active compounds on the dyed fabric. The presence of Phenolics, Flavonoids, and Vitamin C in the Red Amaranth extract suggests that the fabric possesses antioxidant properties.

The antioxidant activity of the Red Amaranth dyed cotton fabric was evaluated using the DPPH (2,2 diphenyl-1-picrylhydrazyl) assay. The test sample was prepared in water/PBS solution and treated with DPPH reagent. The mixture was incubated at 37°C in dark conditions for 30 minutes, and absorbance was measured at 517 nm using a spectrophotometer.

The results indicated that the dyed fabric exhibited 47% antioxidant activity, demonstrating its ability to scavenge free radicals. The increase in antioxidant activity with concentration confirms the presence of bioactive compounds retained from the natural dye.

Standard and Sample Calibration Curve (DPPH Assay)

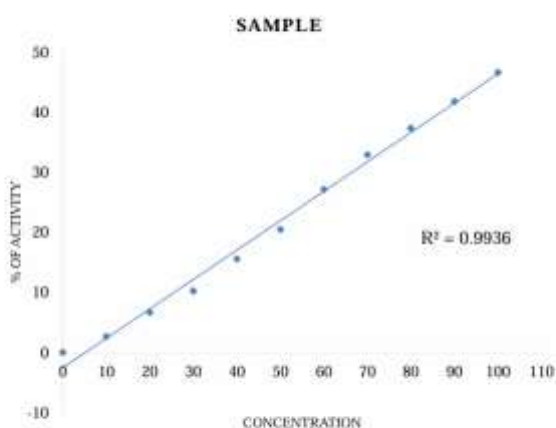
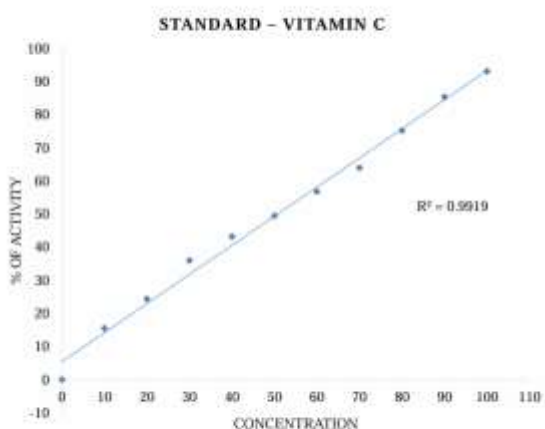
The graphs represent the relationship between concentration and % antioxidant activity for both the standard (Vitamin C) and the dyed fabric sample of Red Amaranth.

- The standard graph (Vitamin C) shows a strong linear relationship with an R^2 value of 0.9919, indicating high accuracy and reliability of the assay.
- The sample graph also shows a linear increase in antioxidant activity with concentration, with an R^2 value of 0.9936, confirming consistent behavior of the dyed fabric.

The linear correlation obtained in both standard and sample curves validates the effectiveness of the DPPH assay and confirms the antioxidant potential of the dyed textile.

Concentration(mg/ml)	B2600002-1 Fabric: Red Amaranth dyed Cotton	
	Standard (%)	Sample (%)
10	15	3
20	24	7

30	36	10
40	43	16
50	49	20
60	57	27
70	64	33
80	75	37
90	85	42
100	93	47
Inference: The sample given showed 47% of antioxidant activity in DPPH assay		



DESIGN AND APPLICATION: ADAPTIVE GARMENTS

The primary application of this research is the development of non-toxic apparel for sensitive demographic groups.

1. **Target Users:** Elderly individuals, bedridden patients.

2. Design Considerations: The garment is designed for ease of use and comfort for elderly and bedridden individuals. A magnetic placket from the high point shoulder to sleeve edge allows easy dressing without lifting the arms. The loose fit and wide openings improve accessibility, while the soft cotton fabric ensures breathability and skin comfort. The design focuses on functional, user-friendly, and irritation free wear.



Potential Applications

The naturally dyed fabric can be utilized in adaptive clothing, healthcare textiles, wellness garments, infant wear, and eco-fashion products. The non-toxic nature of the dye source makes it particularly suitable for sensitive user groups.

Future Scope

Future investigations should focus on bio-mordants, microencapsulation, UV protection finishes, antibacterial functionality, SEM analysis, FTIR characterization, UPF evaluation, and statistical ANOVA validation to enhance scientific robustness.

CONCLUSION

This investigation demonstrated the feasibility of utilizing *Amaranthus tricolor* as a sustainable natural dye source for cotton fabrics. The extracted betalain pigments successfully imparted attractive shades to cotton and exhibited appreciable functional properties. Alum mordanting enhanced color development and dye fixation, while antioxidant evaluation revealed a free-radical scavenging activity of 47%. Although wash fastness remains a limitation due to the water-soluble nature of betalains, the dyed fabrics exhibited satisfactory rubbing fastness and comfort

characteristics. Future studies should focus on bio-mordant systems, microencapsulation techniques, and UV-protective finishing treatments to improve durability and multifunctional performance. The findings support the potential application of Red Amaranth-derived colorants in sustainable and value-added textile product

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