International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 04 | April - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Natural Dyeing of Cotton with Red Amaranth: A Study on its Efficiency and Fabric Properties

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Abstract - The textile industry is under increasing observation for its heavy reliance on various artificial and synthetic dyes, which pose severe environmental and health risks. To address these challenges, this research investigates the potential of Red Amaranth (Amaranthus tricolor) as a sustainable natural dye source for 100% cotton textiles. The study focuses on the extraction of water-soluble betalain pigments and the optimization of the dyeing process using mordants such as Alum. Beyond aesthetics, the dyed fabric was evaluated for its antioxidant properties. The findings suggest that Red Amaranth dye is a viable, non-toxic alternative for the development of Adaptive Garments designed for elderly, bedridden patients, where skin safety and functional benefits are prioritized.

1.INTRODUCTION

The environmental footprint of the global textile sector is dominated by the extensive use of diverse artificial and synthetic dyes. Many of these industrial colorants are notoriously non-biodegradable and persist in the environment, leading to significant water pollution and ecological imbalance. Chemically, several classes of these artificial dyes can break down into hazardous compounds, such as aromatic amines, which are classified as potential human carcinogens. Prolonged exposure to these synthetic chemicals is frequently linked to skin allergies, contact dermatitis, and respiratory issues. This makes conventionally dyed textiles particularly unsafe for demographics with sensitive skin, such as, elderly individual and the bedridden.

As a proactive and sustainable step toward mitigating these industrial hazards, natural dyes derived from plants like Red Amaranth are being explored. Red Amaranth is rich in betalains, which provide vibrant red-violet and yellow-orange hues. These pigments are not only biodegradable but also possess high antioxidant activity. This project aims to transition away from harmful artificial dyes and utilize these biological benefits to create non-toxic apparel that supports skin health through natural coloration.

2. OBJECTIVE:

- To study how Red Amaranth can be used as a natural dye for fabrics.
- To check the effect of different methods on color and fabric properties.
- To explore its use for safe and eco-friendly clothing.

3. MATERIALS AND METHODS:

3.1 Raw Materials and Chemicals

- **Source:** Freshly harvested Red Amaranth leaves.
- **Substrate:** 100% Cotton fabric (120-130 GSM).
- **Mordants:** Alum (Potassium Aluminum Sulphate), Ferrous Sulphate ($FeSO_4$), Tannin and Aluminum Acetate.
- **Pre-treatment ingredient: Soapnut**

3.2 Scouring Process

To ensure maximum dye uptake, the cotton fabric was scoured to remove natural impurities like oils and waxes. For this, soapnut shells are crushed and boiled in water to release natural saponins, creating a mild cleansing solution. Pre – wetted fabric is then soaked and heated in this extract at around 70° to 80° degree Celsius for about an hour, followed by a resting period to enhance cleaning. After rinsing thoroughly, the fabric becomes clean and more absorbent, ready for natural dyeing

3.3 Extraction of Betalain Pigment

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

1. **Hot Aqueous Extraction:** Fresh leaves of Red Amaranth were used for dye extraction. The leaves were washed thoroughly and cut into smaller pieces. The extraction was carried out using a **material-to-liquor ratio (M:L) of 1:0.5** (i.e., **500 g of leaves : 250 mL of water**).The leaf material was immersed in distilled water and heated at **45–60°C** (exceeding 60°C can cause degradation of betacyanin) **for 45–60 minutes**. The mixture was stirred occasionally to facilitate uniform extraction of the pigment. During the process, the solution developed a **deep reddish-pink color**, indicating the release of natural colorants. After extraction, the solution was cooled to room temperature and filtered using muslin cloth to remove plant residues.
2. **Cold Maceration Extraction:** The extraction was carried out using a **material-to-liquor ratio (M:L) of 1:0.5 (i.e., 500 g of leaves : 250 mL of water)**.The chopped leaves were immersed in distilled water at room temperature and kept undisturbed for 24–48 hours to allow the gradual release of natural pigments into the solution. The mixture was occasionally stirred to enhance extraction efficiency.

3.4 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 dying.

Figure 1 Extracted Dye

3.5 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.

Figure 2 Dyed Fabric

4. RESULTS AND DISCUSSION:

4.1 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.

4.2 Color Fastness Evaluation:

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

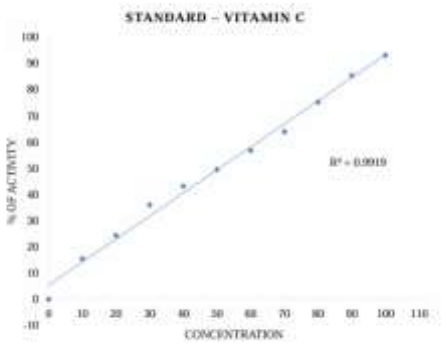
1. **Wash Fastness:** The dyed fabric showed **poor washing fastness**, with significant color loss observed after laundering, resulting in a nearly undyed appearance, caused due to the water dissolving characteristic of the betalain pigment.
2. **Rubbing Fastness:** The rubbing fastness of the dyed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

4.3 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.



4.4 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.

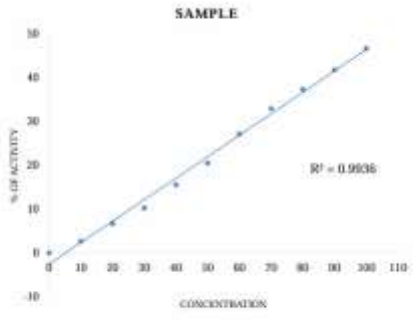
Concentration(mg/ml)	B2600002-1 Fabric: Red Amaranth dyed Cotton	
	Standard (%)	Sample (%)
10	15	3
20	24	7
30	36	10
40	43	16
50	49	20
60	57	27
70	64	33
80	75	37
90	85	42
100	93	47
Inference: The sample given showed 47% of antioxidant activity in DPPH assay		

5. 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**.

Figure 3 Adaptive Garment

6. CONCLUSION:

This study demonstrates that Red Amaranth (Amaranthus tricolor) is a potent and sustainable alternative to the diverse range of harmful artificial dyes used in the textile industry. While challenges regarding wash fastness persist due to the inherent water-soluble nature of betalain pigments, the significant added benefits of antioxidant properties and total non-toxicity make it a superior choice for health-focused and medicinal textiles. The research provides a strong foundation for the further optimization of natural binders and eco-friendly fixatives to enhance the durability of these sustainable colors in the future. By prioritizing skin safety and environmental health, Red Amaranth emerges as a promising bio-colorant for the next generation of Green Fashion.

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