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Beyond Fast Fashion: Embracing Natural Dyes for a Greener Future

Niraj Vaidya

(Assistant Professor, School of Design, AURO University)

PhD Scholar, Sanjeev Agrawal Global Education University, Bhopal)

Guided by: Dr. Amrita Rajput

(Head of Design, Sanjeev Agrawal Global Education University, Bhopal)

Abstract: The fashion world is responsible for some of the most significant environmental pollution on the planet and synthetic dyes are a large problem in this crisis. Synthetic dyes have been extensively used as reaction between salts of azo dyes gave rise to vivid colors, economical, readily accessible f its material. But, the fact that they have a wide impact on the environment and human health, is really alarming. Synthetic dyes are made using toxic chemicals, such as heavy metals, formaldehyde, and petrochemicals, which emit toxic pollutants into the air and water. This causes massive environmental pollution, which enters water bodies, kills fishes and aquatic animals, and leads to global warming due to carbon emission. Soil contamination and decline in agricultural productivity due to poor disposal of synthetic dye effluents. In addition to harming the environment, synthetic dyes have a great impact on human health. Synthetic-dyed fabric can also cause skin allergies due to the toxic chemical agents it contains (such as azo dyes, which can give off carcinogenic amines) and upon prolonged exposure, skin rashes, allergies and other dermatological problems. Also, synthetic dye can affect the regulation of bodily temperature, and when your body gets accustomed to it, it could lead to discomfort, which could amplify the levels of stress and also these two are very unhealthy factors contributing to psychological well-being. For people with sensitive skin problems, the harmful substances found in our clothing can also cause long-term effects on the body. On the other hand, natural dyes offer an ethical and eco-friendly option.

Keywords: Sustainable fashion, Natural dyes, Synthetic dyes, Eco-friendly textiles, Environmental sustainability, Azo dyes, Biodegradable dyes, Dermatological issues, Plant-based dyes, Ayurvedic dyeing, Mordants in dyeing, antimicrobial properties of natural dyes.

1. INTRODUCTION

Derived from plant sources – pomegranate, henna, turmeric, madder, marigold and flame of the forest – natural dyes are biodegradable, nontoxic and devoid of harmful chemicals. These dyes not only provide beautiful finishes to many of the traditional textiles used globally, but they also serve as health benefits and have been used for centuries. Natural dyes (unlike synthetic) also he breathes on the skin, thus controlling temperature of the body effectively. Other advantages include that they generally reduce skin irritations and feel more comfortable, promoting physical and mental well-being. So are some natural dyes with antimicrobial properties, making them an even better alternative for sustainable textile production. Beyond naturally derived dyes are other types of eco-conscious methods of textile dying, such as plant-based mordants, waterless dying technologies, and colors that are bio-based, created from bacteria and fungi. These alternatives also help to reduce chemical waste and water pollution. In fact, traditional dyeing methods including the Ayurvedic dyeing system with its focus on medicinal herbs are gaining ground, promoting both sustainability and well-being. This is the change that is needed to create a sustainable future for fashion, the move from synthetic to natural dyes [1]. Natural dyeing techniques are the answer that allows the fashion sector to maintain its footprint while making clothing that is friendly to the body. Therefore, going back to nature and incorporating natural dyes into the fabric of the mainstream fashion world can revolutionize the process of textile creation, establishing the fact that fashion can be not only beautiful but also sustainable.

The fashion industry has already been ravaging the planet for years, stripping away its resources in the name of fast fashion, favoring cost efficiency and rapid manufacture over sustainability. Because of its low cost, easy application, and vivid colors, synthetic colors have developed into the most essential materials in this swift industry. Synthetic dyeing was created as a replacement for natural dyes starting in the 19th century, and then quickly became the norm. But there have been a heavy cost for their extensive use.

Their synthetic dyes include toxic chemicals such as azo compounds, formaldehyde, and heavy metals that are

released into the air and water during textile production. Because of such pollution, it has also led to the destruction of sea creatures, increased carbon emissions, and soil poisoning. Additionally, these dyes also lead to severe health issues such as skin allergies, respiratory issues, or even cancer. Even if these side effects are harmful, synthetic dyes still dominate the industry because they are cheaper and easily accessible [2]. To combat such issues, the industry has looked towards sustainable dyeing processes as a viable alternative, turning instead to natural dyes sourced from plants and microorganisms. This article discusses the effects of synthetic dyes, the advantages of natural dyes, and eco-friendly dyeing methods which could change the fashion world [3].

2. RESEARCH OBJECTIVES

- To analyze the environmental and health impacts of synthetic dyes.
- To explore various natural dyeing methods and their benefits.
- To assess the feasibility of large-scale adoption of natural dyes in the fashion industry.
- To provide DIY solutions for consumers to create natural dyes at home.
- To highlight future innovations in sustainable dyeing techniques.

3. THE ENVIRONMENTAL AND HEALTH IMPACT OF SYNTHETIC DYES

3.1 Environmental Effects [4]

1. Water Pollution:
Because of its high reliance on synthetic coloring, the textile industry is one of the leading causes of water pollution. During the dyeing process, tonnes of highly polluted water with toxic chemicals, heavy metals and carcinogenic elements are discharged into rivers and lakes. According to the guidelines, these pollutants result in depletion of oxygen levels in water bodies, which impacts aquatic life, causes disruption of ecosystem functioning, and renders water unfit for human consumption.
2. Air Pollution:
Synthetic dyes are produced primarily using petrochemical processes that emit volatile organic compounds (VOCs) as well as greenhouse gases like carbon dioxide and sulphur oxides. These emissions are linked to global warming, acid rain and respiratory problems in humans. Overall, the incineration of dye-contaminated waste releases additional harmful pollutants into the environment.
3. Soil Contamination:
They are thrown away carelessly, and dye effluents pollute the land. Synthetic colors contain heavy metals and toxic compounds that get absorbed by the soil causing a loss in its fertility and leading to soil microbiome ecological imbalance. This threatens agricultural productivity long term and poses risks to food safety. A soil with toxic agents can pass them on to crops that are cultivated in it.

3.2 Health Hazards [5]

1. Skin Allergies and Irritations:
Azo dyes, which are synthetic dyes, release a series of aggressive chemical agents that can cause allergic reactions in newer dyes after coming into contact with the skin. In sensitive people, these dyes can cause rashes, itching, dermatitis and other dermatological conditions.
2. Respiratory Issues:
Textile workers and people who handle synthetic-dyed textiles may inhale toxic dye particles. Chronic exposure can cause respiratory issues including asthma, bronchitis, and other lung diseases. These fine chemical particles can irritate the airways, making it harder to breathe and worsening existing respiratory diseases.
3. Carcinogenic Risks:
Certain synthetic dyes, such as azo dyes, break down into cancer-causing amines when your sweat or bacteria on your skin come into contact with them. Prolonged exposure to such chemicals has been linked with a higher risk of cancer, particularly bladder and liver cancer. Formaldehyde found in some synthetic dyes is also a contributing factor to prolonged health effects.
4. Mental Health Implications:
The continued usage of synthetic against types of dye produce used on fabrics may very well cause skin irritation persisted — irritations will cause illusions that affect the physical body as well with that is hard

to detect that it goes in the country of the mind, and thus mental health. Long-term exposure to some toxic chemicals has been associated with neurological and cognitive dysfunctions characterized by fluctuations in mood and cognition.

5. **Physical and Vital Health Effects:**

The body's own thermoregulation is often inhibited due to synthetic dyes, making it impossible for the skin to breathe. This can lead to overheating or biting cold, causing fatigue, discomfort, and stress. Moreover, while preventing diseases, the exposure to the toxic chemicals of synthetic dyes also leads to hormone disruption and metabolic imbalance, and a weakened immune response which gradually makes a person more vulnerable to ailments.

4. SUSTAINABLE DYEING METHODS

With the fashion world making strides toward being more environmentally friendly, sustainable dyeing techniques are following suit. These methods decrease pollution to the environment and present a safer, non-toxic alternative for synthetic dyes.

4.1 Natural Dyes and Their Benefits

Natural dyes are made from plants, flowers, minerals and even insects, making for an environmentally friendly replacement to synthetic dyes. They are biodegradable and non-toxic and have been used for hundreds of years to create traditional textiles. Lots of natural dyes have medicinal and antimicrobial properties, which is a plus for the skin, too.

Here are some common sources of natural dyes:

- Pomegranate: Generates yellows to browns and tannin-rich, helping to bind color to fabric on its own.
- Henna: Plumbago: Henna, famous for its reddish-brown color, has anticancer effects and has been used in body art and textiles for ages.
- Turmeric: A bright yellow dye known for its antibacterial and anti-inflammatory properties; popular in Ayurvedic textiles.
- Madder: A herbaceous perennial plant species, a deep red dye used in Indian, Persian, and Turkish textiles.
- Marigold & Flame of the Forest: A combination of these flowers make vibrant shades of orange and yellow often used in festive & ceremonial clothing.
- Indigo: One of the most well-known natural dyes, producing deep blue shades which is most notably used in producing denim products.
- Cochineal (Insect-Based): A vivid red coloring created from cochineal insects to be used in textiles and cosmetics, historically.

4.2 Methods of Natural Dyeing

Natural Dyeing process has evolved from traditional dyeing methods way back in ages but old methods still being used along with new techniques for making it more efficient and sustainable.

➤ **Traditional Dyeing Techniques:**

Natural dyeing has been used in many cultures for centuries, often blending with medicinal herbs. Ayurvedic dyeing, for example, infuses fabric with healing herbs that promote wellness as well as color. It is believed that when worn, fabrics can have healing powers.

➤ **Plant-Based Mordants:**

Mordants are applied to make dyes stick to fabrics so that the color does not fade. Chromium, iron salts are synthetic mordants whereas using plant based mordants provides a safe and ecofriendly solution. Some of them are:

- Alum (Potassium Aluminum Sulfate): A widely used, non-toxic mordant, results in making colors brighter, stronger, and more long-lasting
- Tannins: These make the dye more easily absorbed; you'll find tannins in tea, sumac, and oak galls.
- Vinegar and Lemon Juice: Acidic solutions that alter pH and help retain dye color.
- Soy Milk: Acts as a binder for plant-based dyes, improving durability on fabrics.

➤ **Bio-Based Colors:**

Bio-based colors—a new revolutionary concept, bio-based colors are sustainable colors that are derived from bacteria, fungi and algae. Since they use biological resources to generate pigments, they do not depend much on synthetic chemicals. Some examples include:

- **Bacterial Dyes** Some bacteria — Streptomyces, for instance — produce beautiful colors.
- **Fungal Pigments:** Red, orange and yellow pigments produced by some fungi, e.g., Monascus.
- **Algae-Derived Dyes:** Spirulina and other types of algae create social shades of blue and green.

➤ **Waterless Dyeing Technology:**

Water consumption is one of the major environmental concerns regarding the dyeing of textiles. Conventional dyeing processes requires huge quantities of water for dye baths and rinsing. But it is trying to minimize water waste with new waterless dyeing technologies.

Here is a few notable innovations:

- **Supercritical CO₂ Dyeing:** Instead of using water to transfer dye onto fabric, this method uses carbon dioxide, cutting water consumption to nearly zero.
- **Digital Printing:** A process that uses dyes directly on the fabrics with the least amount of water.
- **Foam Dyeing:** Uses dye-infused foam instead of liquid dye baths, significantly cutting down on water usage.

5. DO-IT-YOURSELF (DIY) NATURAL DYEING

Creating natural dyes at home is an easy, cost-effective, and eco-friendly way to experiment with sustainable fashion. With a few simple steps, you can transform everyday kitchen scraps and natural ingredients into beautiful, non-toxic dyes for fabrics.

5.1 Step-by-Step Guide to DIY Natural Dyeing

1. Select Your Dye Material

The first step is to choose the plant-based material that will provide the color. Different ingredients yield different shades, so you can experiment with various sources:

- **Onion Skins:** Golden yellow to orange hues.
- **Beetroot:** Soft pink to deep red shades.
- **Turmeric:** Bright yellow, known for its vibrant color.
- **Coffee or Tea:** Earthy browns and beiges.
- **Red Cabbage:** Blue, purple, or green, depending on pH levels.
- **Avocado Pits and Skins:** Light pink to peach tones.
- **Spinach:** Light green shades.

2. Boil the Plant Material

To extract the natural pigments from the plant material, follow these steps:

- Chop or tear the materials into smaller pieces to release more color.
- Place them in a large pot and add enough water to cover the material.
- Simmer the mixture for **30-60 minutes** on low heat. Stir occasionally to help the color release evenly.
- Once the water takes on a rich, concentrated color, remove the pot from heat and let it cool.

3. Prepare the Fabric

To ensure the dye binds to the fabric properly, it needs to be treated with a mordant, which helps the fabric absorb and retain the dye. Different mordants affect the final shade, so you can experiment with different options:

- **Salt Solution (1:16 ratio of salt to water):** Works best for fruit-based dyes.
- **Alum (1 tablespoon per liter of water):** A common, non-toxic mordant.
- **Vinegar Solution (1:4 ratio of vinegar to water):** Helps brighten colors.

Soak the fabric in the mordant solution for 30-60 minutes, then rinse it with clean water before dying.

4. Dye the Fabric

Once your dye bath is ready and your fabric has been pre-treated, it's time to dye:

- Submerge the fabric in the dye bath and stir gently to ensure even color absorption.
- Let it soak for at least **1-2 hours**, or longer for deeper hues.
- To achieve richer colors, leave the fabric in the dye bath overnight.

5. Dry Naturally

After dyeing, remove the fabric and gently squeeze out excess dye. Rinse it with cold water until the runoff is clear.

- Hang the fabric to **dry in the shade** rather than direct sunlight, as sunlight can fade naturally.
- Let it cure for **at least 24 hours** before washing with mild detergent to help set the color.

Tips for Best Results

- Use **natural fibers** like cotton, silk, linen, or wool, as they absorb dyes better than synthetic fabrics.
- Experiment with **different mordants** to achieve varied shades from the same dye.
- Keep a **dye journal** to track the results of different ingredients and techniques.
- Layer multiple dye baths to create **unique blended colors**.

By using natural dyeing techniques at home, you can reduce your carbon footprint, eliminate harmful chemicals from your wardrobe, and create one-of-a-kind textiles. It's a simple yet powerful step toward sustainable fashion!

6. CHALLENGES OF NATURAL DYES

6.1 Color Fastness Issues

Natural dyes tend to fade overtime due to exposure of sunlight, washing or other environmental factors which are a prominent challenge. Unlike synthetic dyes, which are created chemically to be as resistant to failure as possible, natural dyes are more sensitive to:

- **UV Light Exposure:** Sunlight can break down natural pigments, causing them to fade.
- **Washing & Detergents:** Frequent washing, especially with harsh detergents, can strip the color from natural-dyed fabrics.
- **pH Sensitivity:** Some natural dyes, like red cabbage, change color depending on the pH of the water or sweat they meet.

Solutions & Innovations

- Mordanting better with plant-based fixatives like soy milk or tannins can increase durability.
- Microencapsulation technology, in which dye pigments are encased inside tiny protective capsules, is one area that's being explored to enhance wash and light resistance.
- It helps absorption and durability blending with proteins like wool and silk.

6.2 Scalability & Mass Production Limitations

Natural dyes remain rarely used in industrial-scale textile production, due to barriers in:

- **Inconsistency in Color:** Though consistent colors are possible through synthetic dyes, when creating a natural dye, similar dye baths can produce slightly different colors based on the plant's growing conditions, seasonal timing, and extraction method.
- **Availability of Raw Materials:** Sustaining large-scale production relies on a constant supply of sources for natural dyes, yet the seasonal nature of crop growth, the limitations of agricultural processes, and the difficulty of using permanent land for such systems create challenges.
- **Dye Extraction & Processing Time:** The processes of natural dyeing are more time consuming

Solutions & Innovations

- On a larger scale, standardized processes for color production have been established.
- New agricultural methods, like sustainable production of dye plants and vertical farming, may also make raw materials easier to find.
- Fermentation-driven dye production, natural pigments produced by microorganisms, is being studied as a scalable alternative.

6.3 Higher Cost Compared to Synthetic Dyes

Natural dyeing is more expensive than synthetic dyeing as it generally requires more labor- intensive and requires additional resources. The higher costs come from:

- **Raw Material Collection & Preparation:** Extracting color from plants, flowers, and minerals takes more time and effort.
- **Longer Processing Times:** Natural dyeing often requires multiple dye baths and longer soaking periods.
- **Limited Automation:** The natural dyeing process is less mechanized compared to synthetic dyeing, increasing labor costs.

Solutions & Innovations

- Advancements in bio-engineered dyes can reduce reliance on traditional dyeing methods and lower costs.
- Government incentives & subsidies for sustainable textile industries can help make natural dyeing more competitive.
- Increased consumer demand for eco-friendly products can encourage economies of scale, reducing prices over time.

7. FUTURE PROSPECTS OF NATURAL DYES

Despite these challenges, natural dyes are gaining traction due to advancements in sustainable technology, consumer awareness, and government regulations.

7.1 Bio-Engineered & Lab-Grown Dyes

Scientists are developing bio-engineered natural dyes using bacteria, fungi, and algae to create sustainable and scalable alternatives. Some promising innovations include:

- **Bacterial Pigments:** Certain bacteria, like *Streptomyces*, can produce vivid colors without the need for harmful chemicals.
- **Fungal Dyes:** Some fungi can naturally synthesize pigments like indigo, reducing the need for synthetic processing.
- **Algae-Based Dyes:** Microalgae like *Spirulina* produce vibrant blues and greens, offering renewable alternatives to traditional dyes.

These advancements could significantly improve color fastness, scalability, and affordability, making natural dyes more viable for mainstream production.

7.2 Improved Mordanting Techniques

To address color retention issues, researchers are exploring eco-friendly mordants that enhance the durability of natural dyes without harming the environment. Some promising developments include:

- **Bio-mordants** are derived from plant extracts such as myrobalan and gall nuts.
- **Enzyme-based mordants** that help bind natural dyes to fabric more effectively.
- **Nano-coating technologies** that form a protective layer around dye molecules, preventing fading.

These advancements could make natural dyes just as long-lasting as synthetic dyes while maintaining their environmental benefits.

7.3 Policy Support & Industry Adoption

Governments and regulatory bodies are increasingly recognizing the environmental impact of synthetic dyes and promoting sustainable textile practices. Future trends include:

- **Bans & Restrictions on Harmful Dyes:** Some countries are imposing stricter regulations on toxic dyes and water pollution in the fashion industry.
- **Incentives for Sustainable Practices:** Governments are offering tax benefits and grants for companies adopting eco-friendly dyeing methods.
- **Consumer Awareness & Ethical Fashion Movement:** The growing demand for sustainable clothing is encouraging brands to invest in natural dyes.

Major fashion brands and designers are also embracing slow fashion, supporting ethical dyeing practices, and incorporating natural dyes into their collections [5].

8. CONCLUSION

There are many steps we can take toward a more sustainable and fairer fashion industry, but transitioning from synthetic to natural dyes is one of the most important. Natural dyes are often challenged by scale, color fastness and cost, but constant innovations in bio-dyes, plant- based mordants, and waterless dyeing techniques are making them increasingly viable for large-scale production.

Every time the fashion industry uses natural dyeing processes, it can help to minimize its ecological footprint reducing water pollution, soil contamination and emissions of greenhouse gases. In addition, the natural dyes are also creating healthier lifestyles as they do not use toxic chemicals that cause allergies and skin conditions as well as long-term health risks.

Along this shift, consumer awareness and making informed choices is also critical. As consumers become increasingly aware of the environmental and social implications of the clothing they wear, demand for sustainable, ethically made textiles continues to grow.

Industry by industry, this leads us to believe that governments, brands and researchers must team up to create sustainable solutions and allow fashion to be not just an expression of creativity, but also a commitment to environmental responsibility.

With circularity, sustainability, and innovation, the future of fashion will show that style and sustainability need not be mutually exclusive, paving the way for garments that are not only beautiful to wear but that safeguard our planet for generations.

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