

# Natural Dyeing in Modern Industry

## Environmental Impact, Market Dynamics & Future Solutions



Yingyao Zhao 11432844 & Jingrong Liu 11439390

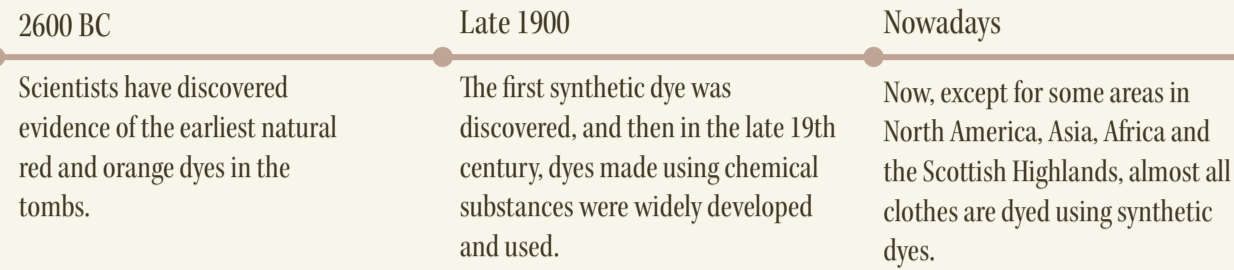
MATS34802 Technology Project

2026 Group Report

### 1. Introduction

- Textile dyeing accounts for 20% of global industrial water pollution, with 200,000–280,000 tons of synthetic dyes lost to wastewater annually.
- Synthetic dyes** dominate 90–95% of the market due to their low cost, colour consistency, and scalability. However, they are petroleum-based, non-biodegradable, and linked to serious health risks including cancer and respiratory disease.
- Natural dyes** offer a renewable, biodegradable alternative, yet they face two major limitations: poor wash and light fastness, and reliance on metal mordants (e.g., alum, copper). This creates a sustainability paradox that the textile industry must urgently address.

### 2. Classifications of Dyeing



Based on their origin, dyes are broadly classified into **natural dyes** and **synthetic dyes**.

**Natural dyes** are non-substantive, they lack intrinsic affinity for fibres and require mordants (metal salts) as binding agents.

**Synthetic dyes** are substantive, they are designed with fibre-specific molecular structures that enable direct, permanent bonding. This fundamental chemical distinction explains why synthetic dyes dominate industrial dyeing.

Natural dyes are derived from renewable sources including:

• Plant-based dyes



• Animal-based dyes



• Mineral-based dyes



### 3. PULL & PUSH Factors

#### PUSH FACTORS :

• Stricter environmental regulations push manufacturers to reduce pollution and adopt cleaner dyeing alternatives.

• Corporate sustainability strategies and ESG commitments encourage manufacturers to explore bio-based and low-impact dye systems.

• Advances in bio-based dyes and material science improve feasibility of natural dyeing.

#### PULL FACTORS :

• Growing consumer demand for sustainable and non-toxic fashion products supports natural dye adoption.

• Cultural value, craftsmanship, and unique aesthetics create niche premium market appeal.

• Unique, non-uniform colours attract consumers seeking individuality and craftsmanship.

#### INHIBITORS:

• Technical limitations such as lower colour fastness and batch inconsistency reduce industrial reliability.

• Higher production costs and longer processing times limit economic competitiveness.

• Difficulty in standardisation limits mass production potential.

#### BARRIERS:

• Fast fashion dominance prioritizes low cost, speed, and colour consistency over sustainability.

• Agricultural dependency, land-use competition, and supply instability restrict large-scale scalability.

• Existing infrastructure and systems are optimised for chemical dyeing, resisting change.

### 4. Synthetic Dyes VS Natural Dyes

#### Advantages of Synthetic Dyes

- Color Range
- Color Consistency
- Price Affordability
- Durability
- Diverse Chemical Properties



#### Advantages of Natural Dyes

- Safer to Environment
- Non-toxic to Human Health
- Traditional and cultural value
- Sustainable-conscious Customer Long-term marketing

#### Disadvantages of Natural Dyes

- Poor Color fastness & inconsistency
- Mordants Reliance
- Scalability & Resource insufficient
- High cost & Limited Colour range
- Traditional and cultural value



#### Disadvantages of Synthetic Dyes

- Water Pollution and Environmental Persistence
- Harm to Human Health
- Health Risks to Production Workers
- Toxic Chemicals in Synthetic Dyes

### 5. Case Studies

#### Colorifix

##### (Biotechnology dyeing)



- Uses microbes to produce pigments
- Reduces water use by up to 90%
- Scalable through fermentation
- Limitation: early-stage commercialisation

#### Aizome

##### (Traditional indigo dyeing)



- Plant-based fermentation dyeing
- Antibacterial and hypoallergenic properties
- Strong cultural storytelling
- Limitation: high cost and limited colours

#### Pangaia

##### (Hybrid innovation)



- Combines science + sustainability
- Uses natural dyes as part of a broader material innovation strategy
- Strong appeal to eco-conscious consumers
- Still reliant on synthetic systems

#### Stella McCartney

##### (Hybrid innovation)



- Positions natural dyes within high-end fashion
- Strong sustainability and influence
- Collaborates with innovators
- Limitations: Cost and consistency challenges remain

### 6. Possible Solutions

Four waste-derived bio-mordant systems validated:



#### COFFEE GROUNDS

Antibacterial, durable on wool



#### TEA WASTE

Ultrasonic-assisted, mordant-free



#### POMEGRANATE PEELS

Natural mordant and dye source



#### WALNUT HUSKS

Reusable bioactive dye

These waste-to-colour pathways eliminate synthetic mordants and reduce water consumption. Market opportunities exist in premium niches (organic certification, baby-wear, medical textiles).

### 7. Conclusion

- Synthetic dyes** remain industrially dominant but carry severe environmental and health burdens.
- Natural dyes** hold ecological promise, yet their dependence on toxic metal mordants undermines their green credentials—a fundamental sustainability paradox.
- This report has identified four waste-derived natural dyes that offer viable, non-toxic alternatives. These solutions eliminate synthetic mordants, valorise agricultural by-products, and align with circular economy principles.
- Overall, despite inherent limitations, natural dyes offer significant potential for advancing environmentally responsible and sustainable textile systems.