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RESEARCH ARTICLE
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Sustainability in Fashion: Natural vs Synthetic Dyes

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ABSTRACT

This research paper explores the comparative aspects of natural and synthetic dyes in the fashion and textile industry, with a focus on sustainability, health, and environmental impact. While synthetic dyes dominate the global market due to cost-effectiveness and wide colour range, natural dyes are regaining attention because of their eco-friendly and non-toxic nature. This study aims to analyse their differences, challenges, and potential for future sustainable fashion.

Key Words : Fashion, Dyes, Environment

INTRODUCTION

The use of dyes to impart colour to textiles is one of the oldest practices in human civilization, dating back thousands of years. Ancient societies such as the Egyptians, Greeks, and Indians relied heavily on natural sources like plants, insects, and minerals to create vibrant hues for clothing and decorative textiles. Indigo, madder, turmeric, henna, and cochineal were among the most prominent sources, and dyeing was often considered both an art and a science that reflected cultural identity, trade, and social status.

The mid-19th century marked a revolutionary shift with the accidental discovery of mauveine, the first synthetic dye, by William Henry Perkin in 1856. This event triggered a transformation in the textile industry, as synthetic dyes quickly replaced natural ones due to their brilliant shades, reproducibility, ease of manufacturing, and affordability. By the late 19th and early 20th centuries, natural dyes had almost disappeared from mainstream use, surviving mainly in traditional crafts and artisanal practices.

Today, the dominance of synthetic dyes in the global textile market is unquestionable. Over 10,000 synthetic dyes are commercially available, and the annual production exceeds 800,000 tons worldwide. Their wide applicability, strong colourfastness, and low production costs make them indispensable in modern textile industries. However, this convenience comes at a significant cost: synthetic dyes contribute heavily to environmental pollution, are often derived from petrochemicals, and in many cases pose risks to human health. Wastewater from textile dyeing processes is a major pollutant, containing toxic substances, heavy metals, and non-biodegradable chemicals that disrupt aquatic ecosystems (Holkar *et al.,* 2016).

The textile industry is recognized as one of the largest consumers of freshwater, particularly in wet processing operations such as dyeing, bleaching, and finishing, which also discharge significant amounts of chemically contaminated wastewater. In response to these environmental and economic challenges, considerable research has focused on sustainable alternatives, with waterless dyeing technologies emerging as a promising solution. Among these, supercritical carbon dioxide (CO_2) dyeing has gained increasing attention. This technique employs recycled CO_2 under controlled temperature and pressure, thereby completely eliminating the need for water and associated effluents. Studies highlight that CO_2 not only addresses the issue of water scarcity but also enhances process efficiency, reduces chemical load, and supports sustainable innovation within the textile sector.

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Overall, CO_2 dyeing is reviewed as a technologically viable and environmentally responsible advancement in modern textile processing (Aksel *et al.*, 2020).

In contrast, natural dyes, though less dominant, are re-emerging in academic, industrial, and consumer discourses, especially with the rise of sustainable fashion movements. They are renewable, biodegradable, and relatively safe for both producers and consumers. Their cultural and historical significance also adds value to their use. Nonetheless, natural dyes face challenges such as poor colourfastness, limited shade range, higher cost of extraction, and difficulty in scaling up for industrial needs.

Thus, the comparison of natural and synthetic dyes is not only a technical or industrial concern but also a social and environmental one. With sustainability becoming a central theme in global industries, it is essential to re-examine the advantages and drawbacks of both dye categories. This paper seeks to provide a detailed analysis of natural and synthetic dyes, highlighting their sources, properties, environmental and health impacts, and their future role in the pursuit of sustainable fashion.

Synthetic Dyes: Risks and Impacts

Synthetic dyes, derived mainly from petrochemicals, provide a wide colour range, brightness, and durability at low cost. However, they also cause serious risks to health and the environment:

- **Environmental Pollution**: Large amounts of unfixed dyes are discharged into water, leading to persistent colour pollution that blocks sunlight and reduces photosynthesis in aquatic systems (Kant, 2012).
  - Synthetic dyes are recognized as one of the most persistent classes of organic pollutants released into the environment through textile effluents. Studies estimate that 10–20% of the total dye used in dyeing operations is discharged directly into wastewater, causing visible coloration and chemical contamination (Holkar *et al.*, 2016).
  - The release of these dyes alters physicochemical properties of water, including increased biological oxygen demand (BOD), chemical oxygen demand (COD), and total dissolved solids (TDS), leading to oxygen depletion and threatening aquatic life (Saratale *et al.*, 2011).
  - Certain classes, such as azo dyes, degrade into aromatic amines, which are known for their carcinogenic and mutagenic potential in humans and animals (Chung and Stevens, 1993). Similarly, anthraquinone and triphenylmethane dyes exhibit strong resistance to microbial degradation and accumulate in sediments, becoming long-term environmental contaminants (Yaseen and Scholz, 2019).
  - Furthermore, dye effluents often contain auxiliary chemicals such as salts, surfactants, and heavy metals (chromium, copper, nickel), which increase toxicity and lead to bioaccumulation in aquatic organisms (Hessel *et al.,* 2007). Light absorption by dyes in water also reduces photosynthetic activity of aquatic flora, disturbing the entire food chain (Kant, 2012).
  - The persistent, toxic, and bio-recalcitrant nature of synthetic dyes makes them a critical pollutant, necessitating advanced wastewater treatment technologies and stricter regulatory frameworks.

- **Human Health Risks**: Synthetic dyes pose several risks to human health due to their toxic, allergenic, and carcinogenic properties. Some azo dyes can release carcinogenic amines; disperse dyes often cause skin allergies and respiratory problems among workers (Chung and Stevens, 1993).
  - *Carcinogenicity of Azo Dyes*: Certain azo dyes, when metabolized, can release aromatic amines such as benzidine, which are strongly linked to bladder cancer and other malignancies (Chung and Stevens, 1993).
  - *Dermal Exposure and Allergies*: Direct skin contact with dyed fabrics, especially disperse dyes, can cause allergic contact dermatitis, rashes, itching, and eczema. Such reactions are common in workers handling dye powders and in consumers wearing synthetic garments (Lisi *et al.*, 2014).
  - *Respiratory Problems*: Inhalation of dye dusts or vapours in textile industries is associated with asthma, chronic bronchitis, and rhinitis among workers. Reactive dye aerosols in particular are strong respiratory irritants (Kant, 2012).
  - *Systemic Toxicity*: Some synthetic dyes and their breakdown products are capable of crossing biological membranes, potentially affecting the liver, kidney, and nervous system after long-term exposure (Yaseen and Scholz, 2019).

Alternatives for Synthetic Dyes:

The alternatives to synthetic dyes primarily include natural dyes, microbial dyes, mineral pigments, eco-friendly synthetic dyes, and green dyeing methods. Natural dyes are obtained from plants, animals, and minerals, offering biodegradable and non-toxic options, though they often face challenges related to colourfastness and shade variety (Samanta and Agarwal, 2009).

Microbial and bio-based dyes, produced through fungi, bacteria, and algae, represent a sustainable and renewable approach, with the advantage of controlled production through biotechnology, although they are still in the developmental stage (Dufossé, 2018).

Mineral and pigment-based dyes, such as iron oxides and ultramarine, provide excellent stability and durability but are limited in colour range. Safer synthetic dyes, designed without toxic amines, halogens, or heavy metals, are emerging as eco-friendly alternatives that combine vibrancy with compliance to international safety standards, though they remain more expensive (OEKO-TEX®, GOTS).

Additionally, innovative green dyeing processes—including enzymatic dyeing, supercritical CO_2 dyeing, and digital printing with natural inks—are reducing environmental impacts by minimizing water, chemical, and energy use (Khatri *et al.,* 2015; Holkar *et al.,* 2016).

Collectively, these alternatives demonstrate the potential to balance sustainability, human health, and industrial performance, marking a pathway toward safer dyeing practices.

Conclusion:

- Synthetic dyes, though economically efficient and capable of producing a vast spectrum of colours with high durability, pose serious environmental and human health challenges. Their persistence in wastewater, toxicity, and potential carcinogenic effects highlight the urgent need for safer and more sustainable solutions.
- Natural dyes, microbial pigments, and eco-friendly synthetic innovations represent viable alternatives. While natural and bio-based dyes are biodegradable and less harmful, they face challenges of scalability, cost, and colourfastness. On the other hand, green synthetic dyes and advanced dyeing technologies offer a middle path—retaining the performance of synthetics while reducing ecological and toxicological impacts.
- The transition towards sustainable dyeing requires multi-dimensional efforts: scientific research to improve natural and bio-based dyes, industrial adoption of eco-friendly processes, policy support for stricter regulation, and consumer awareness to create demand for safer textiles. By integrating these approaches, the textile industry can move "towards safer dyeing practices" that balance colour innovation with environmental and human well-being.

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