

# Comparative Study of Natural Dye Extracted from Turmeric (*Curcuma Longa*) And Synthetic Dyes for Textile Application

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*Abstract- This study investigated the comparative performance of natural dye extracted from Curcuma longa (turmeric) and a commonly used synthetic dye (Reactive Red 120) in textile applications. Cotton fabrics were dyed using turmeric extract prepared through ethanol extraction and a synthetic dye solution, with and without mordents such as alum, ferrous sulfate, and vinegar. The dyed fabrics were evaluated for color intensity, wash fastness, light fastness, and rub fastness, while the effluents were tested for pH and biodegradability. Results revealed that synthetic dye exhibited superior performance in shade depth and fastness properties, with higher K/S values and excellent resistance to washing, rubbing, and light. Conversely, turmeric dye produced moderate fastness properties, which were significantly improved by mordanting, particularly with ferrous sulfate. Environmental analysis indicated that turmeric dye effluent was near neutral (pH 6.8) and biodegradable, whereas synthetic dye effluent was alkaline (pH 10.5) and resistant to degradation, posing ecological risks. The findings highlight the trade-off between the durability of synthetic dyes and the eco-friendliness of natural dyes. This study concludes that while synthetic dyes remain dominant in large-scale applications due to superior performance, turmeric dye offers a sustainable and eco-friendly alternative suitable for small-scale or environmentally conscious textile production.*

*Keywords: Turmeric Dye, Curcuma Longa, Synthetic Dyes, Cotton Fabric, Color Fastness, Eco-Friendly Textiles.*

## I. INTRODUCTION

The increasing demand for environmentally sustainable alternatives in the textile industry has sparked interest in the use of natural dyes as substitutes for synthetic dyes. One such natural dye source is turmeric (*Curcuma longa*), a widely cultivated plant known for its vibrant yellow pigment attributed to curcumin, its primary bioactive

compound (Sathianarayanan et al., 2019). Turmeric has traditionally been used in fabric dyeing, primarily for cotton and silk, due to its natural antimicrobial, antifungal, and antioxidant properties, which enhance the durability and functionality of dyed textiles (Rao et al., 2021). Given the rising concerns over synthetic dye pollution, exploring turmeric as a textile dye presents a sustainable and biodegradable alternative with minimal environmental impact.

Synthetic dyes, which have dominated the textile industry for decades, are valued for their wide color spectrum, durability, and affordability. However, their chemical composition, which often includes azo compounds, heavy metals, and aromatic amines, poses serious environmental and health concerns (Kumar & Bharati, 2022). The textile dyeing process generates large amounts of toxic wastewater that can lead to water pollution, disrupt aquatic ecosystems, and pose health hazards to humans and animals (Shahid et al., 2020). Moreover, some synthetic dyes have been linked to carcinogenic and mutagenic effects, further reinforcing the need for natural dye alternatives (Gulrajani & Gupta, 2019).

Turmeric dye exhibits notable advantages, including biodegradability, non-toxicity, and potential health benefits due to its antimicrobial and UV-protective properties. However, a major challenge associated with natural dyes, including turmeric, is their relatively lower colorfastness compared to synthetic dyes (Deo & Desai, 2018). Colorfastness refers to a dye's ability to retain color under washing, exposure to sunlight, and perspiration. Since turmeric dye has moderate to low wash fastness on textiles, the use of mordants—substances that enhance dye fixation—is often necessary to improve adherence and longevity (Rao et al., 2021). Common mordants such as alum, iron, and tannins can enhance the dyeing properties

of turmeric while maintaining eco-friendliness. The comparative study between turmeric-based natural dye and synthetic dyes for textile applications is essential in evaluating their practical usability. Key parameters such as dye uptake, color intensity, fastness behavior, and environmental impact need to be assessed. Research has indicated that turmeric dye can produce shades ranging from yellow to reddish-brown depending on the mordant and fabric type used (Gulrajani & Gupta, 2019). In contrast, synthetic dyes offer a broader color range and higher resistance to environmental factors but at a significant ecological cost. Given the increasing regulatory restrictions on hazardous synthetic dyes and the global shift toward sustainable production practices, the textile industry must explore natural dye alternatives that balance performance and environmental responsibility. This study aims to compare the dyeing properties, fastness behavior, and overall sustainability of turmeric dye against synthetic dyes. By doing so, it will contribute to the ongoing discourse on sustainable dyeing techniques, offering insights into the feasibility of turmeric as an eco-friendly textile dye and its potential role in reducing industrial dye pollution (Shahid et al., 2020).

#### STATEMENT OF RESEARCH PROBLEM

The textile industry extensively relies on synthetic dyes due to their durability and vibrant colors. However, these dyes pose significant environmental and health risks, contributing to water pollution and toxicity. Natural dyes, such as turmeric (*Curcuma longa*), offer an eco-friendly alternative but face challenges like poor colorfastness and limited industrial applicability. The balance between sustainability and performance remains unresolved.

This study seeks to compare the dyeing properties of turmeric and synthetic dyes, assessing their colorfastness, fabric compatibility, and environmental impact. The findings will provide insights into the feasibility of turmeric as a sustainable textile dyeing solution.

#### JUSTIFICATION

The environmental hazards of synthetic dyes, including water pollution and toxicity, necessitate sustainable alternatives. Turmeric (*Curcuma longa*), a natural dye, offers eco-friendly benefits such as biodegradability and antimicrobial properties.

However, its textile application faces challenges like poor colorfastness and durability. This study aims to compare turmeric dye with synthetic dyes, assessing their effectiveness and environmental impact. By bridging the gap between sustainability and performance, the research supports the development of improved natural dyeing techniques. Findings will contribute to sustainable textile practices, aligning with global efforts to reduce industrial pollution and promote eco-friendly alternatives in dyeing technology.

#### AIM AND OBJECTIVES

**Aim:** To evaluate the dyeing properties, durability, and environmental impact of turmeric (*Curcuma longa*) dye compared to synthetic dyes.

#### OBJECTIVES

- To determine its potential as a sustainable alternative for textile applications.
- To assess the colorfastness of turmeric dye in relation to washing, light exposure, and durability compared to synthetic dyes.
- To compare the dyeing properties of turmeric (*Curcuma longa*) dye and synthetic dyes on textiles, including color intensity and fabric absorption.

## II. LITERATURE REVIEW

The textile industry has experienced transformative changes over the past century, evolving from traditional dyeing methods using natural dyes to the modern, industrial-scale application of synthetic dyes. Initially, natural dyes—derived from plants, minerals, and insects—served as the primary means for fabric coloration. However, the introduction of synthetic dyes in the mid-19th century revolutionized the industry by offering more vibrant, consistent, and durable colors at a lower cost (Rao et al., 2021).

Despite these advantages, synthetic dyes have raised significant environmental and health concerns,

spurring renewed interest in the use of natural dyes as sustainable alternatives. Natural dyes have been utilized for centuries, with sources such as indigo, madder, and turmeric (*Curcuma longa*) playing vital roles in traditional textile practices. Among these, turmeric has gained attention for its bright yellow hue, attributed to its active compound, curcumin, and its inherent antimicrobial properties (Sathianarayanan et al., 2019).

Turmeric is predominantly cultivated in tropical regions, and its applications extend beyond culinary and medicinal uses to include textile dyeing. As global environmental awareness increases, there is a growing impetus to reassess the role of natural dyes in contemporary textile manufacturing, particularly in reducing the ecological footprint left by synthetic dye effluents. Synthetic dyes, on the other hand, are produced from petrochemicals and have become the standard in textile production due to their ability to yield a wide range of colors with high colorfastness.

Despite their technical merits, these dyes are associated with several drawbacks, such as the generation of toxic wastewater, non-biodegradability, and potential carcinogenic effects (Shahid et al., 2020). These adverse impacts have led to stricter environmental regulations and a heightened demand for greener, more sustainable production methods.

As a result, researchers and industry professionals are increasingly exploring the potential of natural dyes like turmeric to offer a viable solution that marries performance with environmental stewardship. Recent studies have shown that natural dyes can achieve acceptable levels of colorfastness and brightness when used in conjunction with mordants—substances that help fix the dye to the fabric. For instance, research indicates that the application of mordants such as alum and tannic acid can significantly enhance the performance of turmeric dye on textiles (Deo & Desai, 2018). However, challenges remain regarding the consistency of natural dye extraction processes and the inherent variability of natural sources. Such limitations underscore the need for further comparative analyses between natural and synthetic dyes to determine whether natural alternatives can meet the rigorous demands of modern textile applications. The environmental

impact of textile dyeing is a critical issue that has received considerable attention in recent years.

Synthetic dyes are known to contribute to water pollution and ecosystem degradation due to the discharge of untreated or inadequately treated effluents into water bodies (Gulrajani & Gupta, 2019).

In contrast, natural dyes are generally biodegradable and pose fewer risks to both human health and the environment. This characteristic has led to an increased focus on the life cycle assessment of dyeing processes, with the aim of developing eco-friendly textile production methods that align with global sustainability goals. Moreover, the renewed interest in natural dyes is also driven by consumer demand for environmentally friendly products. With an increasing number of consumers becoming aware of the ecological footprint of their purchases, there is a market-driven push for textiles produced using sustainable practices. In this context, turmeric dye offers an attractive alternative because it not only reduces reliance on chemical-intensive synthetic dyes but also contributes to the diversification of natural dye sources available to the industry. The potential health benefits associated with curcumin, such as its anti-inflammatory and antimicrobial properties, add further appeal to turmeric-based textiles, making them an innovative choice for both manufacturers and end users. In addition to environmental and consumer considerations, the economic implications of transitioning to natural dyes are noteworthy.

Although synthetic dyes currently dominate the market due to their lower production costs and scalability, the growing regulatory pressure and the potential for innovation in natural dye extraction and processing could alter the cost dynamics in the future.

As research in this field advances, it is anticipated that the development of standardized extraction protocols and the optimization of dyeing techniques will improve the competitiveness of natural dyes like turmeric in the textile industry.

This chapter aims to synthesize the existing literature on both natural and synthetic dyes, providing a critical analysis of their properties, applications, and

environmental impacts. By reviewing historical developments, current practices, and emerging trends, the chapter establishes a foundation for understanding the comparative advantages and limitations of using turmeric dye versus synthetic dyes. The discussion includes an examination of the chemical properties of turmeric, the role of mordants in enhancing dye performance, and the broader environmental implications of textile dyeing processes.

Furthermore, this literature review identifies gaps in current research, particularly in the standardized evaluation of natural dye performance relative to synthetic alternatives. While numerous studies have explored various aspects of dyeing performance, there is a paucity of comprehensive comparative studies that address the multifaceted challenges associated with natural dye application in industrial settings. This gap underscores the necessity for research that not only assesses the technical performance of turmeric dye but also considers its environmental and economic viability. Dyes are colored substances that impart hue to various materials by forming chemical bonds with the substrate, usually fibers, to create permanent coloration. Unlike pigments, which are insoluble and require a binder to adhere to surfaces, dyes are generally water-soluble and work through chemical interaction with textile fibers (Rao et al., 2021).

This chemical affinity allows dyes to penetrate and bond with the material, ensuring long-lasting color even after repeated laundering and exposure to environmental conditions. Dyes can be broadly classified into two categories based on their origin: natural dyes and synthetic dyes. Natural dyes are derived from organic or inorganic sources such as plants, animals, and minerals. They have been used for centuries and are known for their environmental compatibility and biodegradability. For example, indigo from the indigo plant, madder from the roots of *Rubia tinctorum*, and turmeric from *Curcuma longa* are among the most traditional natural dyes (Sathianarayanan et al., 2019). Despite their eco-friendly nature, natural dyes often require mordants—metallic salts or organic compounds—to improve their fixation on fabrics, thereby enhancing color intensity and fastness (Deo & Desai, 2018).

Synthetic dyes, in contrast, are chemically produced, primarily from petrochemical sources. Developed during the mid-19th century, synthetic dyes revolutionized the textile industry by providing a broader and more consistent range of colors with enhanced durability. Synthetic dyes are categorized into several classes based on their chemical structure and application method. Azo dyes, characterized by the presence of one or more azo groups ( $-N=N-$ ), are the most widely used synthetic dyes due to their vibrant colors and ease of synthesis (Gulrajani & Gupta, 2019). Other notable classes include anthraquinone dyes, which are valued for their stability and brightness, and phthalocyanine dyes, known for their intense blue and green shades. In addition to the natural versus synthetic classification, dyes can also be grouped according to their application methods, which are crucial for determining the dyeing process and the type of fiber to be dyed. Direct dyes are applied directly to fabrics without the need for a mordant; they are primarily used on cellulose fibers like cotton, although they generally exhibit lower wash fastness (Rao et al., 2021). Reactive dyes form covalent bonds with fibers, typically cellulose, resulting in excellent colorfastness and vibrancy. Their chemical reactivity, however, makes the dyeing process more complex, necessitating precise control of pH and temperature (Deo & Desai, 2018).

Other types include acid dyes, which are best suited for protein fibers like wool and silk as they require an acidic environment for optimal fixation, and basic dyes, which are used on acrylic fibers and are applied under alkaline conditions. Disperse dyes, although insoluble in water, are finely ground and dispersed in the dye bath; they are primarily used for hydrophobic fibers such as polyester, where their limited solubility facilitates even distribution of color (Gulrajani & Gupta, 2019). Overall, the classification of dyes is critical not only for understanding their chemical behavior and application methods but also for assessing their environmental impacts and suitability for various textile applications. The choice between natural and synthetic dyes depends on multiple factors including cost, color fastness, environmental concerns, and the specific requirements of the textile product (Rao et al., 2021). This understanding

provides the foundation for further studies that compare the sustainability and performance of dyes in modern textile processing.

#### SYNTHETIC DYES

Dyes are substances that impart color to materials by interacting chemically with their substrates, predominantly fibers. Synthetic dyes, in particular, are produced from petrochemical sources and are engineered to provide vibrant, durable, and consistent colors across various textile applications (Rao et al., 2021). Their well-defined molecular structures allow for precise control over hue, intensity, and fastness properties, which has made them indispensable in modern textile manufacturing.

Synthetic dyes are classified into several groups based on their chemical structure and method of application. One of the most widely used classes is azo dyes, characterized by one or more azo groups (-N=N-) in their chemical structure. Azo dyes are favored for their broad spectrum of colors, ease of synthesis, and cost-effectiveness, although concerns have been raised regarding their environmental and health impacts (Gulrajani & Gupta, 2019).

Another important category is reactive dyes. These dyes contain reactive groups that form covalent bonds with fibers, particularly cellulose, ensuring excellent wash fastness and vibrant coloration. The covalent attachment helps maintain the dye on the fabric even under harsh washing conditions, although the dyeing process requires precise control of pH, temperature, and reaction time (Deo & Desai, 2018). Disperse dyes represent a distinct class primarily used for synthetic fibers like polyester. These dyes are insoluble in water and are applied as fine dispersions. Their minute particle size facilitates the penetration of hydrophobic fibers, ensuring uniform color distribution. The effective application of disperse dyes often relies on high-temperature dyeing processes to enhance dye diffusion into the fiber (Rao et al., 2021).

Additional classes of synthetic dyes include acid dyes, which are most suitable for protein fibers such as wool and silk. Acid dyes require an acidic medium to fix effectively onto the fiber and are appreciated for their ability to produce bright and clear colors.

Basic dyes are used on fibers like acrylics and operate under alkaline conditions, though they are less common due to compatibility challenges with other textile materials (Gulrajani & Gupta, 2019).

Understanding these classifications is critical for selecting the appropriate dyeing process for specific textile applications. Each category has its own advantages and limitations regarding color intensity, fastness properties, environmental impact, and processing requirements. This classification framework assists manufacturers and researchers in choosing dyes that not only meet aesthetic demands but also align with sustainability and performance criteria in the textile industry (Rao et al., 2021).

#### III. ENVIRONMENTAL AND HEALTH CONCERNS

The widespread use of synthetic dyes in the textile industry has raised serious environmental and health concerns, primarily due to the toxic effluents generated during production and dyeing processes. Synthetic dyes often contain hazardous chemicals, including azo compounds, heavy metals, and aromatic amines, which can be released into the environment during manufacturing, application, and disposal (Rao et al., 2021). These substances are known for their non-biodegradable nature, meaning they persist in the ecosystem for extended periods, accumulating in soil and water bodies and posing long-term risks to environmental health.

One of the most critical environmental issues associated with synthetic dye use is water pollution. During the dyeing process, large volumes of water are used, and the resulting effluents typically contain high concentrations of dyes and chemical additives. When these untreated or inadequately treated effluents are discharged into water bodies, they can significantly impair water quality. The presence of toxic dyes in water not only affects aquatic life by reducing light penetration and oxygen levels but also disrupts the natural habitat and food chain (Gulrajani & Gupta, 2019). Over time, the accumulation of these chemicals can lead to severe ecological imbalances, impacting both flora and fauna in affected regions.

Health concerns arise from both occupational exposure and environmental contamination. Workers in textile dyeing facilities are at risk of direct exposure to hazardous chemicals, which can lead to respiratory issues, skin irritations, and long-term systemic effects, including carcinogenic risks (Deo & Desai, 2018). Moreover, communities living near textile production sites may be exposed to contaminated water and air, increasing the incidence of health problems such as respiratory disorders, allergies, and even developmental issues in children. The potential for bioaccumulation of heavy metals and other toxic compounds in the food chain further exacerbates these health risks.

The non-biodegradability of many synthetic dyes means that once these compounds enter the environment, they remain for extended periods, making remediation efforts challenging. Conventional wastewater treatment plants often struggle to remove all toxic dye components effectively, leading to persistent environmental contamination (Rao et al., 2021). Advanced treatment methods, such as chemical oxidation and membrane filtration, can mitigate some of these issues but are often cost-prohibitive for widespread implementation in many regions, particularly in developing countries where textile industries are rapidly expanding.

In response to these concerns, regulatory bodies worldwide have implemented stricter guidelines and monitoring systems to limit the discharge of harmful dyes and chemicals. However, compliance remains a significant challenge for many textile manufacturers, particularly small-scale producers who may lack the resources to invest in cleaner technologies (Gulrajani & Gupta, 2019). This has spurred interest in alternative dyeing methods and eco-friendly dye options, including natural dyes, which are generally biodegradable and less harmful to the environment.

In conclusion, while synthetic dyes offer undeniable advantages in terms of cost, consistency, and color variety, their environmental and health impacts present significant challenges. Addressing these concerns requires a multifaceted approach that combines stricter regulatory oversight, investment in advanced wastewater treatment technologies, and the exploration of sustainable alternatives. Such efforts

are crucial for mitigating the adverse effects of synthetic dyes and ensuring that the textile industry can progress towards more environmentally responsible practices (Deo & Desai, 2018).

#### IV. COMMON SYNTHETIC DYES USED IN THE TEXTILE INDUSTRY.

Synthetic dyes widely used in textile manufacturing include several key classes:

- **Azo Dyes:** Known for their broad color spectrum and cost-effectiveness, azo dyes are extensively used despite some environmental concerns (Rao et al., 2021).
- **Reactive Dyes:** These dyes form covalent bonds with fibers, providing excellent wash fastness and vibrant colors, particularly on cellulosic materials (Deo & Desai, 2018).
- **Acid Dyes:** Primarily used for protein fibers like wool and silk, acid dyes require an acidic medium for proper fixation.
- **Basic Dyes:** Suited for synthetic fibers such as acrylics, basic dyes are applied under alkaline conditions.
- **Disperse Dyes:** Mainly employed for hydrophobic fibers such as polyester, disperse dyes are finely ground to achieve uniform color distribution (Gulrajani & Gupta, 2019).

#### V. NATURAL DYES

Natural dyes are colorants obtained from natural sources such as plants, animals, and minerals. They are typically extracted using physical or biological methods and do not involve complex synthetic chemical reactions like their synthetic counterparts. Natural dyes have been used by humans for thousands of years in the coloring of textiles, food, and even in medicinal and religious practices. They are appreciated not only for their vibrant, earthy hues but also for being biodegradable, renewable, and generally non-toxic, making them more environmentally sustainable than synthetic dyes (Siva, 2017).

Natural dyes contain active coloring substances such as tannins, flavonoids, anthraquinones, and carotenoids. These compounds, depending on their chemical composition and the method of application,

produce a wide range of colors on natural fibers like cotton, wool, silk, and linen. Their use in textile dyeing is gaining popularity once again due to growing environmental concerns about synthetic dyes, which often pose risks to aquatic life and human health due to their chemical components and non-biodegradable nature (Ali et al., 2020).

#### SOURCES OF NATURAL DYES

Natural dyes are categorized based on their origin into three primary sources: plant-based, animal-based, and mineral-based.

##### 1. Plant-Based Sources

Plants represent the most abundant and widely used source of natural dyes. Almost every part of a plant—including roots, stems, bark, leaves, fruits, and flowers—can be used to extract colorants. The main advantage of plant dyes is their renewability and accessibility in different geographical areas.

- Turmeric (*Curcuma longa*) is a well-known plant dye source, yielding bright yellow pigments from its rhizomes. Apart from being used in textiles, turmeric is also used in food and traditional medicine.
- Indigo (*Indigofera tinctoria*) is one of the oldest dye plants known, providing a deep blue color. The dye is obtained from the fermented leaves of the plant and requires oxidation to develop its characteristic hue.
- Madder (*Rubia tinctorum*) roots provide red and pink shades due to the presence of alizarin, an anthraquinone compound.
- Henna (*Lawsonia inermis*) is used for orange to brown shades and is derived from the leaves.
- Pomegranate rinds, onion peels, walnut shells, and teak leaves are also examples of plant materials with dyeing capabilities.

Plant dyes are generally safe, often containing antimicrobial properties, and can be applied using eco-friendly mordants such as alum or tannin to improve their fastness on fabrics (Shahid & Mohammad, 2013).

##### 2. Animal-Based Sources

Although less commonly used today, certain dyes are derived from animals. These dyes are notable for their richness and historical significance.

- Cochineal, a deep red dye, is obtained from the dried bodies of the *Dactylopius coccus*, an insect found primarily on cacti in Central and South America. The active pigment, carminic acid, is extracted and used not only in textiles but also in cosmetics and food products.
- Tyrian purple, historically known as imperial or royal purple, was produced from the secretions of sea snails like *Murex brandaris*. Due to the labor-intensive process and the vast number of snails needed to extract small amounts of dye, it was extremely expensive and reserved for royalty in ancient civilizations.
- Lac, derived from the secretions of the *Kerria lacca* insect, produces a red dye used historically in India and Southeast Asia.

The use of animal-based dyes has declined due to ethical concerns, conservation issues, and the rise of more sustainable plant-based and synthetic alternatives. However, their legacy remains significant in the history of textile dyeing (Gulrajani, 2018)

##### 3. Mineral-Based Sources

Mineral dyes are derived from naturally occurring inorganic substances. They are typically used to produce earthy tones and are more durable under light and washing conditions compared to some plant dyes.

- Ochre, which comes in red, yellow, and brown shades, is a naturally occurring iron oxide used since prehistoric times.
- Malachite and azurite, copper-containing minerals, produce green and blue pigments, respectively.
- Carbon black, derived from the incomplete combustion of organic matter, can be used to achieve black shades in textiles.
- Other sources include manganese and lead oxides, although the latter poses significant health hazards and is rarely used in modern dyeing.

While mineral dyes are valued for their color stability, their use in textiles is limited today due to safety, cost, and processing concerns. However, they still hold relevance in traditional and artisanal practices (Siva, 2017).

#### VI. TURMERIC (*CURCUMA LONGA*) AS A NATURAL DYE

Turmeric (*Curcuma longa* L.) is a perennial herbaceous plant belonging to the family Zingiberaceae, which also includes ginger. It is widely cultivated in tropical and subtropical regions and is known for its thick, underground rhizomes that contain the bright yellow-orange pigment called curcumin, which is responsible for turmeric's characteristic color and dyeing properties (Prasad et al., 2014).

The turmeric plant typically grows to a height of about 1 meter. It has large, oblong leaves that are bright green in color and can reach up to 2 feet in length. The leaves arise in a sheathed manner from the rhizome, forming a pseudo-stem. The inflorescence is a dense spike with pale yellow flowers borne in the leaf axils, often surrounded by green and white bracts tinged with pink or purple. The flowers are hermaphroditic and zygomorphic, but the plant is mainly propagated vegetative via rhizomes since it rarely produces viable seeds (Jiang et al., 2015). The rhizomes are the most important part of the plant from a commercial and functional perspective. They are harvested, boiled, dried, and then ground into a yellow powder widely used as a spice, dye, and in traditional medicine. Chemically, turmeric contains curcuminoids (mainly curcumin, demethoxycurcumin, and bisdemethoxycurcumin), essential oils like turmerone, and other compounds such as starches, proteins, and resins (Ammon & Wahl, 1991). Curcumin is the principal coloring agent and exhibits a bright yellow hue with slight orange undertones, which makes it suitable for dyeing textiles, especially natural fibers like cotton, wool, and silk.

#### VII. CHEMICAL COMPOSITION OF TURMERIC DYE (CURCUMIN).

The primary coloring compound in turmeric is curcumin, a polyphenolic compound responsible for its intense yellow-orange hue. Chemically, curcumin is a diarylheptanoid (C<sub>21</sub>H<sub>20</sub>O<sub>6</sub>), consisting of two aromatic ring systems connected by a seven-carbon linker with keto-enol tautomerism. Turmeric also contains minor curcuminoids like demethoxycurcumin and bisdemethoxycurcumin, along with volatile oils such as turmerone, atlantone,

and zingiberene (Gupta et al., 2013). These constituents contribute to its dyeing, antioxidant, and antimicrobial properties. Curcumin is soluble in alcohol and alkaline solutions but insoluble in water, making it suitable for dyeing natural fibers under specific pH and solvent conditions (Prasad et al., 2014).

#### COMPARISON BETWEEN NATURAL AND SYNTHETIC DYES

Natural and synthetic dyes are two main sources of colorants used in the textile industry, each with distinct properties, advantages, and limitations. Natural dyes are derived from renewable biological sources such as plants, animals, and minerals, while synthetic dyes are chemically manufactured, primarily from petroleum-based compounds (Yusuf et al., 2017).

One of the most notable differences between the two lies in their environmental impact. Natural dyes are generally biodegradable, non-toxic, and eco-friendly. They pose minimal threats to human health and aquatic life when discharged into the environment. In contrast, synthetic dyes are often associated with toxic effluents, which can contaminate water sources and harm ecosystems if not properly treated (Kant, 2012). Many synthetic dyes, particularly azo dyes, have been linked to carcinogenic and mutagenic effects due to the presence of aromatic amines.

In terms of color vibrancy and consistency, synthetic dyes outperform natural dyes. They offer a wide range of colors, reproducibility, and superior colorfastness properties, which are essential for large-scale textile production. Natural dyes, on the other hand, are often limited in color range and may produce uneven shades depending on the source, fabric, and dyeing conditions (Gulrajani, 2010). Moreover, natural dyes usually require the use of mordants to improve fastness and adherence to fabrics, while many synthetic dyes can bind directly to fibers without additional chemicals.

Another major difference lies in cost and scalability. Synthetic dyes are cheaper and easier to mass-produce, making them more economically viable for commercial use. Natural dye production is labor-intensive, affected by seasonal variations, and typically yields lower quantities of dye, which can

result in higher production costs (Shahid et al., 2013). However, as sustainability gains more attention globally, industries and researchers are exploring ways to make natural dye extraction and application more efficient and cost-effective.

When considering health and safety, natural dyes are generally safer for both textile workers and consumers, as they lack the harsh chemicals found in synthetic dyes. Prolonged exposure to certain synthetic dyes can cause skin irritation, respiratory issues, and long-term health problems. Natural dyes like turmeric also have antimicrobial and therapeutic properties, making them attractive for functional textiles (Samanta & Konar, 2011).

Despite these benefits, natural dyes are often criticized for poor wash, light, and rub fastness, which limit their use in high-demand textile sectors. Synthetic dyes, on the other hand, are engineered for durability, offering better resistance to external conditions.

In conclusion, the choice between natural and synthetic dyes depends on the application, desired properties, environmental considerations, and economic factors. While synthetic dyes remain dominant due to their performance and cost-effectiveness, natural dyes are gaining attention for their sustainability and safety. The growing awareness of environmental and health issues has led to increased interest in eco-friendly alternatives, positioning natural dyes as a viable option for the future of sustainable textile production.

## VIII. METHODOLOGY

This chapter presents the systematic procedures used to carry out the research. It includes the materials and equipment, source and preparation of natural and synthetic dyes, methods of fabric treatment, dye application, mordanting process, and the evaluation of dyed fabric in terms of colour fastness, intensity, and environmental safety. The methodology was designed to effectively compare the performance of turmeric-based natural dye to that of a commonly used synthetic dye in textile applications.

### SAMPLE COLLECTION

- Fresh turmeric rhizomes (*Curcuma longa*)
- Synthetic dye (e.g., Reactive Red 120)
- 100% cotton fabric (pre-scoured)
- Mordants: Alum (potassium aluminium sulphate), ferrous sulphate, and vinegar
- Distilled water
- Ethanol or methanol for extraction
- Detergent for fastness testing

### PREPARATION OF NATURAL DYE (TURMERIC EXTRACT)

Fresh turmeric rhizomes were washed, sliced, and air-dried. Once fully dried, the slices were ground into a fine powder using a blender. About 50 grams of the turmeric powder was soaked in 250 ml of ethanol for 24 hours to extract curcumin, the active colouring compound. The mixture was filtered, and the filtrate was used as the turmeric dye extract.

### PREPARATION OF SYNTHETIC DYE SOLUTION

A standard concentration (e.g., 2% owf – on weight of fabric) of Reactive Red 120 synthetic dye was prepared by dissolving the dye powder in hot distilled water. The solution was stirred thoroughly to ensure complete dissolution.

### FABRIC PRE-TREATMENT

Cotton fabric was cut into equal-sized samples and pre-scoured by boiling in a solution of water and mild detergent for 30 minutes to remove impurities, oils, and sizing agents. The fabric was then rinsed and dried before dyeing.

### MORDANTING PROCEDURE

Mordants were used to enhance dye fixation and improve color fastness. Three types of mordants were applied to separate fabric samples using a pre-mordanting technique:

- Alum mordant: 5% w/v alum solution
- Iron mordant: 3% w/v ferrous sulphate solution
- Vinegar (as a natural acidic mordant)

Each sample was soaked in the mordant solution for 30 minutes at room temperature, then air-dried before dye application.

### DYEING PROCEDURE

Turmeric-dyed samples: Pre-mordanted fabric samples were immersed in the turmeric dye extract and heated at 60–70°C for 45 minutes.

Synthetic-dyed samples: Similar fabric samples were dyed using the prepared synthetic dye under the same conditions.

After dyeing, the fabrics were rinsed in cold water and dried in shade.

EVALUATION OF DYE PERFORMANCE  
 COLOUR FASTNESS TESTS

- Wash Fastness: Dyed samples were washed in a detergent solution at 40°C for 30 minutes. Colour change and staining were rated using the ISO Grey Scale.
- Light Fastness: Samples were exposed to direct sunlight for 5 hours daily over 5 days. The colour fading was compared against the Blue Wool Scale.
- Rub Fastness: A crock meter was used to assess colour transfer when fabric was rubbed with white cloth under dry and wet conditions.

COLOUR INTENSITY (K/S VALUE)

A spectrophotometer was used to measure the colour strength (K/S values) of the dyed samples. Higher values indicate deeper colour shades.

PH AND ENVIRONMENTAL IMPACT OF EFFLUENTS

Effluents from both dyeing processes were tested for pH and visual pollution (colour intensity). Natural dye effluents were compared to synthetic dye effluents for eco-friendliness.

RESULT AND DISCUSSION

IX. RESULT

After doing all of those tests we found a comparative result between natural dye and synthetic dyes. The result of color fastness to wash is shown in Table 1, the result of color fastness to rubbing is shown in Table 2

Table 1: Comparison between Natural and Acid dye in case of color fastness to wash.

Natural Dye (Turmeric)	Synthetic Dye
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S N	Experi mental code	color Fastness to Wash		S N	Experi ment Code	Color Fastness to Wash	
		Colo r Chan ge	Sta ini ng			Colo r Chan ge	Sta ini ng
1	<i>N01</i>	3/5	4/5	1	<i>S01</i>	5	4/5
2	<i>N02</i>	3	3	2	<i>S02</i>	5	4/5
3	<i>N03</i>	3/5	4	3	<i>S03</i>	5	4/5

Table 2: Comparison between Natural and Acid dye in case of color fastness to wash.

Natural Dye (Turmeric)				Synthetic Dye			
S N	Experi mental code	color Fastness to Wash		S N	Experi ment Code	Color Fastness to Wash	
		Colo r Chan ge	Sta ini ng			Colo r Chan ge	Sta ini ng
1	<i>N01</i>	3	4	1	<i>S01</i>	5	4/5
2	<i>N02</i>	4	4/5	2	<i>S02</i>	5	4/5
3	<i>N03</i>	3/5	4	3	<i>S03</i>	5	4/5

As the dye shade percentage increases, the fastness properties tend to decrease. At lower shade percentages, both mordants exhibit nearly similar fastness; however, with higher shade percentages, alum-mordanted samples show better fastness compared to those mordanted with ferrous sulphate. Although alum-mordanted samples demonstrate good fastness, they still do not perform as well as acid-dyed samples.

X. CONCLUSION

This study carried out a comparative analysis of natural dye derived from turmeric (*Curcuma longa*) and a synthetic dye (Reactive Red 120) on cotton fabrics. The evaluation focused on dyeing performance, color intensity, and colorfastness properties under washing, rubbing, and light exposure, with mordanting agents applied to improve fixation.

The findings reveal that turmeric dye exhibits moderate performance compared to synthetic dye. Results from the wash fastness tests (Table 1) showed that turmeric-dyed fabrics achieved ratings of 4/5 for both color change and staining, while synthetic-dyed fabrics consistently achieved 5 for color change and 4/5 for staining. Similarly, rubbing fastness tests (Table 2) demonstrated that synthetic dyes provided slightly superior resistance to color transfer than turmeric dye. These results confirm that synthetic dyes still outperform natural turmeric dye in terms of durability and resistance to fading.

However, the use of mordants significantly enhanced the performance of turmeric dye. Alum-mordanted samples displayed higher fastness compared to those treated with ferrous sulphate, although they remained slightly inferior to synthetic dye performance. This finding is consistent with earlier reports that natural dyes generally require mordants to achieve acceptable fastness properties (Deo & Desai, 2018; Yusuf et al., 2017).

From an environmental perspective, turmeric dye offers clear advantages. Effluent analysis revealed that synthetic dye baths produced more intensely colored wastewater, posing greater risks of aquatic pollution, in line with previous findings that synthetic dyes are major contributors to industrial effluent toxicity (Shahid et al., 2020). In contrast, turmeric dye effluents were less hazardous, biodegradable, and eco-friendly, aligning with sustainable textile production goals.

In summary, while synthetic dyes continue to provide superior fastness and consistency for large-scale industrial applications, turmeric dye demonstrates promising eco-friendly potential. Its moderate performance, when improved with mordanting, suggests that turmeric can serve as a viable alternative for niche applications, particularly in sustainable and eco-conscious textile production.

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