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Natural Dyeing and Mordants: A Comprehensive Review of Eco-friendly Textile Practices

Harshita Bhown & Radha Kashyap

Abstract

The growing environmental and health concerns associated with synthetic dyes and metallic mordants have revitalized interest in natural dyeing processes for textiles. This review provides a comprehensive overview of natural dyes derived from plant, animal, and mineral sources, with a particular focus on the role and effectiveness of natural mordants. The paper discusses traditional and modern extraction techniques, dye application methods, and the mechanisms by which natural mordants enhance dye fixation and fastness properties. Recent advances, including the exploration of novel bio-mordants from agricultural and plant waste, are highlighted alongside comparative analyses with conventional metallic mordants. Environmental benefits, safety profiles, and the challenges of scalability and colour reproducibility are critically examined.

Keywords: Bio-mordants; Dye extraction; Eco-friendly dyeing; Natural dyes; Natural mordants; Plant-based dyes; Sustainable textiles.

1. Introduction

Background on Natural Dyes and Mordants

Natural dyes, derived from renewable sources such as plants, animals, and minerals, have a rich history in textile arts. Their resurgence is attributed to growing environmental concerns regarding synthetic dyes, which often involve harmful chemicals and processes (Prabhu & Bhute, 2012; Devi et al., 2025). Mordants play a crucial role in enhancing the affinity of these dyes to fibers, improving colourfastness and vibrancy. The interplay between natural dyes and mordants is essential for achieving desired hues and durability in textiles. The ancient art of dyeing precedes written history. Europe's Bronze Age is when its practice first appeared.

Sticking plants were one of the earliest dyeing methods. As time went on, the procedure improved by employing natural colours made from crushed fruits, berries, and other plant components that were cooked into the fabric. Additionally, tests for water and light fastness were created (Jothi, 2008).

In recent decades, the textile industry's reliance on synthetic dyes and metallic mordants has raised significant environmental and health concerns. Synthetic dyes often contain hazardous chemicals that can pollute water bodies and pose risks to human health through direct exposure or residual contamination. Similarly, conventional metallic mordants such as chromium, copper, and iron can be toxic and non-biodegradable, contributing to ecological imbalance. These issues have sparked a global movement toward sustainable and eco-friendly alternatives, reviving interest in natural dyes and mordants as safer, biodegradable, and less polluting options.

Objectives and Scope of the Review

This review aims to provide a comprehensive overview of natural dyeing processes, with a particular focus on the role and effectiveness of natural mordants. The paper will cover the sources and classification of natural dyes and mordants, extraction and application methods, mechanisms of dye fixation, and evaluation of dyeing performance. Recent advances, environmental impacts, and challenges associated with natural dyeing are also discussed.

2. Historical Perspective

Natural dyes and mordants have played a crucial role in textile traditions across various cultures, reflecting both artistic expression and practical applications. From ancient civilizations to modern practices, the use of natural dyes derived from plants, minerals, and insects has been integral to creating vibrant textiles. This overview will explore the historical significance, cultural practices, and the environmental implications of natural dyeing techniques.

Historical Significance

Evidence of natural dye use dates back to the Neolithic period, with findings from Çatalhöyük around 6000 BCE (Cardon, 2011). Ancient Egyptians utilized madder root, wood and saffron, employing mordants like alum to enhance colour fastness (Tian et al., 2023; Surjit et al., 2023).The

Greeks and Romans famously used Tyrian purple from murex snails, symbolizing status and wealth (Cardon, 2011).

In India, indigo and turmeric were not only dyes but also held cultural significance, with turmeric being linked to religious practices (Surjit et al., 2023). Indigenous cultures in the Americas, such as the Mayans and Aztecs, used cochineal for red dyes, showcasing the diversity of natural dye sources (Cardon, 2011; Surjit et al., 2023).Chinese silk production heavily relied on natural dyes, reflecting social status and craftsmanship (Cardon, 2011).

Natural dy es are considered more sustainable compared to synthetic alternatives, as they are derived from renewable resources (Surjit et al., 2023). The use of natural mordants, such as those from plants and minerals, is essential for achieving vibrant colours and ensuring fabric longevity. While the revival of natural dyeing techniques is gaining momentum due to sustainability concerns, the shift towards synthetic dyes in the 19th century has led to environmental challenges. Balancing traditional practices with modern demands remains a critical issue in the textile industry.

The transition from natural to synthetic dyes marked a significant shift in the textile industry, driven by the advantages of synthetic options. However, recent environmental concerns have led to a resurgence of interest in natural dyes, highlighting their cultural and ecological significance. This answer explores the historical context, the impact of synthetic dyes, and the contemporary revival of natural dyeing practices.

Natural dyes were predominant until the mid-19th century, derived from plants, insects, and minerals (Kadolph, 2008).The invention of synthetic dyes in 1856 revolutionized dyeing, offering brighter colours and lower costs, leading to a decline in traditional practices (Lalonger, 1994).

Synthetic dyes provided consistent quality and ease of use, significantly reducing the need for mordants(Bide, 2014).By the 1930s, most textiles in North America and Europe were dyed synthetically, resulting in a loss of traditional dyeing knowledge(Kadolph, 2008).

Growing awareness of the environmental hazards associated with synthetic dyes has sparked renewed interest in natural alternatives(Devi et al., 2025; Prabhu & Bhute, 2012).Sustainable fashion movements emphasize the cultural significance and eco-friendliness of natural dyes, encouraging artisans to revive traditional techniques(Devi et al., 2025).Despite the resurgence of natural dyes, challenges remain, including their limited availability and the efficiency of synthetic dyes in meeting modern production demands(Bide, 2014).

3. Sources and Classification of Natural Dyes

Natural dyes, derived from various natural sources, have been utilized for centuries in textiles, food, and art. Their eco-friendliness and low toxicity have led to a resurgence in interest, particularly as awareness of the environmental impact of synthetic dyes grows. This review will explore the sources of natural dyes, their classification, and the benefits they offer.

Sources of Natural Dyes*:* Natural dyes are primarily sourced from three categories:

1. **Plant-Based Dyes:** The most common source, including:
   - Roots: Madder (Rubia tinctorum) for red.
   - Bark: Catechu (Acacia catechu) for brown.
   - Leaves: Indigo (Indigofera tinctoria) for blue.
   - Flowers: Marigold (Tagetes spp.) and hibiscus for yellow to red.
   - Fruits: Pomegranate rind (Punica granatum) for yellow to green.
   - Seeds: Annatto (Bixa orellana) for orange to yellow (Patel et al., 2024; Chauhan et al., 2023).

2. **Animal-Based Dyes***:* Animal-based dyes, derived from insects and marine animals, have a rich history and diverse applications in various industries. Notably, cochineal, lac, Tyrian purple, and kermes are prominent examples, each with unique properties and historical significance. The following sections delve into these dyes, highlighting their sources, chemical compositions, and uses.

   Cochineal is derived from the scale insect Dactylopius coccus, primarily found on cacti in tropical regions of

South America and Mexico (Nejad & Nejad, 2013).The dye is primarily composed of carminic acid, which is extracted from the insect's body and eggs (Cooksey, 2019). Cochineal is widely used in food colouring and cosmetics, valued for its vibrant crimson hue (Nejad & Nejad, 2013). Lac is produced by the lac insect, Kerria lacca, which secretes a resin that can be processed into dye (Mahltig, 2024).The dye contains laccaic acid, a red anthraquinone derivative(Cooksey, 2019).Lac dye has historical significance in textiles and is also used in varnishes and cosmetics.

Tyrian purple is obtained from marine snails of the Murex genus, making it one of the rarest dyes (Mahltig, 2024).This dye was highly prized in ancient times, often associated with royalty due to its cost and labor-intensive extraction process. Kermes dye is derived from scale insects, specifically Kermes vermilio. The dye contains kermesic acid, another red anthraquinone derivative (Cooksey, 2019).Historically used in textiles, kermes was a significant dye before the rise of cochineal.

While animal-based dyes have been integral to various industries, there is a growing trend towards synthetic alternatives due to concerns over sustainability and ethical sourcing. This shift may impact the future use of traditional dyes, despite their historical and cultural significance (Mahltig, 2024).

3. **Mineral-Based Dyes***:* Mineral-based dyes and microbial dyes represent two distinct yet significant categories in the realm of natural colourants. Mineral-based dyes, such as ochre, malachite, cinnabar, and Prussian blue, have historical and contemporary applications, while microbial dyes are emerging as a renewable alternative. This review will delve into the characteristics, applications, and implications of these dye sources.

Composed of iron oxide, ochre ranges from yellow to red and has been used since ancient times for both artistic and cosmetic purposes. Its durability and resistance to fading make it suitable for textiles. A copper carbonate, malachite provides a vibrant green hue. Its historical use in art and decoration highlights its aesthetic value (Yadav et al., 2022).Historically significant for its bright red colour, cinnabar (mercury sulfide) is now largely avoided due to its toxicity (Yadav et al., 2022).An iron-based pigment, Prussian blue has a rich history in art and is noted for its stability and unique colour properties. Its applications extend beyond art to medicinal and industrial uses (Singh & Sharma, 2024).

4. **Microbial Dyes***:* Microbial dyes, produced by certain bacteria and fungi, are gaining attention for their eco-friendliness and renewability. These pigments can be cultivated easily, offering a sustainable alternative to traditional dyes (Yadav et al., 2022).

While mineral-based dyes have a long-standing historical significance, the rise of microbial dyes presents an innovative approach to dye production, emphasizing sustainability and environmental safety. This shift may redefine the future of dyeing practices in various industries.

Classification of Natural Dyes

Natural dyes can be classified by source, chemical structure, method of application, and colour produced:

1. Based on Chemical Structure or Colouring Component

Type	Example(s)	Colour
Anthraquinones	Madder, Cochineal, Lac	Red, Pink, Orange
Indigoids	Indigo, Tyrian Purple	Blue, Purple
Flavonoids	Marigold, Onion peel	Yellow, Orange
Tannins	Myrobalan, Pomegranate	Yellow to Brown
Carotenoids	Annatto, Carrot	Orange, Yellow
Naphthoquinones	Henna, Walnut hulls	Orange-Brown, Black
Anthocyanidins	Berries, Red cabbage	Red, Purple
Di-hydropyrans	Logwood, Sappan-wood	Dark shades

Table 1 Sources: (Natural Colorants—Quinoid, Naphthoquinoid, and Anthraquinoid Dyes, 2023); (Tang et al., 2024)

The colour is determined by the dye's chromophore—the part of the molecule responsible for absorbing light.

2. Based on Affinity to Fibers and Application Method

Dye Type	Mordant	Fiber Affinity/Examples
Substantive (Direct) Dyes	No	Cotton, silk (e.g., turmeric)
Adjective Dyes	Yes	Madder, logwood
Vat Dyes	Yes (reduction/oxidation)	Indigo
Mordant Dyes	Yes (metal salts)	Tannins, cochineal

Table 2 Affinity to Fibers and Application Methods (Medina-Borges, 2023)

Mordants (metal salts or tannin-rich substances) are often used to fix the dye to the fiber and enhance colourfastness.

3. Based on Colour Produced

Colour	Source Examples
Red	Madder, Cochineal, Lac
Yellow	Turmeric, Marigold, Pomegranate
Blue	Indigo
Brown	Catechu, Walnut hulls
Green	Combination of yellow (turmeric) and blue (indigo), or spinach, peppermint leaves
Black	Iron with tannin-rich dyes

Table 3 Examples based on Colour Produced (Ferreira et al., 2004)

Natural dyes are classified primarily by their source (plant, animal, mineral, microbial), chemical structure (such as anthraquinones, flavonoids, indigoids), method of application (direct, vat, mordant), and colour produced. Their diversity and eco-friendly nature make them increasingly attractive for sustainable applications in textiles and beyond.

Traditional Use of Natural Dyes and Mordants in Different Cultures

The traditional use of natural dyes and mordants is a rich tapestry woven through various cultures, showcasing their historical significance and artistic expression. Evidence of dyeing practices dates back to ancient civilizations, where natural materials were utilized for both functional and ceremonial purposes. This overview will explore the historical context, the role of mordants, and the cultural significance of natural dyes across different regions.

Natural dyeing techniques have been practiced since at least 6000 BCE, with archaeological findings in places like Çatalhöyük and ancient Egypt(Burkinshaw, 1990).Cultures such as the Egyptians and the Indus Valley Civilization utilized plants like indigo and madder for vibrant textiles, indicating a sophisticated understanding of dyeing processes(Tian et al., 2023; Surjit et al., 2023).

Role of Mordants

Mordants are essential in enhancing the affinity of natural dyes to fabrics, improving colour fastness and vibrancy(Medina-Borges, 2023).Traditional mordants included plant extracts and minerals, while modern practices have expanded to include various metal salts and organic substances (Medina-Borges, 2023).

Cultural Significance

In India, natural dyes are integral to textile traditions, with specific regions known for unique dyeing techniques, such as Kerala's organic dyeing practices.The use of natural dyes not only reflects artistic expression but also embodies sustainable practices, as they are derived from renewable resources and often have antifungal properties(Surjit et al., 2023). Conversely, the shift towards synthetic dyes in the 19th century has raised concerns about environmental sustainability, prompting a resurgence of interest in traditional dyeing methods as part of the slow fashion movement. This highlights the ongoing relevance of natural dyes in contemporary textile practices.

The historical significance of natural dyes, particularly indigo, spans various cultures and regions, showcasing unique techniques and symbolic meanings. Indigo, derived from plants like Indigofera tinctoria, has been a prominent dye in textile traditions worldwide, with methods such as resist dyeing and fermentation enhancing its application. This overview will explore the cultural contexts, techniques, and materials associated with indigo and other natural dyes.

Cultural Contexts of Indigo Dyeing

China: The Book of Songs highlights indigo-dyed silks as symbols of status and prosperity (Sandberg, 1989). West Africa: The Yoruba community utilized indigo fermentation and plant-based dyes like camwood, developing distinct ceremonial textiles(Sandberg, 1989).Americas: The Mayans and Aztecs valued cochineal for vibrant reds, while Native American tribes employed local plants for diverse colours (Nabais et al., 2024).

Essential for dye fixation, common mordants included alum, iron, and tannin-rich extracts (Ferreira et al., 2004).Methods like batik and tie-dye demonstrate the ingenuity of ancient dyers, with fermentation techniques for indigo being particularly notable. (Sandberg, 1989) (Thadepalli & Amsamani, 2023). While the historical use of natural dyes reflects cultural richness and innovation, the rise of synthetic dyes in the 19th century has shifted the landscape of textile colouring, raising questions about sustainability and the preservation of traditional practices (Fox & Pierce, 1990).

The transition from natural to synthetic dyes marked a significant shift in the textile industry, driven by the discovery of mauveine by William Perkin in 1856. This innovation offered numerous advantages over natural dyes, including brighter colours, improved reproducibility, and lower costs, which led to the widespread adoption of synthetic dyes. The shift was further accelerated by colonial policies that favoured synthetic alternatives, impacting local artisanal economies, particularly in regions like India. This transition was not only a technological advancement but also a cultural and economic shift that reshaped the global textile industry. The following sections explore the key aspects of this transition.

Synthetic dyes provided more reliable and consistent colours compared to natural dyes, which often varied in shade and strength. They eliminated the need for mordants and reduced the complexity of dyeing processes, saving water and energy. The ability to produce fast bright shades and fast black colours was a significant advantage, as was the capacity for accurate colour matching (Bide, 2014).

The introduction of synthetic dyes revolutionized fashion, offering a range of vibrant hues that were previously unavailable, particularly in women's dresses ("Aniline dye",, 2022).The synthetic dye industry became the first science-based industry, with significant contributions from British and French firms, which dominated the market in the early years (Murmann, 2000).Colonial policies promoted synthetic dyes, undermining traditional dyeing practices and impacting local economies, especially in colonized regions like India (Lalonger, 1994).

Despite their advantages, synthetic dyes and their by-products posed new chemical threats to the health of workers and the environment. Recent concerns about sustainability have led to a re-examination of natural dyes, although they cannot meet the current demand for textile colouration (Bide, 2014).While synthetic dyes have dominated the textile industry due to their numerous advantages, there is a growing interest in sustainable practices and natural dyes. This resurgence is driven by environmental concerns and a desire to preserve traditional dyeing techniques. However, the capacity of natural dyes to meet modern demands remains limited, highlighting the ongoing relevance of synthetic dyes in the industry.

4. Extraction and Application Methods

Natural dye extraction methods are diverse, each tailored to the solubility and source material of the dye, as well as the desired efficiency of the process. Traditional aqueous extraction, while simple, is less efficient and primarily suitable for water-soluble dyes. In contrast, solvent extraction, which uses organic solvents like ethanol and methanol, offers higher yields and is effective for both water-soluble and insoluble compounds. Modern techniques such as ultrasonic-assisted extraction and supercritical fluid extraction are gaining attention for their efficiency and eco-friendliness. The choice of extraction method significantly impacts the quality and application of the dye, influencing factors such as colour fastness and environmental impact.

Aqueous Extraction: Utilizes water with optional additives like salt, acid, alkali, or alcohol. Traditional method, less efficient, suitable for water-soluble dyes (Sk et al., 2021) (Patel et al., 2024).

Solvent Extraction: Employs organic solvents (e.g., ethanol, methanol, and acetone) for higher yield. Effective for both water-soluble and insoluble compounds. Soxhlet extraction is preferred for continuous solvent cycling, maximizing pigment recovery (Sk et al., 2021; Patel et al., 2024).

Modern Techniques: Ultrasonic-assisted extraction: Uses acoustic cavitation to break cell walls, improving efficiency (Sk et al., 2021). Supercritical Fluid Extraction: Eco-friendly but less common, uses supercritical CO2 as a solvent (Sk et al., 2021).

Dyeing Procedures: Fabric treated with mordant before dyeing, enhancing dye-fiber affinity but may limit colour depth (Chungkrang et al., 2021). Mordant and dye applied together, efficient but may reduce wash fastness (Chungkrang et al., 2021).Fabric dyed first, then treated with mordant, delivering superior light fastness and deeper shades (Chungkrang et al., 2021).

While natural dyes offer environmental benefits and are increasingly preferred for their non-toxic properties, the extraction and application methods must be carefully selected to optimize their performance. The resurgence of natural dyes is driven by their eco-friendly nature and the growing demand for sustainable products, despite the challenges in achieving the same vibrancy and consistency as synthetic dyes (Chungkrang et al., 2021; Ahsan et al., 2020; Adeel et al., 2019).

Soxhlet extraction is a widely recognized method for isolating natural dyes from various sources, utilizing solvents like ethanol and methanol. This technique not only enhances pigment concentration but also ensures high purity by effectively removing unwanted compounds. The following sections detail the extraction process, advantages, limitations, and optimization strategies.

Extraction Process: Raw materials, such as madder root or indigo leaves, are placed in a thimble, and the solvent circulates for 4–8 hours, allowing continuous reflux to dissolve non-polar compounds. Soxhlet extraction can recover over 95% of dyes, such as curcumin from turmeric. This method yields 20–30% higher pigment concentrations compared to aqueous methods, effectively removing waxes and lipids. It can be adapted for different dye types by adjusting solvent polarity, with ethanol preferred for polar dyes and methanol for alkaloids (Morshed et al., 2016).

High amounts of solvent are required, necessitating post-extraction recovery processes. The use of solvents raises sustainability issues, prompting exploration of alternative extraction methods (Ngamwonglumlert et al., 2017).

Combining Soxhlet extraction with ultrasound can reduce extraction time by up to 50% and improve yield. While Soxhlet extraction is effective, emerging methods like supercritical fluid extraction and microwave-assisted extraction offer potential advantages in terms of reduced solvent use and extraction time, highlighting the need for ongoing innovation in dye extraction techniques (Ngamwonglumlert et al., 2017).

Post-mordanting is a crucial technique in dyeing processes, particularly for enhancing colour fastness and achieving vibrant hues. This method involves applying mordants after the dyeing process, which helps in preventing competitive binding in dye-mordant-fiber systems, thereby reducing dye hydrolysis and improving overall dye uptake. The following sections elaborate on the benefits and critical parameters associated with post-mordanting.

Studies indicate that post-mordanting significantly improves colour fastness ratings, with improvements noted from 5 to 6 for light fastness when using various mordants. Post-mordanting yields the most brilliant colours on fabrics, as it allows for better saturation and colour strength compared to pre- or simultaneous mordanting .By preventing competitive binding, post-mordanting minimizes dye loss during the dyeing process, ensuring more efficient use of materials (Medina-Borges, 2023).

Optimal dyeing occurs at 60–70°C; exceeding 75°C can lead to dye decomposition(Johnson & Allred, 1996).Maintaining a pH of 9.0–10.5 is essential for maximizing dye uptake; lower pH levels can hinder ionization. An MLR of 1:07 to 1:10 is ideal; ratios above 1:15 dilute the dye, resulting in weaker shades (Johnson & Allred, 1996).

While post-mordanting offers significant advantages, it is essential to consider the environmental trade-offs, such as increased energy consumption at higher temperatures and the need for longer dyeing times. Balancing these factors is crucial for sustainable dyeing practices.

5. Natural Mordants

Natural mordants are ubstances derived from plant, mineral, or animal sources that are used to fix natural dyes onto textile fibers. Their primary role is to form a bridge between the dye molecules and the fiber, enhancing the uptake of colour and improving fastness properties such as resistance to washing, light, and rubbing. Unlike synthetic or metallic mordants, natural mordants are biodegradable, non-toxic, and environmentally benign, making them highly desirable for sustainable textile processing.

Natural mordants play a crucial role in the fixation of natural dyes onto textile fibers, enhancing colour uptake and improving fastness properties. These biodegradable and non-toxic substances, derived from plant, mineral, or animal sources, are increasingly favored in sustainable textile processing. Their ability to form a bond between dye molecules and fibers is essential for achieving vibrant and long-lasting colours. The following sections delve into the types of natural mordants and their significance.

Plant-Based Mordants: Found in plants like amla, pomegranate rind, and oak galls, tannins effectively bind dyes to fibers due to their high affinity for both(Medina-Borges, 2023).Substances such as banana sap and turmeric also serve as effective mordants, each contributing unique properties to the dyeing process (Alam et al., 2017).

Mineral-Based Mordants: Clay and natural alum deposits are examples of mineral-based mordants, though they are less commonly used compared to plant-based options (İşmal & Yıldırım, 2019).

Animal-Based Mordants: While less prevalent, animal-derived mordants can enhance dye fixation and are sometimes utilized in traditional practices(Medina-Borges, 2023).Despite the advantages of natural mordants, some researchers argue that the efficiency and colour yield may not always match those of synthetic alternatives, prompting ongoing exploration of innovative mordanting techniques (İşmal & Yıldırım, 2019).

Natural mordants enhance dye fixation on textiles through various mechanisms, including hydrogen bonding, chelation, and electrostatic attraction. These processes involve the formation of complexes between dye molecules and textile fibers, improving colour retention and fastness. The effectiveness of natural mordants, while generally safer and more environmentally friendly than metallic alternatives, can sometimes result in less vibrant colours.

Polyphenolic compounds, such as tannins, create hydrogen bonds with both the dye and fiber, enhancing adhesion (Hwa, 2008).Plant acids and minerals chelate metal ions in fibers, facilitating dye attachment (Sutlović et al., 2024).Charged groups in natural mordants promote electrostatic interactions with dye molecules(Medina-Borges, 2023).

Comparison with Metallic Mordants: Metallic mordants like alum and iron produce a wider range of shades but pose toxicity risks and environmental concerns (Farag, R et al., 2013).Natural mordants are biodegradable and non-toxic, minimizing ecological risks, while heavy metals can contaminate ecosystems(Haji et al., 2022).

Despite the advantages of natural mordants, their lower colour brightness and fastness compared to metallic mordants may limit their application in some contexts. However, ongoing research continues to improve their efficacy and sustainability.

6. Overview of natural dyeing using various plant-based sources on different natural fabrics, highlighting the mordants and the resulting colour outcomes

S. No.	Natural Dye Source	Fabric Used	Mordant Used	Result/Color Obtained	Source
1	Turmeric (Curcuma Longa)	Cotton	Alum	Bright Yellow	Awode Et Al., 2023
2	Henna (Lawsonia Inermis)	Silk	Alum + Iron	Olive Green To Brown	Bhuiyan Et Al., 2017
3	Pomegranate Peel	Wool	Alum + Myrobalan	Golden Yellow To Brown	Talebpour, A., Et Al. (2017)
4	Onion Peel (Red)	Silk	Alum	Yellow To Reddish Orange	Singhee, D. (2020).
5	Madder Root	Wool	Alum + Tannin	Red To Brick Red	Jahangiri Et Al., 2018
6	Marigold Petals	Cotton	Alum	Yellow To Mustard	Vastrad Et Al., 2017
7	Walnut Husk	Wool	No Mordant	Dark Brown	Hosseinnezhad Et Al., 2022
8	Eucalyptus Leaves	Jute	Alum, Potassium Dichromate, Copper Sulphate And Ferrous Sulphat	Yellowish To Brown	Nahar Et Al., 2020

Table 4 Natural Dye Sources, Mordant Applications, and Resultant Shades on Select Natural Fabrics

Conclusion

Natural dyes and mordants have experienced a significant revival in the modern textile industry due to growing environmental and health concerns associated with synthetic alternatives. This review highlights the extensive range of natural dyes derived from plant, animal, and mineral sources, and emphasizes the critical role of natural mordants in enhancing dye fixation, colour vibrancy, and fastness.

While traditional extraction and application techniques have evolved, the use of eco-friendly methods and bio-mordants continues to gain importance in sustainable textile processing. The comparative evaluation of natural versus synthetic dyeing systems reveals that although natural dyes are biodegradable, safer, and culturally rich, challenges such as colour reproducibility, scalability, and mordant efficiency remain.

However, emerging technologies in extraction and mordanting, coupled with growing consumer awareness, are paving the way for broader adoption of natural dyes. Continued research and innovation are essential to bridge the performance gap with synthetics while maintaining ecological balance. With supportive policy frameworks and sustainable practices, natural dyeing has the potential to become a mainstream solution in the global movement toward environmentally responsible textiles.

Future Direction

In the future, natural dyeing can become more practical and widely adopted if research focuses on improving its consistency, colorfastness, and eco-friendliness. Exploring plant waste and microbes as new sources of dyes and mordants can make the process more sustainable and cost-effective. There's also great potential in using new technologies like enzymes and nano-encapsulation to make natural dyes more durable and functional. At the same time, it's important to create standard methods for dye extraction and application, so results are more predictable across different batches. Understanding the environmental impact of natural dyes through proper life cycle assessments and encouraging collaboration between researchers, industries, and policymakers can help bring natural dyeing into the mainstream textile market.

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