Sustainable Colorants from Natural Resources

K. Nivedha and K. Kalaiarasi

Abstract In order to better understand the evolution and scientific improvements in textile dyeing throughout various archaeological periods, the dyestuffs applied to textile materials by ancient civilizations have been investigated. The utilization of sustainable natural bioresources in advanced garment developments is gaining momentum right now. Research and development in the textile industry have undergone a revolution as a result of the public's increased awareness of environmental preservation, eco-safety, and health issues. The textile industry has recently been under pressure from the public to utilize natural colorants with more advanced functions, without any negative effects on the environment or aquatic ecosystem. Natural dyes are an environmentally friendly substitute for synthetic colors. Natural dyes are increasingly being used to color textiles as people become more aware of adverse health effects of synthetic colors. Natural colorants won't cause any effluent issues when used. Natural dye, which is derived from tree, bark, leaves, flowers, and many other readily accessible sources, can provide vibrant colors. This article examines several starting materials for natural dye extraction, modern extraction procedures, surface modification approaches for improving dyeing, and colorfastness characteristics. Some artisans, weavers, and knitters employ natural dye as a distinctive aspect of their work due to the many benefits of this process. The majority of natural dyes have unique characteristics including antimicrobial and UV protection. This review paper will cover important topics including classification, extraction and dyeing, sustainability, as well as the isolated and widespread effects of bio-colorants obtained from bioresources.

Keywords Eco-preservation · Eco-safety · Sustainability · Bioresource · Natural dyes

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1 Introduction

William Henry Perkin, a scientist who was 18 years old at the time and working on a malaria cure, made the discovery of synthetic colors in 1856. The word mauveine, which gave rise to the name mauve, was given to this purple dye [1]. Even though the color was temporary, it stimulated research into synthetic dyes and helped develop the color range we use today [2].

Today, synthetic dyes are the source of practically all textile colors. This is an issue because synthetic dyes were listed as one of the top 10 pollutants in the world in 2012 by the Blacksmith Institute and the UN [3]. One of the biggest contributors to water pollution is synthetic colors, and according to the survey, 200,000 tons of these dyes are released as effluents into the environment annually [4]. The risk of exposure to chemicals like chromium, a known carcinogen, which is known to cause neurological developmental and cardiovascular harm, cadmium, and chlorine compounds affects an estimated one million individuals, mostly in South Asia [5]. The main cause of this exposure is water contamination brought on by dye factories discharging untreated effluent into nearby water sources. According to estimates, textile dyeing contributes between 17 and 20% of all industrial water contamination [6].

Due to the health advantages, eco-friendliness, and age-old technique, natural coloring resources are increasingly being used to dye textiles to overcome the drawbacks of synthetic dyes [7]. Manufacturers of synthetic dyes have recently been required to limit effluent toxicity and cease production of hazardous synthetic dyes and pigments. As a result, the use of natural dyes is expanding quickly worldwide. In order to produce textiles of high quality and sustainability, natural dyes are extracted from flora and wildlife utilizing a variety of extraction processes and mordanting procedures [8]. Due to the use of natural dyeing processes, several researchers have also reported achieving UV and antibacterial characteristics.

By focusing sustainable dye, the membrane process has recently become one of the most cutting-edge procedures [9]. This procedure is a quick and crucial way to separate micro-macromolecules based on the size and shape of the molecules. It is used in the fields of biotechnology, textiles, chemical engineering, and food technology. By using membrane techniques, it improved the quality with a high yield, low energy consumption, and minimal operating conditions.

A variety of techniques, including UV radiation, microwave ultrasonic treatment, biopolishing, cationization, mercerization, gamma rays, and nanoparticles, [10] are being suggested for surface modification of fabric by scientists working in the fields of plasma treatment and application of natural colorant techniques, [11] with a focus on improving the extraction of colorants from plant sources. These methods are one of the more effective ways to replace various wet operations while using less energy, water, and chemicals [11, 12].

This review article provides a brief explanation of the different concerns of sustainable natural dyes in the textile industry, such as suppliers, extraction procedures, application techniques, modern techniques, and sustainable problems encountered in day-to-day upkeep.

2 Classification of Natural Dyes

2.1 Plant Sources

Natural dyes have historically been heavily derived from plant sources. Different plant materials, such as roots, leaves, twigs, wood, bark, flowers, fruit, hulls, and husks, were employed. The majority of plants used to make dyes also have additional uses, such as those for food coloring, medicine such as antimicrobial agents and skin care products, etc. The list below includes some of these significant and often used dyes.

2.1.1 Indigo (Leaves)

The bean family member whose scientific name is *Indigofera tinctoria* produces the blue dye from its leaves. This dye is referred to as the "King of Natural Dyes" since it has been used from ancient times to create blue colors, particularly for dyeing denim materials.

2.1.2 Madder (Root)

The dyestuff "madder" is made from colorants taken from the roots of several plant species belonging to the genus *Rutria*.

2.1.3 Cutch (Wood)

Natural yellow-brown dye known as "cutch" is made from *Acacia catechu* family wood. It is a natural dye that can be used to tan and color cotton, silk, and wool [13]. Cutch-dyed fabrics are particularly good at withstanding light and washing [14].

2.1.4 Jungle Geranium

One of the floral anthocyanins is the jungle geranium (*Ixora coccinea*). It's a member of the Rubiaceae family. It is a shrub that grows in gardens as well as all over forest terrain. This flower is native to Asia and is also known in Ayurveda as Vetchi or Flame of the Wood. By using different colored flowers, such as pink, red, yellow, and orange, to dye fabric, we were able to get various shades.

2.1.5 Kamala

The dried fruit kamala (*Mallotus philippensis*) capsules produce a reddish-orange powder that can be used to dye silk and wool, giving off vibrant orange-yellow and golden-yellow hues.

2.2 Animal or Insect Sources

Animals are a natural source of dyes. With the aid of animals and insects, people have been extracting red- and purple-based dyes since ancient times. Dried insect corpses are a key source of natural colors [15].

2.2.1 Laccifer lacca

Ancient cultures also used lac to dye animal fibers since it comes from the secretions of the microscopic insects *Laccifer lacca*, which are found on Indian tree twigs.

2.2.2 Coccus ilicis

The scale bug *Kermes vermilio* (also known as *Coccus ilicis*), which is a member of the Kermeside family, produces a vivid reddish-purple color. Both the eggs and the adult females have been used to extract the red color. This dye is frequently used in the textile, art, and cosmetic industries.

2.2.3 Coccus cacti

Dactylopius coccus is the plant that produces cochineal dye, the color that gives scarlet its hue. The colors were taken from mature female cochineal's dried corpses.

2.3 Mineral Sources

Malachite, ultramarine blue, gypsum, red and yellow ochre, and charcoal black are all pigments derived from minerals. Additionally, minerals are employed to improve and fix the fastness of vegetable dyes [16].

3 Extraction Medium of Natural Dyes

3.1 Conventional Extraction/Aqueous Method

The dye supplies from the chosen plants, vegetables, or other materials were traditionally and often extracted by aqueous extraction. The chosen dye source is either broken up into little bits or made into powder in order to increase dye efficiency [17]. After about a night of soaking in the necessary amount of water, it is then boiled to remove the color. The bath's contents are cooled to room temperature, and using trickling filter paper to remove fine plant material from the dye source can guarantee the removal of the material and greater solubility of the natural dye. The types of plants, animals, or mineral species or parts employed determine the color of the dyes recovered through this technique [18].

3.2 Supercritical Fluid Extraction

The textile industry is currently focused on safe manufacturing processes that can guarantee good end-use qualities for colored textiles as well as uniformity and specified color for natural fibers. Natural dyes and biodegradable materials are also of interest [19]. Using a lot of water is a drawback of traditional dyeing methods that employ water as the dying agent. Further development is taking considerable steps beyond the use of traditional solvent extraction technologies to address these problems. Carbon dioxide is used as the extraction medium in this method [20].

3.3 Enzymatic Extraction

Enzyme-assisted extraction (EAE) is a green strategy that is regarded as a strong complement or alternative to traditional procedures. Cellulases, hemicelluloses, and pectinases are the enzymes that are most commonly used for extraction [21]. They primarily come from bacteria and fungi, but they can also be made from animal organs, vegetable and fruit extracts, and bacteria and fungi. Higher yields that can be directly linked to the breakdown of cell walls are one of the benefits of EAE. Higher purity results from the selectivity. High catalytic efficiency, preserving the original effectiveness of natural compounds, shortened extraction times, and less solvent requirement are further advantages [22].

3.4 Ultrasound Extraction

Due to its many benefits, ultrasound-assisted extraction (UAE) is regarded as a "green method." In order to protect the heat-sensitive bioactive components of the extract from harm, the ultrasound tool performs best at lower temperatures [23]. Due to acoustic cavitation, which is more effective at lower temperatures, the ultrasonic (US) technique offers a good extraction yield at a lower temperature. Another benefit is that ultrasonic (US) treatment allows for improved functional component isolation due to mass-based transfer kinetics. To extract a biologically potent functional chemical from natural fibres used for dyeing, US treatment is clean, homogeneous, cost-effective, and time-effective.

3.5 Magnetic Stirring

The molten matrix and the reinforcing particles can be mixed via electromagnetic stirring. Additionally, an electromagnetic force can be used to disseminate the particles if the electrical conductivity of the matrix phase is much higher than the electrical conductivity of the reinforcing particles [24]. Dendritic microstructures can be diminished by electromagnetic stirring. Additionally, it may work well for distributing reinforcement particles during MMC formation [25]. An induction furnace was utilized to melt the aluminum matrix, and a mechanical stirrer was used to combine the molten metal with the reinforcements. However, the electromagnetic field used in induction furnaces stirs molten metal uncontrollably and perhaps unintentionally and cannot be used until the solidification processes are complete.

4 Characterization of Natural Dye

Ultraviolet-visible spectroscopy is used to characterize natural dyes. Absorption spectroscopy in the ultraviolet and visible wavelength bands, 180–380 nm and 380–750 nm, is used in ultraviolet-visible spectroscopy (UV-vis spectroscopy) to analyze molecules. One of the simplest methods for analyte characterization is this one. Chromophores are specific light-absorbing functional groups that are present in all significant classes of biomolecules. These chromophores are stimulated from the ground state to a higher energy level upon absorption of UV-vis light, producing distinctive spectra that help identify particular proteins [26].

Infrared spectroscopy using the Fourier transform. Based on the observation that most molecules absorb light in the infrared region of the electromagnetic spectrum, Fourier transform infrared spectroscopy (FT-IR) was developed. Wavenumbers in the 4000–400 cm1 range are commonly used to measure frequency ranges. Due to the variety of functional groups, FT-IR is mostly effective for detecting organic molecular groups and compounds. Due to their transparency, KBr salts are used to make sample pellets because they provide superior spectral resolution [27]. The most used method for determining the structure of bioactive plant extracts is FT-IR. For instance, the IR spectrum of an extract of *Euphorbia thymifolia* leaves from the Kumaon Himalayas revealed absorption bands at 3407 cm1, 1666 cm1, and 1562 cm1 for hydroxyl, carbonyl, and unsaturation, respectively [28].

Spectrometry using electrospray ionization and mass. An electric potential is provided to a flowing liquid in electrospray ionization-mass spectrometry (ESI-MS), which causes the liquid to charge and then spray. This electrospray creates incredibly tiny solvent-and-analyte droplets. The direct integration of HPLC instruments with MS is made possible by ESI. In *Tragia involucrata*, the ESI-MS method is utilized to analyze phenolic-rich fractions and find flavonoids like gentenstein 7-glucoside, iridine, orientin, dihexosyl quercetin, quercetin-3-O-rutinoside, and rhamnosyl hexosyl methyl quercetin [29].

A thermal analysis technique known as thermogravimetric analysis (TGA) or thermal gravimetric analysis (TGA) measures a sample's mass over time as the variations in temperature. According to thermogravimetric analysis, this measurement can reveal information on both chemical and physical events, such as chemisorptions, heat breakdown, and solid-gas reactions [30]. It is vital to use differential scanning calorimetry the nature of thermal natural dye component dissociation at various dyeing temperatures as well as temperature for use examined the impact of various mordants on textiles dyed with a novel natural dye in cotton and linen (Commiphora gileadensis) and presented numerical data on weight change throughout heating procedure for uncolored, coloured, and coloured cotton that has been chrome- and alum-mordanted as well as ferrous sulphate [31].

5 Mordanting

Chemicals called mordants are used to fix a dye to fibers [32]. For coloring with natural dyes, there are three different types of mordanting processes that are frequently used: pre-mordanting, meta-mordanting, and post-mordanting. Pre-mordanting involves treating the substrate with the mordant before dyeing, meta-mordanting involves adding the mordant to the dye solution itself, and post-mordanting involves treating the dyed material with a mordant.

5.1 Types of Mordants

Chemicals called mordants are used to fix a dye to fibers. Pre-mordanting, meta-mordanting, and post-mordanting are the three main types of mordanting processes that are frequently used to color materials using natural dyes. In pre-mordanting, the substrate is treated with the mordant before being dyed, in meta-mordanting, the mordant is included in the dye solution itself, and in post-mordanting, the material that has already been colored is subjected to a mordant treatment.

Metallic stains. Only naturally occurring metal salts were employed as mordants in the past. Today, however, metal salts of chromium, iron, copper, tin, aluminum, and chromium are employed as mordants. Alum, potassium dichromate, ferrous sulfate, copper sulfate, stannous chloride, and stannic chloride [33] are a few examples of frequent mordants.

Tannic acid and tannins are generally used to keep leather from deteriorating. In addition, they are utilized in mordants, stains, and glues. Vegetable tannins are astringent and bitter compounds found in plants, frequently excreted in the bark and other components (especially leaves, fruits, and galls). The extractions are either utilized directly for tanning purposes or used in a concentrated form by extracting the tanning ingredients [34].

Oil mordants are mostly utilized to create the turkey-red color from madder [35]. The primary purpose of the oil mordant is to create a complex with the principal mordant, alum. Alum is easily removed from the treated cloth because it is water soluble and does not have a preference for cotton. Fatty acids and related glycerides, including palmitic, stearic, oleic, and ricinoleic acids, are present in the naturally occurring oil.

6 Application of Natural Dyes

Natural dyes largely disappeared from the textile dying industry when Henry Perkin created a synthetic dye in 1856. Natural dyes were seldom ever employed in textile dyeing with the advent of synthetic fibers. Only cotton, linen, silk, wool, and other natural fibers were dyed using natural materials. Natural dyes are regaining popularity today as individuals begin dying synthetic fibers with some natural colors due to the increased focus on safety problems including health and environmental safety [36]. For the creation of green products with added value as well as for the environment in general, natural dyes are especially suitable and practical. Applications and future prospects for dye development are excellent. The ensuing factors are especially significant.

6.1 Health Safety of the Underwear Product

People are starting to pay attention to health safety in today's society as a result of the rise in living standards. For the dyeing and finishing of underwear, pajamas, and other clothes, specifically clothing, as well as children's clothing, health safety is a need [37]. The majority of natural colors have therapeutic properties, some may fight off infection and inflammation, some can stimulate blood flow and break up stasis, some can block ultraviolet radiation, and all are safe for use on people [38].

As a result, they acquire the new power of children's clothing and underwear that are dyed with natural colors.

6.2 Health Safety of Household Textiles

Home textile items have evolved from being affordable and useful to being practical and environmentally friendly, thanks to technology advancement. Natural colored sheets, blanket covers, towels, and other home textile products must adhere to environmental and ecological requirements and serve a medical purpose [39].

6.3 Modern Textiles

Due to their unique composition and structure, several natural dyes are utilized in the creation of new functional modern textiles, [40] including soy protein and rhubarb anti-ultraviolet fabrics [41]. The cloth is both esthetically pleasing and practical because to the brilliant, steady color.

7 Natural Dyes in Functional Finishing of Textiles

A careful balance must now be struck between the compatibility of various finishing products and the treatments and application procedures used to assure textiles with the necessary qualities. The role of the textile finisher is becoming more and more demanding. Customers all around the world are looking for apparel and other textile products that are more comfortable to wear while still being clean, hygienic, and odor-free. It is urgently necessary to do research into novel techniques for creating hygienic textile goods, in textile finishing procedures, and in related applications and issues. The use of natural dyes to give textiles multifunctional qualities, such as antimicrobial, [42] insect repellent, [43] and deodorizing, [44] is presently the subject of a number of reports.

8 Future Prospects of Natural Dye

For the weaker segment of the population in rural and suburban regions, natural dyes provide sustainable work and income for dyeing as well as for growing nonfood crops to create plants for natural dyes. The use of natural dyes has the potential to generate carbon credits by decreasing the usage of synthetic colors derived from fossil fuels (petroleum). Natural dyes typically generate gentle, glossy, and calming hues for the human eye. Natural dyes are useful for maintaining and understanding ancient dyeing techniques, preserving and restoring the history of old textiles, and conserving and restoring colored museum textiles and other textiles found through archaeology. If biotechnological advances such as tissue culture or genetic engineering enable the very high availability of natural dyes in the future, Natural dyes and mass synthesis of these colours by Microbes must first become affordable for mainstream textile processing before their use can be sustained.

9 Conclusion

The conservation and restoration of historic textiles using natural dyes than synthetic dyes (which employ violent technology) for textiles, food, safety, and other purposes has been a major manifestation of interest in natural dyes in recent years. The amount of research and development being done to standardize natural dyes is minimal to nonexistent. There haven't been many genuine attempts to produce new data on the use of natural dyes. The majority of studies in this field are led astray by empirical data provided in the literature that lacks any kind of scientific foundation or justification. Natural colors are not readily available, especially in standardized forms like paste, powder, or solutions. The standardized natural extracts have a lot of applications in the fields of textiles, food, medicine, and cosmetics. Working out suitable, standardized applications of natural dyes on textiles with eco-friendliness is a task for any educated dyer.

Consumer confidence in natural dyed textiles would increase with the establishment of adequate characterization and certification processes, which would be advantageous to both producers and consumers. There is a lot of room for small-scale dyeing units to use natural dyes if their availability can be increased through the aforementioned strategies and their costs can be reduced through a proper certification mechanism. This is because they lack the funding to set up and run the pricey effluent treatment plants required to bring the synthetic dye effluent within the regulations established by the government. Natural dyes can complement synthetic dyes as an eco-friendly alternative for the environmentally conscious consumer at the current stage of scientific development, but only for small-scale applications. They can also help the various stakeholders in the natural dye value chain units make a living because they lack the resources to set up and run the pricey effluent treatment plants required to bring the synthetic dye effluent within the legal limits.

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