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REVIEW ARTICLE

# Potential of natural dyes from non-traditional flowers for textile application– A comprehensive review

**Kamaleshwaran Nanjundapuram Karunamoorthy[1*] & Subasni Ganesan[2]**

[1]Department of Floriculture and Landscape Architecture, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam 625 604, Tamil Nadu, India
[2]Department of Biotechnology, Sri Krishna Arts and Science College, Coimbatore 641 008, Tamil Nadu, India

*Correspondence email - kamalskhp2001@gmail.com

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## Abstract

Environmental degradation caused by textile industry effluents drastically damages aquatic ecosystems and groundwater tables by increasing biological oxygen demand (BOD) and chemical oxygen demand (COD). The synthetic dyes used in textiles are carcinogenic and mutagenic in nature and pose several risks to human health. This review discusses the use of natural dyes from non-traditional flowers as alternatives to synthetic textiles dyes. Non-traditional flowers are underutilized species that are not widely cultivated and their use has not been fully explored. Since flowers are diverse in color, they can be utilized for dye extraction to produce various shades. The literature review provides a list of non-traditional flowers that can be used as textile dyes along with advanced extraction methods. Proper characterization and toxicity analysis are essential for natural dyes after extraction, prior to their application in textiles to confirm the absence of heavy metals. The application part addresses advanced substrate pretreatment and the use of mordants to fix the natural colours to the fabric. The use of bio-mordants is an emerging technique in terms of the environment, which is related to floral dyes. Advanced dyeing methods and characterization of dyed fabrics are essential for commercial use. Challenges involved in various processes associated with natural dyes in textiles are listed and need to be addressed by further research in the future.

**Keywords:** dyeing; fastness test; mordant; natural dyes; non-traditional flowers; textile

## Introduction

Color has always played a central role in human culture and industry. Natural dyes, used since 5000 BC, were displaced by synthetic dyes after the discovery of aniline purple by William Henry Perkin in 1856 (1). While synthetic dyes are durable and affordable, they poses severe environmental and health issues due to their non-biodegradable and toxic nature (2). Many synthetic dyes are now restricted or banned (3).

Natural dyes are biodegradable, non-toxic and often multifunctional, offering properties such as antimicrobial activity, UV protection and fragrance retention (4). However, their commercial use is still limited due to lower dye uptake, reproducibility issues and cost challenges. Non-traditional flowers—those not widely cultivated or commercially exploited—represent an untapped resource for eco-friendly dyes. Unlike commonly used traditional flowers (e.g. hibiscus, marigold, safflower), non-traditional flowers such as *Ixora coccinea, Lantana camara, Tecoma stans* and *Plumeria rubra* offer unique pigment profiles (anthocyanins, betalains, carotenoids) that may enhance dyeing diversity and sustainability (5). A comparison between traditional and non-traditional flower dyes are given in Table 1. The classification of natural dyes is presented in Fig. 1. This review highlights recent research on extraction methods, characterization, biochemical analysis, applications in industry, toxicity and challenges in natural dyes extracted from flowers, with a primary focus on applications in the textile industry.

### Extraction of natural dyes

Extracting dyes from natural sources is one of the most important stages in the preparation of textiles for dyeing. Efficient extraction is essential for reproducibility and cost-effectiveness. Both conventional and advanced extraction methods are used (6). The different methods used to extract natural dyes are listed in Table 2.

#### Aqueous extraction

In the aqueous method, flower petals are dried and powdered and then soaked in water to extract the dye. When fresh petals are used, they are made into a paste, boiled with water and filtered to obtain the pure dye (7). The aqueous method is a simple, inexpensive, oldest and eco-friendly method of extraction. However, it has the disadvantages of low dye yield, degradation of dye during boiling and low colour fastness in textiles (8). The dyes from the powdered flower samples of *Clitoria ternatea, Tagetus erecta* and *Punica granatum* were extracted via the aqueous method at different pH values ranging from 28 at 100 °C with an M:L (material-to-liquid) ratio of 1:10, which was further used for dyeing cotton and synthetic fabrics with good results (9).

**Table 1.** Comparison of traditional vs. non-traditional flower dyes

| | Traditional flower dyes | Non-traditional flower dyes |
|---|---|---|
| **Availability** | Widely cultivated, established supply | Underutilized, often from wastelands |
| **Cost** | Higher raw material cost | Lower cost if sourced from waste |
| **Colour range** | Common shades (red, yellow, orange) | Unique pigments (anthocyanins, betalains) |
| **Dye yield** | Generally standardized | Variable, optimization required |
| **Fastness** | Well-documented | Promising but less studied |
| **Industrial adoption** | Some commercialization achieved | Mostly experimental stage |

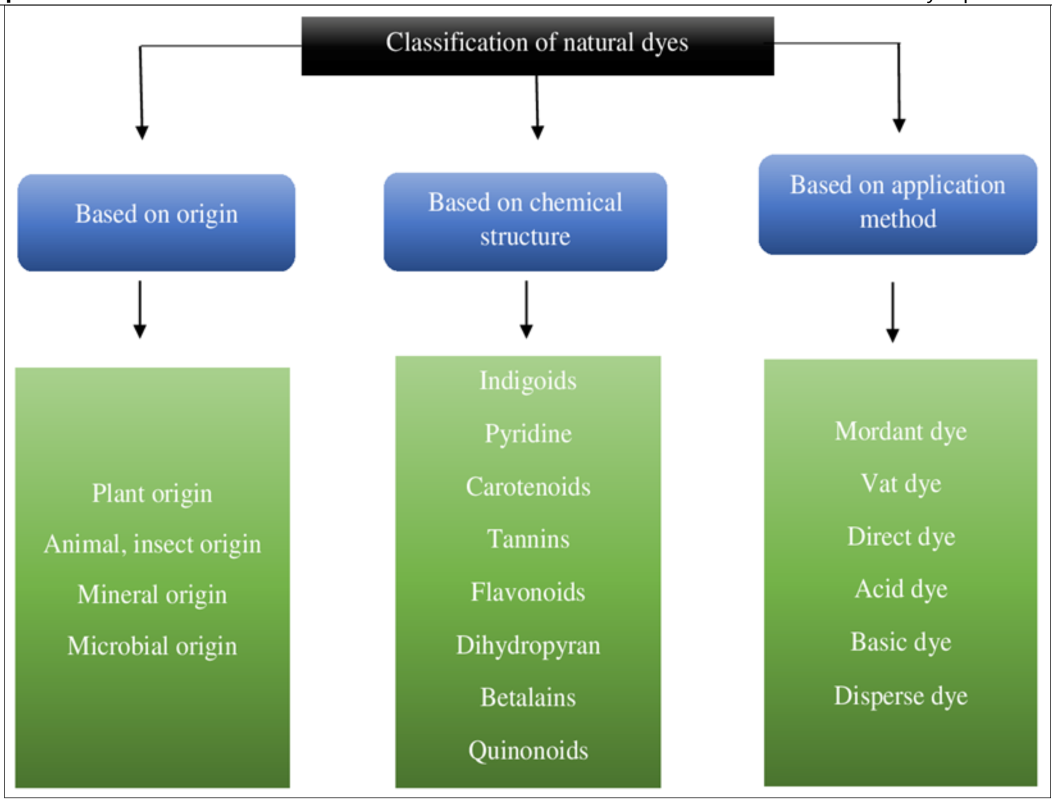


**Fig. 1.** Classification of natural dyes.

**Table 2.** Extraction methods for natural dyes from flowers

| Methods | Principle | Conditions | Advantages | Limitations | Example species |
|---|---|---|---|---|---|
| Aqueous | Boiling/soaking | Hot water, pH control | Simple, eco-friendly | Low yield, poor fastness | *Tecoma stans,* Rose |
| Solvent | Solvent dissolution | Methanol, ethanol, acetone | Higher yield, darker shades | Solvent cost, toxicity | *Ixora coccinea, Lantana* |
| Acid/alkali | pH-assisted solubility | Acid (pH 4), alkali ( > 9) | Intense colours | Disposal issues | Safflower, *Butea monosperma* |
| Ultrasonic | Cavitation disruption | 30–60 min, ethanol/water | High yield, low temp | Scaling challenges | *Hibiscus, Dahlia* |
| Microwave | Electromagnetic heating | 60–80 °C, 5–15 min | Rapid, high recovery | Limited scale-up | *Clitoria*, Rose |
| Supercritical $CO_2$ | High-pressure solvent | 31.7 °C, 73.8 bar | Solvent-free, pure extracts | Expensive equipment | *Acacia, Eucalyptus* |

The aqueous mixture of marigold flower dye was extracted in water at 80 °C for 45 min at pH 11 and an MLR (material to liquid ratio) of 1:20, which resulted in 40 % (w/w) extract, proven to be best (10). Rose petals were subjected to extraction via the aqueous method at 100 °C for 30 min, after which they were used for colouring cotton yarns (7). Dye from the shade-dried petals of *Tecoma stans* was extracted in water by boiling for 2 hr at  and stored overnight, from which most of the colorants were extracted (11). The total betalain contents from *Bougainvillea spectabilis* and *Celosia cristata* flowers were recorded to be highest with the aqueous method of extraction using 100 mL of water, kept overnight in a shaker at 25 ± 2 °C, whereas different solvents, such as 50 % and 100 % ethanol and methanol, respectively, were also used (12).

**Solvent extraction**

Solvent extraction involves the use of solvents to extract the colours in the Soxhlet apparatus. The solvents used for extraction include ethanol, methanol, chloroform, acetone, n-hexane and ether. Solvent extraction has higher yield than aqueous methods do but requires more time for extraction (13). Compared with the aqueous method, the extraction of dye from *I. coccinea* petals was easy in methanol at 80 °C for 2 hr, resulting in more pigments and darker shades on the cotton material (5). The dried, powdered petals of the *L. camera* were subjected to dye extraction by using 70 % ethanol for 2 hr at 60 °C and a 1:20 MLR for colouring cotton fabrics, which resulted in good extraction (8). In addition to aqueous extraction, the solvent method is widely used for commercial extraction of natural dyes.

### Acid and alkali extraction

The alkaline method of extraction is used for phenolic group dyes, which are readily soluble in alkaline solutions and yield dyes. This method is used for extracting red dye from safflower petals, dye from lac insect secretions and dye from seeds of annatto (14). However, methanol is the optimum solvent for the extraction of bixin from annatto seeds because of its greater total phenol content and color (15). Alkaline aqueous media is used to extract maroon red color from Indian madders and orange yellow color from *B. monosperma* flowers (16). Acid extraction at pH 4.0 is the best method for extracting dye from red sandal wood under various pH conditions (17). These methods yield more dye with the added advantages of intense color and good color fastness. However, acid or alkaline waste disposal and dye degradation are the major issues associated with this method (18).

### Ultrasonic assisted extraction

The dyes extracted via ultrasonic energy waves require low temperatures and less time, resulting in high-quality dyes with good color retention in textiles (13). The highest anthocyanin content of 179.32 mg $L^{-1}$ was recorded in the *Hibiscus rosa-sinensis* flower extract by ultrasound-assisted extraction at a frequency of 40 kHz for 30 min with a 1:15 MLR, which was greater than that of the other methods of extraction. The extraction efficiency was also high in ultrasound-assisted extraction using water as the solvent compared with other solvents (19). Solvents with low vapour pressure, high viscosity and high surface tension have a relatively high rate of extraction in ultrasound-assisted extraction (20). Ultrasonic-assisted extraction has proven to be the best method for extracting compounds such as anthocyanins and phenolic compounds from *H. sabdariffa* flowers at 65 °C for 45 min with 25 % ethanol: water as the solvent (21). Cavitation produced by ultrasonic waves breaks the cell wall mechanically to increase material transfer, which is the underlying mechanism (22).

### Microwave assisted extraction

This method involves the use of microwaves to stimulate the movement of liquid molecules for extracting the components required and has the advantages of a short extraction time, low solvent cost and improved extraction of the required compounds (23). The principle of this method is that an electromagnetic field is used as a heating source, where the electromagnetic waves provide volumetric heating by penetrating into the sample through dipole rotation and ionic conduction (24). This method is used in two forms. Closed vessel systems require less solvent and no loss of volatile substances and process many samples at a time, whereas open vessel systems cannot process many samples at a time and work at atmospheric pressure (25).

Microwave assisted extraction has been shown to be the best method for extracting anthocyanins from *C. ternatea* flowers at 60 °C with 15:1 MLR for 15 min for use as a food colorant as an alternative to synthetic colors (26). Microwave assisted extraction resulted in high recoveries of anthocyanin, total phenolic, total flavonoid and antioxidant properties and a brilliant blue color from *C. ternatea* flowers for use as food colorants (27). The red pigments extracted from *R. damascena* flower petals via the microwave-assisted method were high at 60 °C for 5 min at a 1:15 MLR (28). This method can be adopted in industry for commercial extraction.

### Supercritical fluid extraction

Supercritical fluid extraction is an eco-friendly and advanced method for extracting compounds from different materials, including dyes. Supercritical $CO_2$ is the most commonly used solvent in this method because it is inexpensive and nontoxic, with a low critical temperature of 31.70 °C and a low critical pressure of 73.8 bar (29). Small changes in temperature and pressure result in large changes in the density and solubility of the solvent in this method (30). Supercritical fluid extraction is used for the extraction of compounds for food, pharmaceutical and cosmetics, as the extracts are free from solvent residues and have better retention of bioactive compounds (31). Compared with the aqueous and Soxhlet methods, the use of supercritical $CO_2$ in the extraction of natural colours from the flowers of *Acacia cyanophylla*, leaves of *Tamarix aphylla*, tomato processing residues and pepper (*Capsicum annuum* L.) resulted in good extraction efficiency, which was confirmed by UV spectroscopy and gravimetric analysis (32).

## Characterization of natural dyes

### Spectrophotometric analysis

It is used to measure the amount of incident light transmitted through the solution that is used to measure the amount of light passing through a sample. A UV spectrophotometer model-SS 5100 A was used to measure the quantity of pigments in Annatto seed, Sappan heartwood and marigold flower extracts and the ABS values were measured for color analysis (13). The UV–vis spectra of *I. coccinea* flowers extracted with aqueous and methanol contained maximum wavelengths of anthocyanin at 525 nm, 535 nm for cyanidin, 538 nm for betalain, 500 nm for carotenoids and 475 nm for xanthophyll (5).

The absorption spectrum revealed that organic pigments exhibited polarity towards cotton fabric after adding different contaminants to the dye solution. The UV–vis absorption spectrum of the *L. camera* flower extract revealed absorption at a wavelength of 330 nm in the visible light region, which is used to characterize the coloured compounds (8). LMSP-UV 1200-UV visible spectrophotometer was used to analyse the water-extracted mulberry leaf sample, which revealed that the extracted leaf dye exhibited a high absorbance peak value at 370 nm and low absorption in the 674 nm spectrum (33).

### Fourier-transform infrared (FTIR) spectrometric analysis

FTIR absorption spectroscopy is used to identify the functional groups present in the extracted dye solution through the absorption of infrared radiation by molecules in the wavelength range of 700 $nm^{-1}$ mm (34). The FTIR study of *L. camera* flower extracts confirmed the presence of amines, alkanes, aldehydes, esters, proteins, flavonoids, saponins, CHOs and phenolic compounds that add medicinal value (8). The dye of the *Dahlia variabilis* flower extracted by ultrasound-assisted extraction was characterized by FTIR through the KBr pellet method, which resulted in a broad peak at 3100-3600 $cm^{-1}$ and indicated the presence of flavonoids, mostly anthocyanins (35).

### Gas chromatography-mass spectrometric (GC-MS) analysis

Gas chromatography/molecular spectroscopy involves a combination of two methods for the identification of complex volatile compounds. Gas chromatography allows the sample to be further analysed by separating different constituents and magnesium is used for identification (36). The results of the GCMS analysis of the methanolic extract of *Spathodea campanulata* dye were compared with those of the National Institute Standard and Technology (NISTH) and WILEY 9 databases. The results indicated the presence of pectinose β-galactosidase, 1-hexadecanol, dodocane and methyl stearate (37). GCMS analysis of dyes from *C. ternatea* flowers revealed the presence of nonacosane, eicosane, stigmasterol and beta-sitosterol, which provides evidence for their use in the food and beverage industry (26). By employing these studies, natural dyes can be characterized to determine the compounds present in them, which can be used in diverse industries.

## Toxicity studies

Natural dyes must meet international standards (GOTS, Oeko Tex 100, Bluesign). Toxicity evaluations include antimicrobial activity, heavy metal analysis and $LD_{50}$ studies. Several floral dyes (e.g. *L. camara, C. ternatea*) are confirmed free of toxic metals, making them safe for textiles (16). The toxicity of a dye depends on the structure of the dye and not on the process of dying. Dyes that contain heavy metals and are carcinogenic must be avoided. Dyes play a major role in the pollution of water by leaching organic effluents into water that is not degradable (38). Long-term effects, such as carcinogenic, mutagenic and reproductive toxicity effects, are also tested for natural dyes before their use in textiles (39). The $LD_{50}$ value is the best method for rating toxicity, in which half of the tested population dies. Marigold exhibited a negative test result against the microbial control of *Escherichia coli* and *Salmonella*. Inductively coupled plasma mass spectrometry (ICP-MS) was used to detect the heavy metals in the *L. camara* dye extract, as it may cause skin-related issues while it is used as a textile dye. The results of the study confirm that the dye is free from heavy metals such as antimony, arsenic, cadmium and lead (8).

## Application in textile industry

Dyes extracted from flowers have been used in textiles for centuries. They exhibit a variety of colours that cannot be produced by synthetic dyes. Dyes from flowers are used in fabrics such as cotton, silk, wool, linen and synthetic fibres (40).

### Substrate pre-treatment

The cloth material used for dyeing should be pretreated to remove the impurities and to improve the water absorbency, dyeability and overall purity of the material. In cotton, pretreatment involves steps such as desizing, scouring and bleaching (41). Mordants and biomordants are used to improve the retention of dyes on fabric. In addition, new emerging and eco-friendly techniques, such as enzyme treatment, nanotechnology and irradiation, such as plasma, ultrasonic, microwave, ultraviolet and gamma irradiation, are used for pretreatment to increase the dyeability of the material. They act by modifying the surface of a material at the nanoscale without modifying its bulk properties (42).

**Enzyme treatment:** Enzymes are used in various processes in textiles, including desizing, scouring, bleaching, dyeing and finishing, as alternatives to harmful chemicals (43). Among these enzymes, lipase, pectinase, xylanase and cellulase are commonly used in pretreatment and finishing of the textile fibre process to modify the physical and chemical properties of the fibre surface and to introduce functional groups of interest into it (44, 45). Enzymes such as acid cellulose, neutral cellulose and xylanase were used to pretreat cotton fabric before it was dyed with *Acacia catechu,* which resulted in improved dyeing and color fastness in addition to antimicrobial and UV protection of the dyed fabric (46).

**Irradiation treatment:** The use of ultrasound radiation, ultraviolet radiation, gamma radiation, electron beam irradiation and plasma treatment for use in the textile dyeing process is gaining momentum (47). They impart different qualities while dyeing by modifying the surface of the fabric without modifying the bulk properties of the material by improving adhesion, dyeability, fastness, antimicrobial activity and shrink resistance (48).

The interaction of a fabric with a dye is enhanced by introducing carboxylic groups to the surface of the fabric through pretreatment of the cloth with heat via ultraviolet radiation (49). The characteristics of UV-irradiated cotton and its dyeing mechanism were studied with the use of lutein dye from marigold flowers. UV treatment reportedly enhances the dyeing process without causing any physical damage to the material when pretreatment is performed for both the fabric and the dye solution (50).

Gamma-irradiated cotton presented improved color fastness when dyed with red calico leaf extract. The interaction of fabric with dye molecules is enabled by the transformation of the hydroxyl groups of cellulose to carboxylic groups at the optimum dose of 15 kGy (51). Pre-treatment with gamma rays increased the uptake of natural dyes by cotton and flax fibres at 40 kGy and resulted in maximum colour strength (52).

Plasma treatment is a fast and dry method that requires no solvent for pretreatment (53). Pretreatment of cotton with low-temperature oxygen plasma prior to dyeing with the madder and weld extract improved the dyeability of the fabric. The dye uptake was improved, as plasma provides an etching effect, removes impurities and inserts carbonyl groups at the surface layer of the fabric (54).

### Mordants

Mordanting is a process of binding dyes to a textile material via the use of metallic salts or various complex-forming agents (16). Protein fibres such as silk and wool bind easily to mordant, whereas cellulose fibres such as cotton do not bind to mordant and are less insoluble (55). Mordants are mostly metallic salts such as aluminium, iron, copper, tin and chromium are used to dye bind with fabric (56). The use of different mordants with the same dye results in different shades strength and fastness (55).

**Biomordant:** Metallic materials used in the dyeing of textiles have residual effects on the water used in the process and cause severe threats to the environment (57). As an alternative, mordants from plants and other living sources replace metallic mordants and are eco-friendly. Biomordants are extracted from plants that have high contents of tannins and chlorophyll, which include substances such as tartaric acid, tannins and tannic acid (58). Hyperaccumulator plants such as *Camellia* spp. clubmosses and *Symplocos* spp. absorb aluminium in their roots and used as biomordants (56). Premordanting of cloth and yarns with myrobalan for 30 min resulted in an attractive and intense color on fabric from *Woodfordia fruticosa* flower dye (59).

Banana pseudo stem sap was used as a biomordant in the dyeing of cotton fabric with floral dye extracted from *Delonix regia,* which resulted in good wash fastness, rub fastness and color strength up to 60 °C. The presence of tannins in pseudo stem sap improves the binding of anthocyanin-rich extracts to the fabric, improves their properties (60). The combination of alum and vinegar on silk and cotton fabric with dyes from *Impatiens balsamina* and *H. rosa-sinensis* resulted in a bright shade retention even after several fastness tests (61).

A comparative analysis of metallic and biomordant studies was conducted on cotton dyed with *H. sabdariffa* using tannic acid, pinecone and lemon peels. The results revealed that the use of biomordant increased color fastness, light, washing and rubbing fastness and resulted in more than 90 % antibacterial properties (62). On the basis of application time, mordanting is classified as pre mordanting, simultaneous mordanting or post mordanting.

**Pre mordanting:** The application of mordants to a fabric before dyeing is termed pre mordanting. Here, the textile material is first immersed in aqueous mordant solution for an optimum time of 30-60 min at 70 °C -100 °C with a 1:5-1:20 material-to-liquid ratio and then dried with or without washing. Compared with other methods, premordanting bleached cotton fabric with copper sulfate, ferrous sulfate, nickel sulfate, potassium dichromate, stannous chloride and potassium aluminum sulfate resulted in better uptake of *L. camara* flower dye compounds with copper sulfate salt, resulting in greater color strength. Compared with other mordants such as alum, ferrous sulfate and copper sulfate, those premordant with stannous chloride presented a better colour and fastness for dyes from *T. stans* flowers (8, 11).

**Simultaneous mordanting:** This method involves dyeing fabric simultaneously with mordants at a specific quantity. The simultaneous mordanting of cotton with dye extracted from *R. centifolia* resulted in an attractive and uniform color with good fastness properties (7). Simultaneous mordanting of tannins and alum with *Calendula officinalis* dye had the greatest effect on cotton fabrics. The absorption of the dye was good, as the number of reactions between different components of the dye and the substrate increased (63).

**Post mordanting:** In this method, the fabric is treated with mordant solution in another bath after dyeing. The treatment conditions depend on the dye used, type of fabric material and mordant (64). Postmordanting with tartaric acid in dye extracted from *Plumeria rubra* flowers improved the K/S value for color strength in cotton fabrics (65).

**Dyeing of textiles**

The process of dyeing refers to the aqueous application of colours to fibres, yarns and fabrics with the additional use of chemicals to obtain a uniform colour (66). The important parameters used in dyeing are the temperature of the dye bath, time, material–liquid ratio and pH (40). The method for dyeing of textiles is enclosed in Fig. 2.

**Conventional dyeing:** Dyeing of fabric can be performed via an alkaline dye bath, an acid dye bath or a neutral dye bath on the basis of the chemical nature of the dyes. Floral dye from *Delonix regia* was used for cotton fabric at a 1:20 fabric-to-dye ratio at temperatures ranging from 40 °C to 90 °C for 60 min. After dyeing, the material was dried at room temperature (60). Dyeing of cotton fabric with dyes from *C. ternatea*, pomegranate and *T. erecta* flowers was carried out at 28 °C for 30 min (67). The dyeing of cotton cloth with *T. stans* flowers at 70 °C for 45 min at an M:L ratio of 1:20; the mixture was incubated overnight in dye solution, removed the next day and washed in water three times, after which it was finally dried in open air (68). This conventional method is simple and is most commonly used for the dyeing of fabrics.

**Nonconventional dyeing:** In addition to the conventional dyeing method, several advanced methods for the dyeing of fabrics have been used to obtain enhanced results that have been adopted recently (69). Advanced methods include

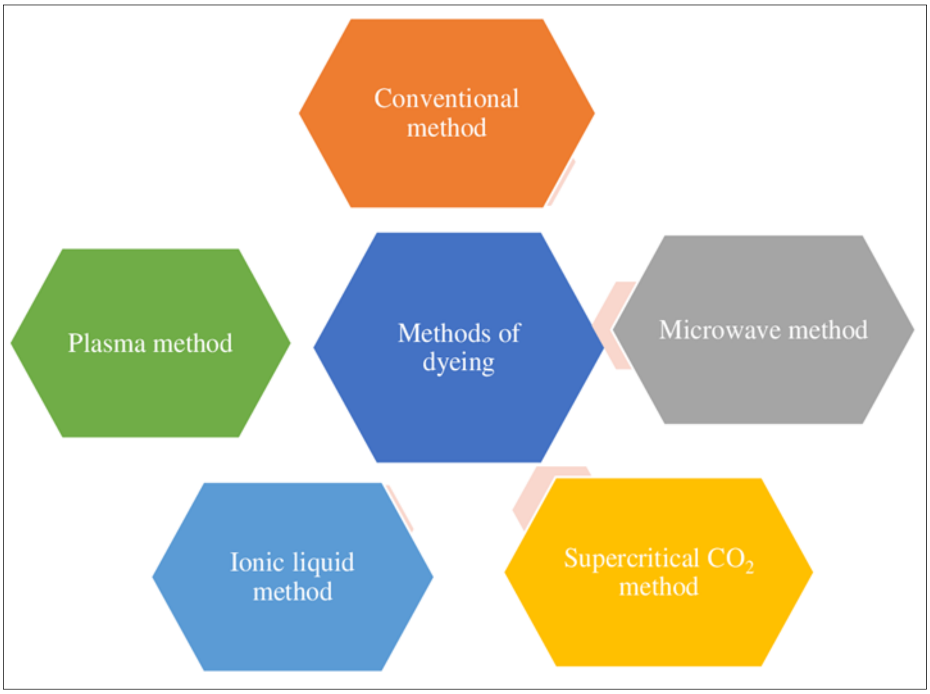


**Fig. 2.** Methods for the dyeing of textiles.

ultrasonication, microwaves, supercritical $CO_2$ and ionic solvents. Dyeing of cotton with extracts from *Eclipta alba* was studied via both conventional and ultrasonic methods, in which the latter method was shown to have high color strength, dye uptake and fastness properties. Ultrasound improves physical and chemical processes through the cavitation phenomenon (70). The use of the microwave method to dye wool fibres with *C. ternatea* extract resulted in good colour depth and shade at a pH of 5 in a 1:50 MLR (material to liquid ratio) for 5 min, after which the samples were subsequently washed at 50 °C with detergent and dried (71). This method provides good affinity of color to fabric with the required fastness properties.

Supercritical $CO_2$ can be used instead of a solvent, resulting in a waterless dyeing process and residual dye is easily separated from the solvent (72). Supercritical $CO_2$ acts as a unique medium for transporting chemicals inside and outside the substrate because of its thermophysical and transport properties (16). Ionic liquids are fully composed of ions with a melting point of less than 100 °C. Ionic solvents can be used because they are eco-friendly and can be reused in other processes. Deep eutectic solvents that fall under ionic liquids are used to increase the dyeability of fabric in the dyeing process and in wastewater management (73). Compared with conventional methods, the use of nanoscale pigments in the exhaust dyeing of cationic cotton results in brilliant shades of color and soft handling with fewer pigment requirements (74).

## Characterization of the dyed material

### Colour strength

An Ultrascan PRO spectrophotometer is used to measure the colour strength (K/S) and CIELAB value of the dyed material (71). The surface colour strength (K/S) value was measured via the equation developed by Kubelka and Munk.

$$\frac{K}{S} = \frac{(1-R)^2}{2R}$$

Where, R is the reflectance of the fabric at λ max; K is the absorption coefficient; and S is the scattering coefficient.

The actual K/S value is calculated along with the undyed sample as

$$\frac{K}{S} = \left(\frac{K}{S_d}\right) - \left(\frac{K}{S_u}\right)$$

Where, d refers to the dyed sample and where u refers to the undyed sample.

CIELAB coordinates such as Δ L, Δ a, Δ b and Δ c are measured via a reflective Spectro photometer and related software. Δ L represents the degree of lightness, Δ a represents the degree of redness and greenness, Δ b represents the degree of yellowness and blueness and Δ c represents the difference in saturation. The difference between the highest and lowest colour difference index (CDI) values of natural dyes used in different proportions with constant shade percentages under standard dyeing conditions was used to measure the relative compatibility rating (RCR) (9). Color strength is an important parameter for assessing the intensity of an extracted natural dye prior to its application.

### Colour fastness of dyed fabrics

The change in color intensity of the dyed fabric or the staining of adjacent material while washing is referred to as color fastness. Fading may be due to exposure to light, washing and rubbing. The quality of dye on fabrics is measured by color fastness properties such as wash fastness, rub fastness, light fastness and perspiration fastness (75). International standard protocols are available to measure fastness properties. Cotton fabrics dyed with *L. camera* were subjected to fastness tests through the standard BIS method, which includes wash fastness (IS-687-79), light fastness (IS-766-88), rub fastness (IS-2454-85) and perspiration tests (IS-971-1983) (8). The color fastness of the dyed fabric with *Delonix regia* was subjected to rub fastness with both the wet and dry methods via the AATCC method 8-1996 via a manually operated SDL Atlas Crockmeter and the assessment was based on the grayscale rating through the ISO-05-A02 method for staining (60). On the basis of these tests, the choice of flowers suitable for producing natural dyes can be optimized for textile industry applications.

## Challenges and future aspects

The consistent availability of flowers for extracting dyes is a limiting factor that results in insufficient raw material for dye extraction industries. The dye industry lacks knowledge of standardized and advanced extraction methodologies for natural dyes that are specific to crops (76). Natural dyes have low dye uptake and poor fastness properties and the mordants that are used to fix the dye to the fabric are mostly metallic salts that cause environmental pollution (77). The colour shade produced by flowers cannot be reproduced, as the quality of flowers differs on the basis of various factors. Some dyes are sensitive to pH, so any difference in the pH of the water used also affects the color of the dye (40). The extraction and application of natural dyes from flowers are expensive and the process requires a large amount of water, which makes it complicated (9). This problem can be addressed by the utilization of a by-product from the dye industry to any value-added product. The utilization of a by-product reduces the cost incurred in indigo dye production by 22 %. The challenges pertaining to natural dyes must be addressed in the future (78). List of non-traditional flowers used as a source for natural dyes is listed in Table 3.

The market for sustainable fashion is expected to reach a growth of 20 % equivalent to $450 billion by 2025. People are more conscious of eco-friendly products and are ready to grab them at any cost, which is possible through the use of natural dyes that produce unique colors. Dyes from flowers possess nontoxic, antimicrobial properties on textiles that can be utilized in the medical field for patients who do not cause any allergies (76). Natural dyes extracted from flowers have potential for use in cosmetics, pharmaceuticals, dye-sensitized solar cells, toys and the food industry to impart natural colours as substitutes for synthetic colours.

## Conclusion

This review on the potential of natural dyes from non-traditional flowers highlights the need for natural dyes over synthetic dyes and lists potential non-traditional flower crops that can be

**Table 3.** List of non-traditional flowers as a source for natural dyes

| Sl. No | Common name | Botanical name | Family | Colour of extract | Pigment responsible for colour | Application | Reference |
|---|---|---|---|---|---|---|---|
| 1 | Pot marigold | *Calendula officinalis* | Asteraceae | Yellow | Carotenoids | Dyeing of paper pulp, textile | (79) |
| 2 | African tulip | *Spathodea campanulata* | Bignoniaceae | Red | Anthocyanin | Textile | (80) |
| 3 | Bottle brush | *Callistemon citrinus* | Myrtaceae | Purple | Anthocyanin | Textile | (81) |
| 4 | Night flowering jasmine | *Nyctanthes arbor-tristis* | Oleaceae | Brown | Carotenoids | Textile | (82) |
| 5 | Aparajita | *Clitoria ternatea* | Fabaceae | Blue | Delphinidin | Food and textile | (26) |
| 6 | Flame of the forest | *Butea monosperma* | Fabaceae | Yellow | Isobutrin | Textile | (83) |
| 7 | Scarlet cordia | *Cordia sebestena* | Boraginaceae | Brown | Carotenoids | Textile | (84) |
| 8 | Fire flame bush | *Woodfordia fruticosa* | Lythraceae | Yellowish brown | Carotenoids | Textile | (85) |
| 9 | Cosmos | *Cosmos sulfureus* | Asteraceae | Yellow, orange, brown | Flavonoids | Textile | (86) |
| 10 | Bougainvillea | *Bougainvillea glabra* | Nyctaginaceae | Red | Betalain | Food and textile | (87) |
| 11 | Champak | *Magnolia champaca* | Magnoliaceae | Pale yellow | Flavonoids | Textile | (88) |
| 12 | China aster | *Callistephus chinensis* | Asteraceae | Pink | Flavonoids | Textile | (89) |
| 13 | Cockscomb | *Celosia cristata* | Amaranthaceae | Brown | Betacyanins (Betalain) | Food and textile | (90) |
| 14 | Lantana | *Lantana camara* | Verbanaceae | Yellow | Anthocyanin | Textile | (8) |
| 15 | Bachelor's button | *Gomphrena globosa* | Amaranthaceae | Purple | Betacyanin | Food and textile | (91) |
| 16 | Ixora | *Ixora coccinea* | Rubiaceae | Red and purple | Anthocyanin | Textile and cosmetics | (92) |
| 17 | Nerium | *Nerium oleander* | Apocynaceae | Dark blue | Polyphenol | Textile | (93) |
| 18 | Snapdragon | *Antirrhium majus* | Plantaginaceae | Orange | Carotenoids | Textile | (94) |
| 19 | Red flag bush | *Mussaenda erythrophylla* | Rubiaceae | Red | Anthocyanin | Textile | (95) |
| 20 | Yellow bells | *Tecoma stans* | Bignoniaceae | Yellow | Carotenoids | Textile | (68) |
| 21 | Garden nasturtium | *Tropaeolum majus* | Tropaeolaceae | Yellow | Carotenoids | Textile | (96) |
| 22 | Red frangipani | *Plumeria rubra* | Apocynaceae | Yellow | Quercetin | Textile, pharmaceuticals | (97) |
| 23 | Porcupine flower | *Barleria prionitis* | Acanthaceae | Yellow | Carotenoids | Textile | (98) |
| 24 | Peacock flower | *Caesalpinia pulcherrima* | Fabaceae | Red | Anthocyanin | Textile, nanotechnology | (99) |
| 25 | Golden rod | *Solidago canadensis* | Asteraceae | Yellow | Flavonoid glycosides | Textile | (100) |

exploited for the extraction of dyes and their application in textile fabrics. In addition to the advantages of natural dyes, such as biodegradability and eco-friendly and nontoxic properties, there are certain challenges, such as cost, color fastness properties and reproducibility that should be addressed by advanced methodologies and future research. Conventional and advanced methods of extracting natural dyes from flowers are important criteria in the textile industry. Characterization and toxicity analysis of dyes are essential before their application. The application of dye to fabric involves the use of mordants and other advanced methods to fix the color to the fabric. Dyeing of fabric involves various methods and the fastness properties of the dyed material can be evaluated through standard ISO protocols. Although the use of natural dyes from flowers presents several challenges, the demand for them in diverse fields makes exploration necessary, which is possible through further advanced studies. To realize commercial potential, further research should focus on optimization of extraction at industrial scale, development of standardized dyeing protocols eco-friendly mordanting solutions and integration of floral dyes in sustainable textiles and allied industries. While challenges exist, the growing demand for natural, biodegradable and safe alternatives underscores the urgent need to advance research and commercialization of dyes from non-traditional flowers.

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## Authors' contributions

KNK and SG were involved in collecting, reviewing, compiling, drafting and revising the manuscript, ultimately finalizing the article. All authors read and approved the final version of the manuscript.

## Compliance with ethical standards

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