



## Comprehensive Study of Plant-Based Natural Dyes: Extraction Techniques, Characterization, and Applications Across Food, Cosmetics, and Cotton Products

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### ABSTRACT

This study explores the extraction, characterization, and application of plant-based natural dyes in cosmetics, food products, and textiles, emphasizing their potential as sustainable alternatives to synthetic dyes. Plant sources, including *Beta vulgaris*, *Lawsonia inermis*, *Punica granatum*, *Mentha spp.*, *Curcuma longa*, *Rosa spp.*, *Daucus carota*, and *Coriandrum sativum*, were procured from markets in Butwal, Nepal. Natural dyes were extracted using aqueous and organic (methanol) solvents and characterized through phytochemical screening and Fourier-transform infrared (FTIR) spectrophotometry. Phytochemical analysis revealed the presence of bioactive compounds such as alkaloids, flavonoids, quinones, coumarins, saponins, phenols, and tannins. FTIR spectra of *Lawsonia inermis* and *Punica granatum* highlighted functional groups including -OH, -CH<sub>3</sub>, -CH<sub>2</sub>, -CH, -C≡N, -C≡C, -C=C, and C=O, confirming the presence of diverse bioactive constituents. The extracted dyes were incorporated into cosmetic lip balms, noodles, and cotton fabrics, with and without mordants. Lip balms colored with natural dyes demonstrated stability for up to four weeks at room temperature and 4°C, exhibiting consistent texture and vibrant hues. Cotton fabrics dyed with copper sulfate mordants displayed brighter and more vivid colors, whereas ferrous sulfate produced deeper, muted tones. Using mordants significantly enhanced the durability of the natural dyes on cotton compared to untreated samples. This research highlights the advantages of natural dyes, including their safety profile, reduced risks of toxicity and allergic reactions, and environmental benefits. Natural dyes are biodegradable, contributing to reduced pollution in food processing and textile industries. By promoting renewable resources and minimizing dependency on petroleum-based synthetics, these dyes offer a sustainable alternative to synthetic dyes.

**Keywords:** Biodegradability, Durability, FTIR, Mordants, Natural dyes, Phytochemicals, Vibrancy, Toxicity.

### INTRODUCTION

Natural colors are mostly derived from plants, animals, and minerals, of which plants comprise the majority. Among the plant components used as dyes are roots, berries, bark, leaves, seeds, and wood. Other sources include fungus and lichens <sup>1</sup>. Natural dyes are sustainable, biodegradable, and environmentally beneficial goods with little effect on the environment. Nowadays, many prefer natural colors over synthetic ones because they are aware of the potential environmental harm that artificial dyes can create <sup>2</sup>. Fabrics, paper, leather, and other things are colored using dye, a natural or synthetic substance that makes color changes difficult. Artificial dyes have been widely used since the beginning. Commonplace items, including apparel, food, cosmetics, and so on, contain them <sup>3</sup>.

Natural dye compounds, particularly those derived from plants, are becoming more and more significant substitutes for synthetic colors in the textile sector. Natural dyes are biodegradable, non-toxic, and typically more environmentally friendly than their synthetic equivalents <sup>4</sup>, in contrast to synthetic dyes that are poisonous and detrimental to the environment.

The quality of color that may be produced using natural dyes is the primary factor that makes them appealing. Plant-based dyes are not the 'pure' pigments found in modern chemical dyes because they comprise a variety of

pigments. It is impossible to replicate the rich and occasionally surprising color created by these imperfections. Many find that the process of removing the dyes from their natural sources offers them control over every stage of the creation process and helps them feel connected to their work <sup>5</sup>.

In this research work, extraction of natural dyes from *Beta vulgaris*, *Lawsonia inermis*, *Punica granatum*, *Mentha spp.*, *Curcuma longa*, *Rosa spp.*, *Daucus carota*, *Coriandrum sativum* was selected for exploitation. The dyeing of cotton fabrics with the extracted dyes and spectral characterization of the dyed fabrics are reported.

Its main edible part is the red tuberous root of beetroot (*Beta vulgaris* L.), an annual or biennial crop in the Amaranthaceae family. Beetroot preparations have been shown to offer a wide range of bioactive properties, including lipid-lowering, anti-inflammatory, anti-hyperglycemic, anti-cancer, and anti-hypertensive effects <sup>6</sup>. Beetroot is a functional food that includes valuable active components such as minerals, amino acids, phenolic acid, flavonoids, betaxanthin, and betacyanin. Beetroot's stability, non-toxicity, non-carcinogenicity, and non-poisonous qualities have led to its employment as a food processing additive or preservative <sup>7</sup>.

*Lawsonia inermis* Linn, a member of the Lythraceae family, sometimes referred to as henna, has been shown to possess several chemicals in its stem, bark, flowers, and



seeds that have both industrial and therapeutic uses<sup>8</sup>. *L. inermis* had the greatest lawsone content<sup>9</sup>.

One of the Mediterranean medicinal plants, *Punica granatum L.* (Pomegranate), has been used for generations to cure male infertility, diarrhea, and ulcers<sup>10</sup>.

*Mentha* is a fragrant, medicinal, and perennial herb that grows widely all over the world. There are 25-30 species in the genus *Mentha*, which is a member of the Lamiaceae family<sup>11</sup>.

In Asian countries, *Curcuma longa*, a perennial plant that belongs to the Zingiberaceae (ginger) family, is frequently planted<sup>12</sup>.

*Rosa* is a genus with a long history of use and great culinary and medicinal value. With over 200 species found in the temperate and subtropical regions of the northern hemisphere, primarily in Asia, Europe, and North America, this genus is among the most widely dispersed members of the Rosaceae family. *R. rugose* is primarily represented in the food business by tea and jam. In addition to its usage as a food additive, rose pigment has medicinal uses<sup>13</sup>.

As a member of the *Daucus* genus, a polymorphic taxon with several species and subspecies, *Daucus carota* is a member of the Apiaceae or Umbelliferae family. The wild carrot has long been used to treat cancer, prostatitis, gout, cystitis, urinary calculus, and other conditions<sup>14</sup>.

A member of the Apiaceae (Umbelliferae) family, *Coriandrum sativum* is well known for its applications in traditional medicine and cooking<sup>15</sup>.

Numerous investigations have shown that plants contain extremely high levels of phenolic chemicals, specifically phenols, flavonoids, terpenes, quinines, and polysaccharides. Significant use in the pharmaceutical, food, and beverage industries was made possible by these phytochemicals. *Almost all the dyes extracts show pharmacological properties*, including anti-diabetic, anti-tumor, anti-inflammatory, anti-malaria, anti-fibrotic, anti-fungal, anti-bacterial, and other benefits, according to mounting data. For thousands of years, people have used aromatic and medicinal plants, particularly those having ethnopharmacological applications, as a natural source of

cures and medicinal treatment. Powers, tinctures, macerations, teas, infusions, percolation products, poultices, decoctions, tinctures, inhalations, and other herbal preparations were among the early forms of these widely used drugs<sup>16</sup>.

## MATERIALS AND METHODS

### Selection and Collection of Different Parts of Plants:

The collection of samples has been conducted in the market of Butwal sub-metropolitan city Rupendehi, Lumbini Province, Nepal. The study area is situated in the geographical coordination within the latitude of 27° 42' 0" North and latitude of 83° 27' 0" East.

**Table 1:** Collected plant details

Plants	Scientific Name	Parts Used
Beetroot	<i>Beta vulgaris</i>	Root
Peppermint	<i>Mentha piperita</i>	Leaves
Coriander	<i>Coriandrum sativum</i>	Leaves
Henna	<i>Lawsonia inermis</i>	Leaves
Turmeric	<i>Curcuma longa</i>	Root
Carrot	<i>Daucus carota</i>	Root
Rose	<i>Rosa sp.</i>	Flower
Pomegranate	<i>Punica granatum</i>	Peels

### Chemical and Instrument Used:

The Instruments used in this research work were: centrifuge, FTIR-Instrument, analytical balances, constant temperature water bath, and other micropipettes, graduated pipettes, burettes, thermometers, beakers, conical flasks, test tubes, reagent bottles, incubator, vials, and others.

### Collection and Identification:

Freshly eight different plant sources were collected for extraction of dyes of four different colors. Beetroot & Rose for Red, Pomegranate peels & Henna for Brown, coriander & Peppermint for Green, Carrot & turmeric for Yellow.

The collected samples were identified and named according to the Nomenclature from the Botanist of the Department of Botany, Butwal Multiple Campus, Butwal, Nepal.



**Figure 1:** Collection of different Plants

**Drying:**

Collected samples were washed carefully with distilled water. Samples were shade-dried in a laboratory at room temperature. After drying the surface, the plant parts were crushed into small pieces by using the conventional method and stored for further use.

**Extraction of Natural Dyes**

The plant material was weighed using a chemical balance of 50 grams. The chopped plant materials were dissolved in 500 mL of distilled water in a beaker and heated for 30 minutes at a temperature range of 80-85°C until the dye was released. The dye from aqueous extraction was filtered through a funnel and filter paper. In the same way, organic solvent (Methanol) dye was prepared. After the dye was extracted, it was stored in a closed flask in the refrigerator store at 4°C for further use.

**Qualitative Phytochemical Analysis:**

The components of plant extracts and their predominance are evaluated using phytochemical screening and bioactive components that may be helpful in the development of pharmaceuticals<sup>17</sup>. Phytochemical screening is the scientific method of identifying several classes of phytoconstituents found in various areas of the base for drug development through analysis, examination, extraction, and experimentation; the active components can then be taken for additional research and study<sup>18</sup>.

The content of flavonoids, alkaloids, terpenoids, tannins, steroids, saponins, and phenols was analyzed using methanol and aqueous extracts. According to<sup>19,20</sup> standard qualitative methodologies were used to conduct the screening tests for these main phytoconstituents.

**Detection of flavonoids (Alkaline reagent test):**

A solution of 2% sodium hydroxide was added in six drops to 0.2 g of extracts. The presence of flavonoids in the extracts was shown by the production of a strong yellow color that turned into a colorless solution when diluted acid was added.

**Detection of alkaloids (Mayer's test):** Extracts 0.5 g were dissolved in 3 mL of 2% dilute hydrochloric acid, and the solution was divided into two test tubes and the following test was performed;

- **Mayer's Test:** The presence of alkaloids is shown by the appearance of a pale yellow color after a few drops of Mayer's reagent were added.

**Dragendorff's Test (DDT):** The presence of alkaloids is also shown by the appearance of an orange-red ppt. After a few drops of Dragendorff's reagent were added.

**Detection of terpenoids (Salkowski's test):** 2 mL of chloroform (CHCl<sub>3</sub>) and 3 mL of strong sulphuric acid were carefully added to 0.2 g of the extracts. The presence of terpenoids in the extracts was shown by the production of a reddish-brown precipitate.

**Detection of tannins (Ferric chloride test):** 3 drops of diluted ferric chloride (FeCl<sub>3</sub>) solution were added to a test tube containing 0.2 g of the extracts and an equal volume of distilled water. The presence of tannins in the extracts was indicated by the development of a dark or brownish-blue color.

**Detection of steroids (Liebermann Burchard's test):** 2 mL of chloroforms were combined with 0.5 g of extracts. The mixture was then placed in a test tube and treated with 2 mL of strong sulphuric acid (H<sub>2</sub>SO<sub>4</sub>). The appearance of the red color in the lower chloroform layer gave a positive result for steroids in the extracts.

**Detection of saponins (Foam test):** 6 mL of distilled water was added to 0.2 g of the extracts, and the mixture was rapidly agitated for 15 minutes lengthwise in a graduated cylinder. The presence of saponin in the extracts was indicated by the production of bubbles or a continuous foam after 10 minutes.

**Detection of phenols (Ferric chloride test):** To 0.2 g of the extracts, 2 mL of 5% aqueous ferric chloride was added. The formation of a dark green color gave a positive result for phenols in the extracts.

**Test for Quinones:** 1 mL of freshly prepared ferrous sulphate (FeSO<sub>4</sub>) solution was added to around 2 mL of extract, along with a few ammonium thiocyanate (NH<sub>4</sub>SCN) crystals. The solution was then treated with concentrated H<sub>2</sub>SO<sub>4</sub> drop by drop. Quinones can be identified by the appearance of a persistent deep red color.

**Detection of Coumarin:** The presence of coumarin is indicated by the production of a yellow color after adding 1 mL of a 10% NaOH solution to approximately 1 mL of extracts.

**Characterization of Dyes: Using FTIR Spectrum**

A solid, liquid, or gas's infrared spectrum of absorption or emission can be obtained using a method called Fourier transform infrared spectroscopy (FTIR). High-resolution spectral data throughout a broad spectrum range is concurrently collected by an FTIR spectrometer<sup>21</sup>. Through structural elucidation, FTIR spectroscopy is a nondestructive technique that can be utilized for the qualitative assessment of natural dyes and dyed substrates. The ease of use and speed of FTIR analysis, the accessibility of FTIR equipment, and the capacity to provide accurate data from a small sample size are the main factors contributing to its appeal for sample characterization. A potassium bromide (KBr) pellet for FTIR analysis normally requires 1-2 mg of the sample and less than 0.5 mg if a micro-pellet is used with a beam condenser<sup>22</sup>.

**Application of Dyes**

**Application of Dyes to Fabrics:** The dye is applied to fabric by two methods

- Without Mordant
- With mordant



## Preparation of Mordant

**Mordant:** Mordanting is the process of forming a chemical bond between a dye and textile fibers to enhance dye adherence, vibrancy, and durability. This step is essential in natural dyeing, as it significantly influences the colorfastness and shade of the dyed material <sup>20</sup>.

In this investigation, metallic mordants, i.e., copper sulphate (CuSO<sub>4</sub>) and ferrous sulphate (FeSO<sub>4</sub>), were prepared by using <sup>24</sup> methods with some modifications.

- **Copper Sulphate:** 0.10 g of Copper Sulphate was dissolved in 100 mL of distilled water.
- **Ferrous Sulphate:** 0.10 g of Ferrous Sulphate was dissolved in 100 mL of distilled water.

## Dyeing and Mordanting

The dyeing and mordanting of cotton cloth were carried out using <sup>25</sup> and <sup>26</sup> methods. The cotton used for the fabric was bought from the neighborhood market. For dyeing, it was reduced in size to tiny pieces (10 x 10 cm). To get rid of the cellulose, starch, and other dirt particles, it was dissolved in sodium hydroxide and refluxed for fifteen minutes. After 15 minutes of immersion in the mordant solution, the sodium hydroxide-treated cloth was removed.

**Without mordant:** The fabric, which is treated with sodium hydroxide, is directly immersed in the dye bath, and the fabric is simmered for half an hour. After the dye enters through the cloth. The cloth is taken out and dried for further studies.

**With mordant:** The mordant fabric is immersed in the dye bath for half an hour. After that, the dye enters the cloth. The cloth is taken out and dried.

## Use as Food Coloring Agents:

The noodles were colored by boiling them in water containing the dye for 5-10 minutes, while doughs of white flour were prepared using dye mixed with water <sup>1</sup>.

## Application in Cosmetic production (Lip-balm):

The prepared dye solution from different plant sources was then added to natural ingredients like aloe gel 2 mL, almond oil 2 mL, beeswax 2 g, rice powder 2 g & cornstarch 2 g, which were mixed well. The mixture is then put in the water bath until all materials in the mixture melt and transfer to

liquid form. The prepared lip balm was then stored at 4°C for 4 days and at room temperature for 4 days <sup>27, 28</sup> with some modification.

## RESULTS AND DISCUSSION

The extracted dyes showed a good color-imparting ability and were of the desirable consistency. Natural dyes are obtained from coriander, Peppermint, Beetroot, Rose, Carrot, turmeric, Henna, and Pomegranate peels.

### Qualitative phytochemical analysis:

Phytochemical analysis revealed the presence of important metabolites like flavonoids, alkaloids, terpenoids, Phenols, Tannins, Terpenoids, and Glycosides. These are major metabolites present that are responsible for several additive properties of the plants.

The qualitative data revealed the presence of important metabolites in most of the dyes, like flavonoids, terpenoids, phenol, and saponin. Dyes of pomegranate peel and mint show positive results in both solvents. Dyes of henna show an absence of tannins and quinones with water solvent but the presence of methanol as solvent. Likewise, Turmeric and Rose dyes were absent of flavonoid and alkaloid constituents. Phytochemicals play a crucial role in plant defense against predators, microorganisms, and stress and have been used as drugs for millennia. Therefore, phytochemical screening is an essential initial step in predicting the types of potentially active compounds in plants <sup>19</sup>.

We conducted an FTIR analysis of the Pomegranate and Henna aqueous extracts because they exhibited higher phytoconstituents during analysis in our study. The FTIR-Spectrophotometer in PerkinElmer spectrum IR version 10.6.2 at Amrit Science College in Kathmandu, Nepal, analysis laboratory was used to characterize the generated natural dyes.

### Characterization of Dyes: Fourier Transform Infrared Spectroscopy (FTIR):

Anthocyanin, flavonoids, and tannis are the primary components of pomegranates. The intense red-to-blue color of many plants is caused by anthocyanins, which are naturally occurring hydrosoluble pigments that belong to the flavonoid family.

**Table 2:** Phytochemical analysis of the dyes in organic solvent (Methanol)

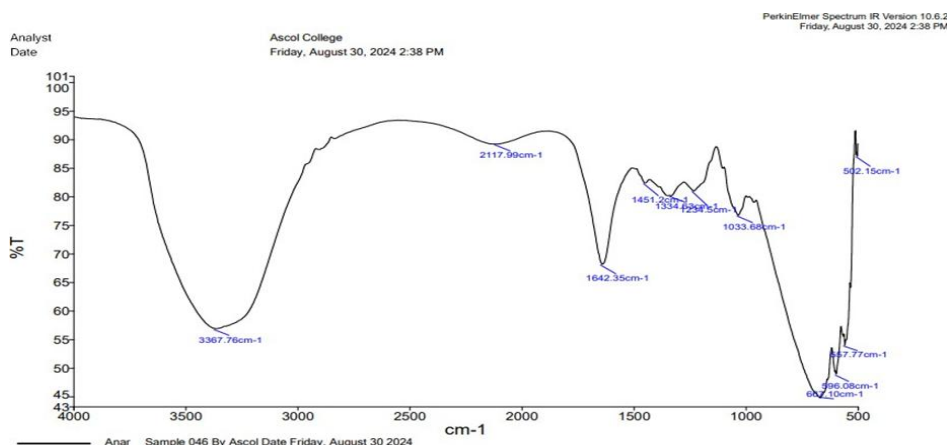
Phytoconstituents	Beetroot	Coriander	Henna	Pomegranate	Turmeric	Rose	Carrot	Mint
Flavonoids	+	+	+	+	+	-	-	+
Alkaloids (Mayer's)	±	-	+	+	-	-	+	+
Terpenoids	-	+	+	+	+	+	+	+
Tennis	-	-	+	+	-	+	+	+
Phenols	±	+	+	+	+	-	+	+
Quinones	+	+	-	+	+	+	+	+
Coumarin	-	+	+	+	-	-	+	+
Saponin	+	+	+	+	+	+	-	+



**Table 3:** Phytochemical analysis of the Dyes in Aqueous solvent (Water)

Phytoconstituents	Beetroot	Coriander	Henna	Pomegranate	Turmeric	Rose	Carrot	Mint
Flavonoids	+	+	+	+	-	-	-	+
Alkaloids	+	+	+	+	-	-	+	+
(Mayer's) Terpenoids	+	+	+	+	+	+	+	+
Tennis	+	-	-	+	-	+	-	+
Phenols	+	+	-	+	+	-	-	+
Quinones	+	+	-	+	+	+	+	+
Coumarin	+	+	+	+	-	-	+	+
Saponin	+	+	+	+	+	+	-	+

Where, + = Strongly Presence    - = Absence    ± = Moderately Presence



**Figure 2:** The FTIR spectrum of *Punica granatum* (Pomegranate)

**Table 2:** Characterization of functional group in the extract of Pomegranate peels (*Punica granatum*)

Absorbance peak obtained in (cm <sup>-1</sup> )	Intensity	Functional Group	Vibration Type	Comments
3367.7	Strong	O-H (Hydroxyl)	Stretching	Typically associated with hydroxyl groups from water or phenolic compounds (like tannins) in pomegranate. Strong due to hydrogen bonding.
2117.99	Medium	C=C (Alkene) or C=N (Nitrile)	Stretching	This is less common in natural dyes, but could indicate the presence of nitrile or alkyne groups.
1642.35	Medium	C=C (Alkene) or C=O (Carbonyl)	Stretching	This could indicate C=C stretching in conjugated systems like flavonoids.
1451.2	Weak to Medium	C-H (Methyl /methylene)	Bending	Likely due to bending vibrations of C-H bonds from methyl or methylene groups.
1334.63	Medium	C-H or C-N (Aromatic nitro)	Stretching or bending	Can indicate C-H bending or potentially nitro groups in aromatic compounds.
1234.5	Medium	C-O (Alcohol or Ester)	Stretching	Likely due to C-O stretching in alcohols, ethers, or esters.
1033.68	Strong	C-O (Alcohol or Ether)	Stretching	Typically associated with C-O Bonds in alcohols, ethers, or glycosidic bonds. Strong in phenolic compounds.
667.10	Weak	C-H (Aromatic)	Out-of-plane bending	Indicative of out-of-plane bending in aromatic C-H bonds.
557.77	Weak	Aromatic ring or skeletal vibrations	Bending	This could be related to skeletal vibrations of aromatic compounds.
502.1	Weak	Skeletal vibrations (fingerprint region)	Bending	This is in the fingerprint region, often associated with complex molecular vibrations, difficult to assign to specific functional groups.

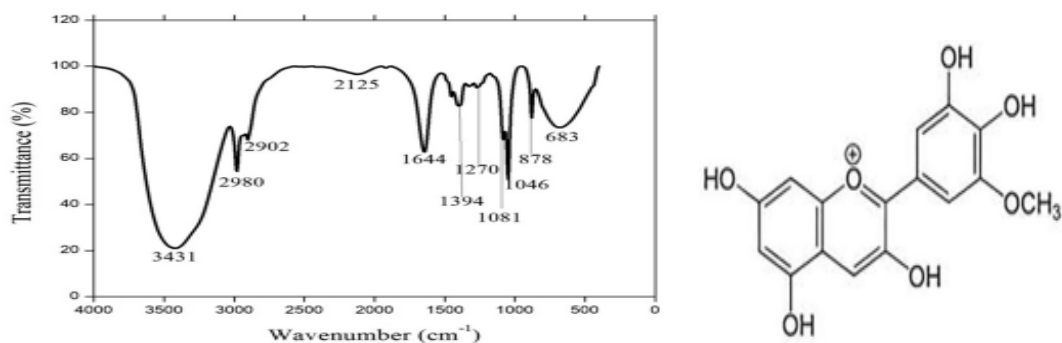


Figure 3: The FTIR Spectrum of Anthocyanin extracted from food plants and its molecular structure<sup>30</sup>

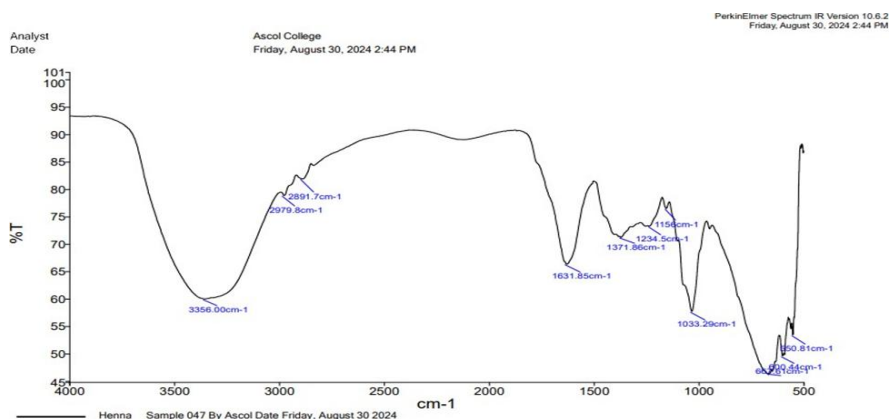


Figure 4: The FTIR Spectrum of Lawsonia inermis (Henna)

Table 3: Characterization of Functional Groups Presence in the Aqueous Extract of Henna (*Lawsonia inermis*)

Absorbance peak obtained (cm <sup>-1</sup> )	Intensity	Functional group	Vibration type	Comments
3356.00	Strong	O-H (Hydroxyl)	Stretching	Associated with hydroxyl groups, likely from water phenols or alcohols in henna. Strong due to hydrogen Bonding
2979.	Medium	C-H (Alkane)	Stretching	Typically, from C-H stretching in alkanes or methyl group.
2891.7	Medium	C-H (Alkane)	Stretching	Another C-H stretching peak, possibly from methylene or methyl groups.
1631.85	Medium	C=O (Carbonyl) or C=C(Alkene)	Stretching	This could be from conjugated carbonyl C=O or C=C bonds, which are common in flavonoids and other phenolic compounds.
1371.86	Medium	(C-H Methyl /Methylene)	Bending	Likely due to C-H bending in methyl or methylene groups
1234.5	Medium	C-O (Alcohol or Ester)	Stretching	Suggests the presence of C-O bonds, typically in alcohol ethers or esters.
1156	Medium	C-O (Alcohol or Ester)	Stretching	Another peak associated with C-O stretching common in polysaccharides or phenolic esters.
1033.29	Strong	C-O (Alcohol or Ether)	Stretching	Strong absorption, likely indicating C-O bonds in phenolic compounds or polysaccharides.
667.61	Weak	C-H (Aromatic)	Out-of-plane bending	Out-of-plane bending of C-H in aromatic rings, possibly from hennas quinones or other aromatic structures.
600.44	Weak	Aromatic ring or skeletal vibrations	Bending	Likely due to skeletal vibrations in aromatic compounds or quinine structures.
550.81	Weak	Skeletal vibrations Fingerprint region	Bending	Difficult to assign specifically, but associated with complex molecular structures in the fingerprint region

A system of two aromatic rings (A and B) connected by a C-ring with two double bonds, the flavonoid C<sub>6</sub>-C<sub>3</sub>-C<sub>6</sub> skeleton is structurally the same for all anthocyanins and is also known as the 2-phenyl-benzopyrylium cation or flavylum<sup>29</sup>. The higher wavenumber at 3431 cm<sup>-1</sup> in the FTIR spectrum was attributed to –OH stretching vibrations in a prior work by<sup>30</sup> that examined the FTIR spectra of the natural pigment anthocyanin that was isolated from food plants.

In FTIR spectra, the aliphatic C-H stretching bands are located between 2900-3000 cm<sup>-1</sup>. It shows the stretching of the alkyne group was seen to bend asymmetrically wave number at 2125 cm<sup>-1</sup>. In FTIR spectra, the methyl (-CH<sub>3</sub>) group in the plant-derived anthocyanin pigment is confirmed by this band. The bending of the –OH group was identified as the cause of the weak band in the spectra at 1394 cm<sup>-1</sup>. The –CO stretching mode is located at 1270 cm<sup>-1</sup>. These results show that almost all vibrational assignments

were similar to the spectrum obtained from our study of the pomegranate peel dyes.

Lawson (2-hydroxy-1,4-naphthoquinone), an orange-red pigment that gives conventional plant-derived henna its characteristic color, is its active constituent<sup>31</sup>. Lawson, the primary ingredient in henna extract, has been utilized as a dye in the cosmetics industry, according to a prior study by<sup>32</sup>. The lawson molecule's capacity to absorb visible light with a wavelength between 400 and 600 nm is its most important characteristic. Three valence bands at 1338 cm<sup>-1</sup>, 1421 cm<sup>-1</sup>, and 1458 cm<sup>-1</sup> are linked to C=C aromatics in the FTIR spectrum of henna extract, as shown in Figure 9. Additionally, there is a stretching absorption band at 3368 cm<sup>-1</sup> that corresponds to the vibration of the related O—H bond.

These results show that the FTIR spectrum obtained from our henna extracts remains almost similar.

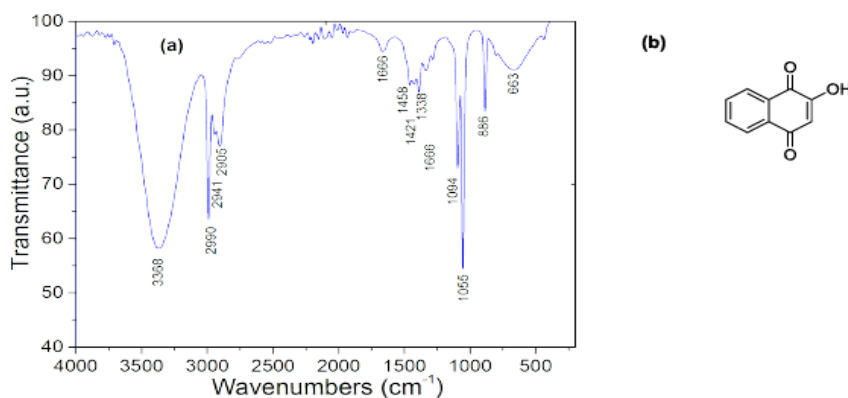


Figure 5: The FTIR Spectrum of Lawson<sup>32</sup> and structure of Lawson

Table 4: Comparison of color in cotton with and without mordant

Aspect	Without Mordant	With Copper Sulphate	With Ferrous Sulphate
Color Intensity	Light pen	Brighter, often greenish or bluish	Darker, muted, and earthy
Color Fastness	Poor	Moderate	High
Shade Variation	Minimal, original, dye color	Alters hues toward blue or green	Darkens colors, and shifts to greys /browns
Durability	Low	Improved wash and light resistance	Strong resistance to fading

#### Application of dyes in cotton:

**With and without using Mordants:** Using copper sulphate as a mordant tends to result in brighter, more vibrant colors, while ferrous sulphate gives deeper, more muted shades. Both mordants significantly improve the durability of natural dyes on cotton compared to dyeing without any mordant.

To overcome the poor substantively and fastness properties of natural dyes, fabrics are traditionally treated with substances called mordants, used to form a stable dye-metal complex and fix the color of the fabric. The

mechanism of action is different depending on the type of fiber; in the case of protein fibers, the mordant binds to it, while in cellulose fibers, it is left as an insoluble compound on the fiber, and the dye binds to the mordant<sup>33</sup>.

Naturally occurring metal salts were once used as mordants to ensure reasonable fastness of color to sunlight and washing. Today, metal salts of aluminium, chromium, iron, copper, and tin are also used. Some of the important metallic mordants are alum, potassium dichromate, ferrous sulphate, copper sulphate, stannous chloride, and stannic chloride. Most natural dyes can form metal complexes and

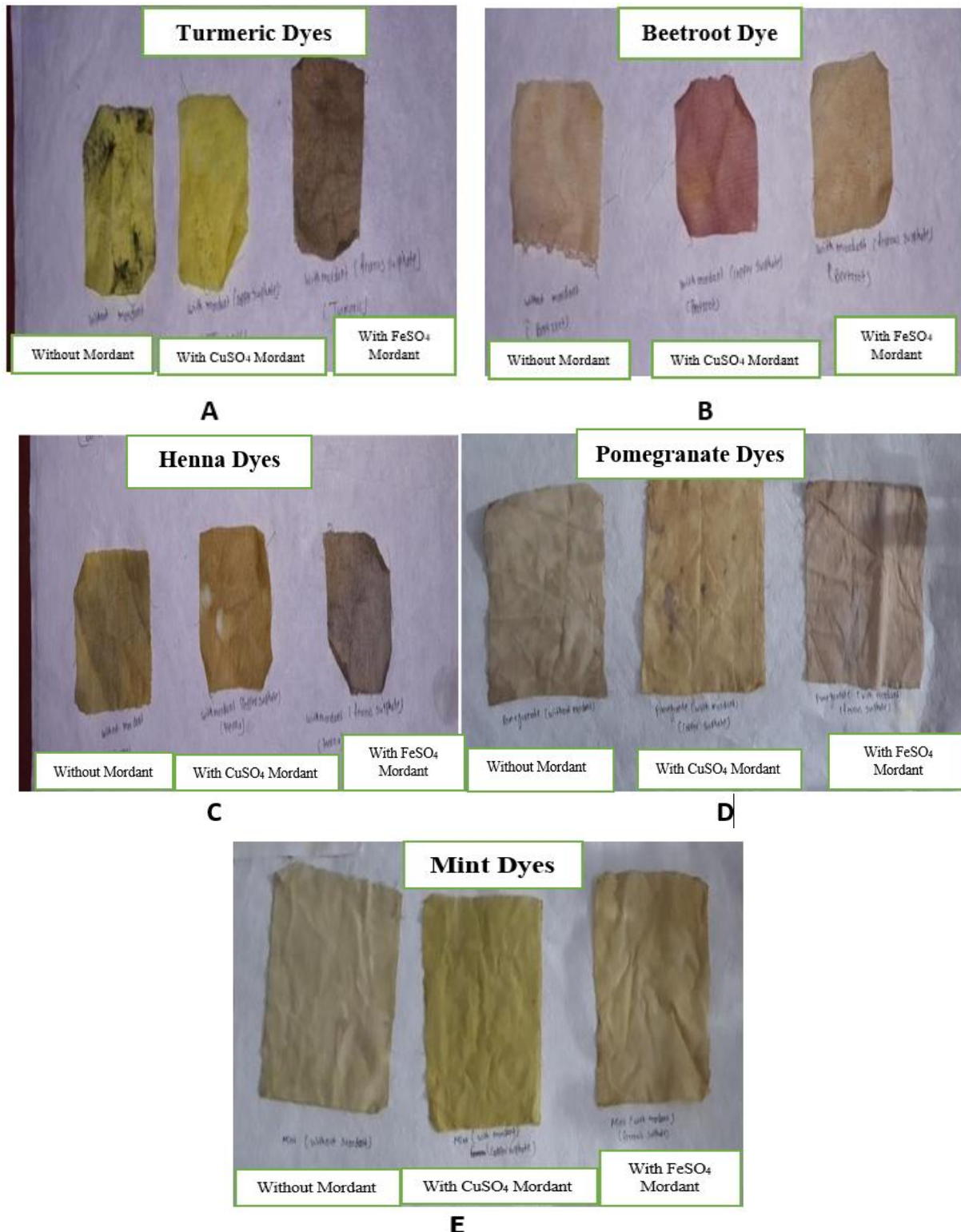
thereby produce different shades (hues). Therefore, virtually all types of metal salts can be used for this purpose<sup>34</sup>.

**Application of dyes in lip balm:**

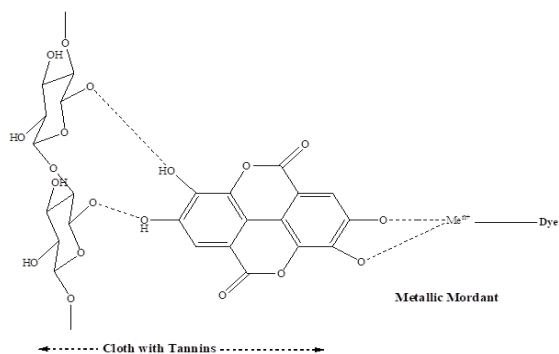
The stability, color, and functionality of lip balm containing natural dyes were greatly impacted by the storage temperature. It was discovered that the manufactured lip balm remained stable for up to four weeks when stored at

room temperature and 4 ° C. They added an intense color and had a decent consistency. Additionally, because the dyes were made with only natural chemicals, they left the skin feeling calm and refreshed.

The stability and shelf life of natural dyes in lip balms depends on several factors, including the type of dye, exposure to environmental elements, and the composition of the lip balm base.



**Figure 6:** Using Different Plant Dyes in Cloths as Without, CuSO<sub>4</sub>, FeSO<sub>4</sub> Mordants



**Figure 7:** The Mechanism of cotton cloth with tannins (as phytoconstituents), Metallic mordants, and dye <sup>33</sup>



**Figure 8:** The Application of Dyes (Mint and Pomegranate) in Lip Balm Preparation

#### Stability of Natural Dyes:

Natural dyes, such as those derived from plant or fruit extracts, are prone to oxidation over time, which may cause color fading or changes. This is especially true if the product is exposed to light, heat, or air by using <sup>35, 36</sup>.

#### Texture and Application

The texture of the lip balm remains smooth and suitable for application due to the base ingredients, such as oils and waxes, which help keep the balm soft and the dye well dispersed throughout the product <sup>36</sup>.



**Figure 9:** Noodles before and after using Dyes (Turmeric and Beetroot)

#### Shelf Life

Lip balms with natural dyes generally have a shorter shelf life at room temperature compared to synthetic alternatives. This is due to the potential degradation of both the dye and the base ingredients. Using antioxidants like Vitamin E in the formulation can help mitigate oxidation and extend shelf life <sup>35, 36</sup>.

The prepared lip balm was stable when stored at both room temperature and 4°C for up to 4 weeks, maintaining good consistency and vibrant color. The use of natural ingredients contributes to a soothing and refreshing effect

on the skin. However, for long-term storage, cold storage is preferred to maintain color stability and overall quality. On the other hand, for immediate use, room temperature storage offers a more user-friendly texture for application<sup>37</sup>.

#### Application in Noodles (As Food Products):

Natural dyes from plants tend to produce more muted, earthy tones. They are often less vibrant than synthetic dyes and can vary depending on the source and concentration <sup>35</sup>. Turmeric dyes result in yellows, beetroot dyes result in red. However, achieving strong, vibrant colors is more difficult. Plant-based dyes are generally less stable than synthetic dyes. They change color during the cooking process due to heat sensitivity. So, beetroot loses its red color and turns brownish after boiling.

These natural dyes also contribute to sustainable practices by promoting organic farming and reducing reliance on petrochemical-based resources, aligning with broader goals of sustainability and environmental conservation <sup>36</sup>.

#### CONCLUSIONS

The study concludes that natural dyes extracted from plants such as beetroot, henna, pomegranate, mint, turmeric, rose, carrot, and coriander show good affinity for cotton fabrics, with water and methanol being the most effective solvents for different plants. Mordants enhance the dye's fastness, with the dyes producing non-spectral colors like brown, red, and green. The presence of functional groups in the dyes contributes to their interaction with fabrics, highlighting the potential of natural dyes as a sustainable alternative for textile applications.

#### RECOMMENDATION

The recommendations for further work are as follows;

- Research and development can create innovative, eco-friendly extraction methods like supercritical fluid extraction, microwave-assisted extraction, or enzyme-assisted extraction for more efficient dye recovery
- Focus on maximizing the purity and yield of dyes from beetroot, henna, turmeric, pomegranate, and mint by adjusting parameters such as solvent type, pH, extraction temperature, and time.
- Investigate the stability of natural dyes under different environmental conditions (light, temperature, humidity) and their degradation pathways to improve their practical applications in textiles, food, and cosmetics.
- Experiment with natural and synthetic mordants (such as alum, iron, and tannins) to enhance dye fixation, colorfastness, and wash resistance when applied to cotton and other textiles.
- Used advanced techniques such as HPLC, GC-MS, and NMR to analyze the chemical structure and properties of the dyes. This will help in better understanding their behavior and potential applications.

- Assessments to compare the environmental impact of natural dye extraction and application processes versus synthetic dyes, focusing on water usage, waste generation, and energy consumption.
- Explore the blending of different plant-based dyes (e.g., beetroot with turmeric) to create new color shades and enhance their use across multiple industries like textiles, cosmetics, and food.

#### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

#### AUTHOR CONTRIBUTIONS

The study was designed by Arjun B., Ramita P. The manuscript was written by Arjun B. and Ramita P. The experiments and data were analyzed by Arjun B., Ramita P., Rupa A., and Gautam PC. All the authors helped with the final draft.

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