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Extraction, Phytochemical Profiling, FTIR Characterization, and Textile Application of Natural Dyes from the Bark of *Ficus religiosa* and *Bombax ceiba*

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Abstract

Synthetic dyes commonly used in the textile industry pose significant environmental and health concerns due to their toxic, non-biodegradable nature. In response, natural dyes from plant sources are gaining attention as sustainable alternatives. This study investigates natural dyes derived from the barks of Ficus religiosa (Peepal) and Bombax ceiba (Semal), focusing on their extraction, characterization, and textile application. Dyes were extracted using aqueous and organic solvents, and subsequently characterized through phytochemical screening and Fourier Transform Infrared (FTIR) Spectroscopy to identify the key bioactive constituents and functional groups. The extracted dyes were then applied to cotton and silk fabrics, with evaluations for colourfastness and mordanting behaviour. Phytochemical analysis confirmed the presence of tannins, flavonoids, and anthraquinones, while FTIR spectra validated the presence of chromophoric functional groups. The dyed fabrics exhibited vibrant colours with favourable fastness properties, demonstrating both aesthetic appeal and functional performance. These findings suggest eco-friendly alternatives to synthetic dyes. The novelty of this work lies in its integration of phytochemical profiling, FTIR-based characterization, and practical textile application, offering a comprehensive approach to natural dye research.

Keywords Extraction, FTIR analysis, Mordant, Natural dyes, Phytoconstituents, Functional group

1. Introduction

In a variety of industries, such as food, printing, textiles, and cosmetics, dyes are necessary materials that give things colour. Dyes are chromophoric materials that can interact chemically or physically with substrates to selectively absorb particular light wavelengths, producing a colour display. Usually, these substances have conjugated systems of π-electrons, which help them absorb light and control the spectrum of colours they emit (Alegbe & Uthman, 2024). Certain wavelengths of visible light are absorbed by dyes, giving them their color. While dyes are colorful, not all colored substances are dyes.

Yadav and Basnet (2023) state that an ideal dye should be sufficiently soluble in water, able to give the substrate a distinctive colour, and resistant to fading when washed, dried, cleaned, and exposed to light. A long-lasting colouring, it must have good chemical stability and be efficiently absorbed and maintained by the substance being dyed. The earliest colouring agents were from plants (foh, indigo) and animals (cochineal). Nowadays, colours with acidic and basic properties have been developed specifically, and they are utilized in food and clothes. A variety of classifications, including azo, carmine, saffron, and others, are used to classify both natural and synthetic dyes (Ali, 2024).

Natural dyes are increasingly preferred because they are non-toxic, biodegradable, and suitable for diverse applications, including food, cosmetics, leather, pharmaceuticals, and textile dyeing. Since many natural dyes do not strongly bind to fibers on their own, mordants are commonly used to enhance dye fixation and prevent colour fading during washing and light exposure. Mordants form stable complexes with dye molecules and fiber surfaces, thereby improving light fastness, dry fastness, and overall colour intensity. Commonly used mordants in textile dyeing include alum, potassium dichromate, ferrous sulphate, tannin, and tannic acid (Bhandari et al., 2020). Various dyeing methods have also been investigated to compare the effects of pre-mordanting and simultaneous mordanting, along with the advantages of combining tannic acid and metal mordants, which significantly improve wet fastness on cotton. For instance, tannin binds to celluslose well, allowing alum to interact strongly with the tannin-cellulose and improve dye uptake, while alum does not easily link with cotton (Ding & Freeman, 2017).

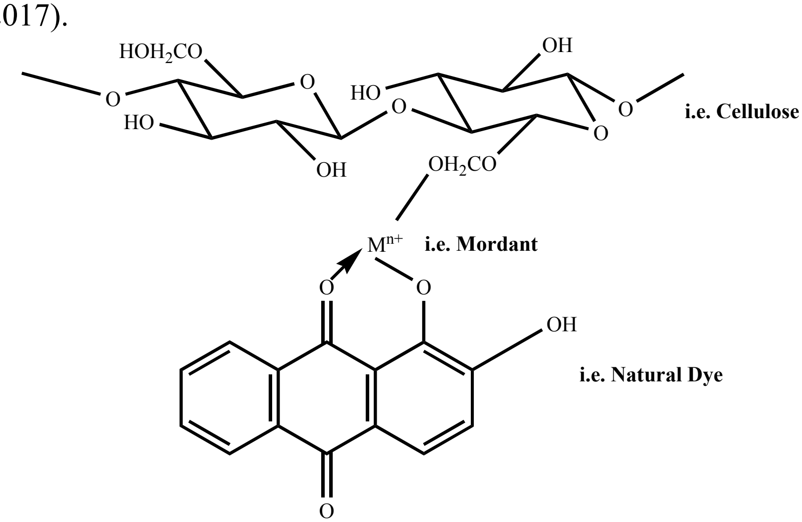

Figure 1. Attachment of a natural dye to cellulose via a mordant (Mn^{+}), exemplified by alizarin (a natural dye).

Bombax ceiba, a member of the Bombacaceae family, is commonly known as the Kapok tree, Moca, and Semal. Following numerous scientific investigations, its many therapeutic applications have been listed in Indian traditional pharmaceutical systems, including Ayurveda, Siddha, and Unani. In tropical Asia, Africa, and Australia, it is extensively accessible (Gupta et al., 2023). In tropical and subtropical India and the surrounding nations, it is a valuable medicinal plant (Tiwari et al., 2022). *B. ceiba* has significant ethnomedical relevance for numerous indigenous societies. Several portions of the tree have historically been used medicinally, according to Hossain et al. (2025). Bark paste is used to treat wounds and injuries, bark infusion is used to treat toothaches, and bark decoction is taken to treat diarrhea and dysentery. Different parts of the tree have historically been used medicinally, according to Hossain et al. (2025). Bark paste is used to treat wounds and injuries, bark infusion is used to treat toothaches, and bark decoction is taken to treat diarrhea and dysentery.

Ficus religiosa, sometimes known as peepal, belongs to the Moraceae family. *F. religiosa* is widespread throughout the continent of Asia, which includes India, Pakistan, and Bangladesh, as well as the Assam region, the Eastern Himalaya, the Nicobar Islands, and a portion of Indochina, in Florida and tropical Asia (Kapile et al., 2022). According to Sonawane et al. (2015), the plant's many parts are utilized for a variety of therapeutic purposes in traditional medicine. The bark is used to treat burns, hemorrhoids, gastrointestinal disorders, and infections because of its astringent, cooling, antibacterial, and anti-inflammatory qualities. Skin conditions, scabies, gonorrhea, hiccups, and vomiting are all treated with bark decoction.

The specific goal of this study was to use water and an organic solvent (methanol) to extract natural dye from the bark plants *Ficus religiosa* (Peepal) and *Bombax ceiba* (Simal), which were collected from the Kapilvastu district of Lumbini province, Nepal. It looks into methods for extracting bark, characterizing it, and using it in cotton fabrics and other fabric samples.

2. Method and Methodology

2.1 Plant Collection and Processing

In June and July 2024, fresh bark samples of *Bombax ceiba* and *Ficus religiosa* were collected from Kapilvastu District, Lumbini Province, Nepal, which is situated between latitudes 27°32’ N and 25°32’ N and longitudes 83°3’ E to 83°5’ E (Wikipedia Contributors, 2025). The Department of Botany, Butwal Multiple Campus, Butwal, Nepal, provided nomenclature and identification for the collected specimens.

The collected samples were washed carefully with distilled water. Samples were shade-dried in a laboratory at room temperature. After drying the surface, the plant bark parts were ground into small pieces by using a conventional method and stored in the Chemistry Laboratory of Butwal Multiple Campus for further use. In order to extract the natural dyes, 50 g of the processed bark was dissolved in 500 mL of distilled water and heated to 80-85 °C for 30 minutes. The aqueous dye extract was then obtained by filtering the mixture. The same process was also used to prepare an organic solvent extract using methanol. Before being used again, all extracts were kept at 4 °C.

A **B**

Figure 2. Collection of Plant Sample A- *Bombax ceiba* (Semal); B- *Ficus religiosa* (Peepal) (Fieldwork)

Bark of Peepal (*Ficus religiosa)*

Bark of Semal (*Bombax ceiba)*

Figure 3. Crude Sample Peepal (*Ficus religiosa*) and Simal (*Bombax ceiba*)

Figure 4. Extracted dyes by using an aqueous solvent and Methanol

2.2 Chemicals and Standards

The chemicals used in this study included mercuric chloride, potassium iodide, 1-naphthol, concentrated sulphuric acid, concentrated Nitric acid, hydrochloric acid (Thermo Fisher Scientific India Pvt. Ltd.), Ferric chloride, gelatin (Loba Chemie Pvt. Ltd.), and aluminium chloride (Sisco Research Laboratories Pvt. Ltd.). Functional group analysis was performed using a Fourier Transform Infrared (FTIR) Spectrophotometer (PerkinElmer Spectrum IR, version 10.6.2). the equipment used in this study graduated pipette, thermometer, and other standard laboratory apparatus.

2.3 Phytochemical Screening

2.3.1 Reagents used for Phytochemical Screening

a) Mayer's Reagent: In a 50 mL volumetric flask, 0.679 g of mercuric chloride was weighed and dissolved in distilled water; 2.5 g of potassium iodide were added to this mixture. The ppt. is scarlet re. Shaking caused it to dissolve, and distilled water was added to bring the volume up to the mark.

b) Dragendroff's Reagent: Solution A was created by dissolving 4 g of bismuth nitrate in 10 mL of 5 N nitric acid. Solution B was then created by dissolving 13.5 g of potassium iodide in 20 mL of distilled water. Mixed these two solutions.

c) Molisch Reagent: α-Napthol 5 g was dissolved in 50 mL of methanol to prepare the Molisch Reagent.

d) Neutral $FeCl_3$ solution: 1 g of ferric chloride crystals was dissolved in 100 mL of distilled water. Sodium carbonate crystals were gradually added to this mixture while being stirred until a small turbidity remained. The combination was then filtered, and a neutral $FeCl_3$ solution was made from the colourless filtrate.

Figure 5. Preparation of Different Reagents

2.3.2 Qualitative Phytochemical Tests:

Standard qualitative methodologies were used to conduct the screening tests for the extracts phytoconstituents as explained by Khanal and Bhandari (2024).

Detection of flavonoids (Alkaline reagent test): Six drops of a 2 % sodium hydroxide solution were added to extracts weighing 0.2 g. The presence of flavonoids in the extracts was shown by the production of a strong yellow colour that turned into a colourless solution when diluted acid was added.

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

- **a)** Mayer's Test: A Few drops of Mayer's reagent were added to the first part, and the formation of a pale yellow color indicates the presence of alkaloids.
- **b)** Dragendorff's Test (DDT): A Few drops of Dragendorff's reagent were added to the second part, forming an orange-red ppt. indicates the presence of alkaloids.

Detection of terpenoids (Salkowski's test): 2 mL of chloroform and 3 mL of concentrated 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): Three drops of diluted ferric chloride were added to a test tube containing 0.2 g of the extract and an equivalent volume of distilled water. The formation of a dark or brownish blue colour indicated that the extracts contained tannins.

Detection of steroids (Liebermann-Burchard's test): 2 mL of chloroform were combined with 0.5 g of extracts. The mixture was then put into a test tube with 2 mL of concentrated sulphuric acid. The lower chloroform layer turning red showed the presence of steroids in the extracts.

Detection of saponins (Foam test): 0.2 g of the extracts, 6 mL of distilled water, and 15 minutes of vigorous shaking in a graduated cylinder. The presence of saponins in the extracts is indicated by the production of bubbles or a persistent form for 10 minutes.

Detection of phenols (Ferric chloride test): 2 mL of 5 % aqueous ferric chloride was added to 0.2 g of the extracts. The formation of a dark green colour indicated that the extracts include phenols.

Test for Quinones: After adding 2 mL of extract, 1 mL of freshly made ferrous sulphate solution, and a few crystals of ammonium thiocyanate (NH_4SCN), the mixture was treated drop by drop with concentrated H_2SO_4. Quinones are present when a persistent deep red coloration appears.

Detection of Coumarin: 1 mL of extract, 1 mL of 10% NaOH solution was added; formation of a yellow colour indicates the presence of Coumarins.

2.4 Application of Dyes

2.4.1 Application of Dyes to Fabrics

The dye is applied to fabric by two methods

- Without Mordant
- With mordant

2.5 Preparation of Mordants (Jha et al., 2015, with modification)

Mordanting is the process of forming a bond between the coloring matter and the fiber.

- 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.

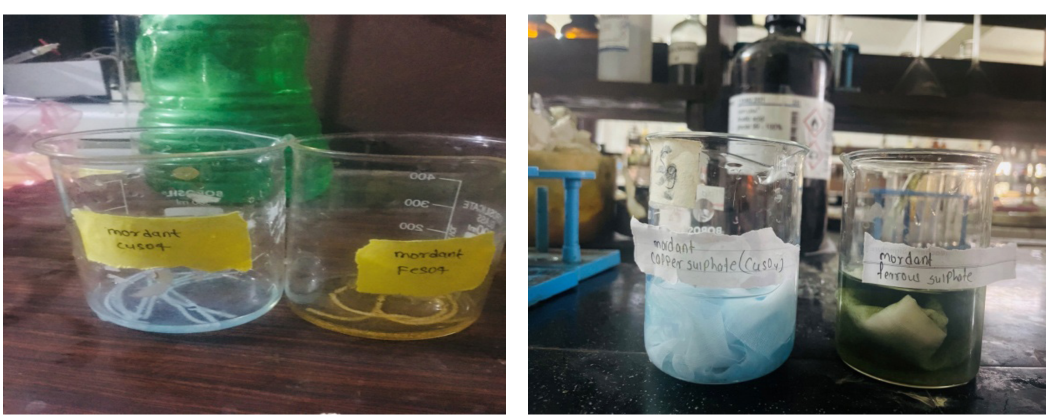

Figure 6. Use of Copper sulphate and Ferrous sulphate Mordants in cotton and wool cloths

2.6 Preparation of the cloth

Sashikala et al. (2024) state that to estimate starch, cellulose, and other dirt particles, the fabric material (cotton) is chopped into tiny pieces (10 x 10 cm), dissolved in sodium hydroxide and refluxed for 15 minutes. After being submerged in the mordant solution for 15 minutes, the sodium hydroxide treated cloth was removed.

Figure 7. Preparation of Cotton and Wool cloths

- **Without mordant:** After being treated with sodium hydroxide, the cloth is submerged in the dye solution and boiled for 30 minutes. Once the cloth has been penetrated by the dye. For more research, the cloth is removed and dried.
- **With mordant:** The fabric is submerged in the dye bath for 30 minutes after being mordanted. The dye then permeates the fabric. The fabric is removed and allowed to dry.

2.7 Characterization of Dyes

2.7.1 By Fourier-Transform Infrared Spectroscopy (FTIR-Spectroscopy): Fourier-transform infrared (FTIR) spectroscopy measures how molecules absorb infrared light at frequencies that correspond to the vibrations of their chemical bonds in order to identify and classify compounds. Functional groups provide discrete spectral bands that function as chemical fingerprints by absorbing infrared radiation in consistent wavenumber ranges. This makes it possible to identify organic and inorganic chemicals with accuracy. Analysis is most frequently conducted in the mid infrared range of 4000-400 cm^{-1} (Pasieczna-Patkowska et al., 2025).

Following dye production, the FTIR spectrometer identified the functional groups in the sample under examination by scanning the mid-infrared band 4000-400 cm^{-1}. This provided details about the dyes composition, purity, and possible applications in conservation and textile dying (Bydoon & Saad. 2023).

3. Results and Discussion

The extracted bark dyes from Peepal and Semal exhibited strong colour-imparting ability and desirable consistency.

3.1 Qualitative Phytochemical Analysis: Flavonoids, alkaloids, terpenoids, phenols, tannins, and glycosides were the main metabolites identified by phytochemical study. These are responsible for the plant's numerous advantageous qualities.

Table 1. Phytochemical analysis of the (*F. religiosa*) Peepal and (*Bombax ceiba*) Semal dyes in water and organic solvent (Methanol)

Phytoconstituents	*F. religiosa* **(Water)**	*F. religiosa* **(Methanol)**	*B. ceiba* **(Water)**	*B. ceiba* **(Methanol)**
Flavonoids	+	-	±	-
Alkaloids(Mayer's)	+	+	+	+
Terpenoids	+	+	+	+
Alkaloids (DFT)	+	+	±	+
Tannis	+	+	-	±
Phenols	+	+	+	+
Quinones	+	-	+	+
Coumarin	-	-	±	-
Saponin	+	+	+	+

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

Alkaloids, terpenoids, flavonoids, tannins, phenols, quinones, and saponins were found in the aqueous extract of *F. religiosa*, but flavonoids and quinones were absent from the methanol bark extract. Alkaloids, terpenoids, flavonoids, phenols, quinones, and saponins were present in the aqueous extract of *B. ceiba*, however the methanol bark extract lacked flavonoids and coumarins during the qualitative phtochmical analysis of extract natural dyes.

3.2 Characterization of Dyes

FTIR spectra of the aqueous extracts of *F. religiosa* and *B. ceiba* are shown in Figures 7 and 8, respectively.

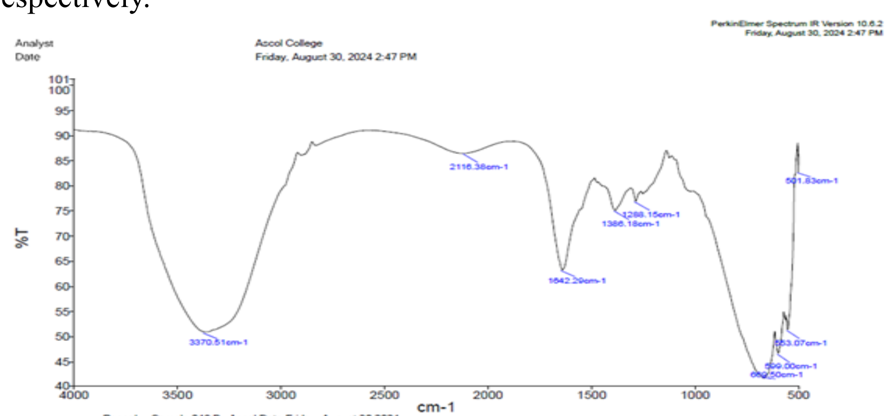

Figure 8. *F. religiosa* (Peepal) FTIR spectrum of aqueous dyes

The FTIR spectrum of *Ficus religiosa* shows several characteristic absorption bands that indicate the presence of important functional groups. A strong peak at 3370.51 cm^{-1} corresponds to O–H stretching, suggesting the presence of alcohols or phenolic compounds. The band at 2116.38 cm^{-1} is associated with C≡C or C≡N stretching, indicating the presence of complex organic structures. The peak at 1642.29 cm^{-1} represents C=C or C=O stretching, which is typical of flavonoids and other carbon-based compounds. Additionally, the fingerprint region between 1288.15 and 653.07 cm^{-1} displays multiple bending vibrations characteristic of various organic molecules present in In summary, the spectrum indicates that the *Ficus religiosa* sample contains functional groups such as alcohols, alkenes, and other plant-derived organic compounds.

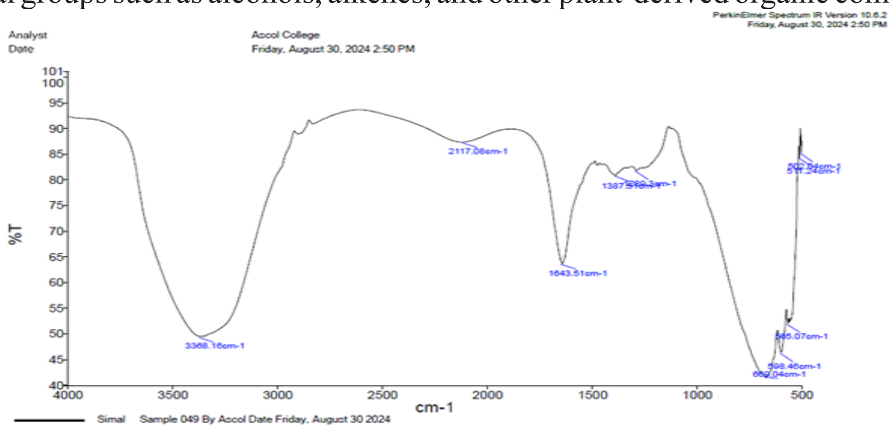

Figure 9. *B. ceiba* (Semal) FTIR spectrum of aqueous dyes

The FTIR spectrum of *Bombax ceiba* exhibits several characteristic absorption bands that indicate the presence of important functional groups. The broad peak at 3368.16 cm^{-1} corresponds to O—H stretching, suggesting alcohols or phenolic compounds. The band at 2117.08 cm^{-1} represents C≡C or C≡N stretching, indicate the presence of alkyne or nitrile groups. A prominent peak at 1643.51 cm^{-1} is associated with C=C or C=O stretching, characteristic of alkenes and carbonyl-containing compounds. The signal at 1387.84 cm^{-1} lies within the fingerprint region and may be attributed to C—H or C—O bending vibrations. Additional peaks at 698.46, 605.04, and 561.24 cm^{-1} further contribute to the fingerprint region, representing distinct bending vibrations that help define the molecular structure. Overall, the spectrum confirms the presence of hydroxyl groups, triple bonds, and other organic functional groups in the *B. ceiba* extract.

3.3 Application of Dyes in Cotton and Wool

- *With and without using Mordants*

Copper sulphate as a mordant produces brighter and more vibrant colours, whereas ferrous sulphate yields deeper, more muted shades. Both mordants significantly enhance the durability of natural dyes on cotton compared to dyeing without a mordant.

Figure 10. Using different Dyes in cotton and wool clothes

4. Discussion

In a previous study, *Ficus religiosa* and *Bombax ceiba* were found to contain multiple bioactive compounds. According to Ved Prakash et al. (2017), the methanol extracts of *F. religiosa* had all of these components except alkaloids, while the aqueous extract contained carbohydrates, saponins, phenols, flavonoids, tannins, and terpenoids. Polyphenols (tannins and flavonoids), steroids, alkaloids, carbohydrates, and glycosides were found in the methanol extract of *B. ceiba* bark, according to preliminary testing (S. C. Beldal & Londonkar, 2018). These phytoconstituents are probably what give both plants their therapeutic qualities. B-sitosteryl-D-glycoside was found to be a significant component of *F. religiosa* by Pandey et al. (2020).

The extracts FTIR examination showed distinctive peaks at 3250 cm^{-1} (phenolic –OH stre.), 2900 cm^{-1} (C—H stretching), 1610 cm^{-1} (Aromatic C=C), 1380 cm^{-1} (ethereal –OCH_3), 1070 cm^{-1} (C—O—C pyranose ring), and 600-830 cm^{-1} (C—H bending of C—H or traces of heavy metals).

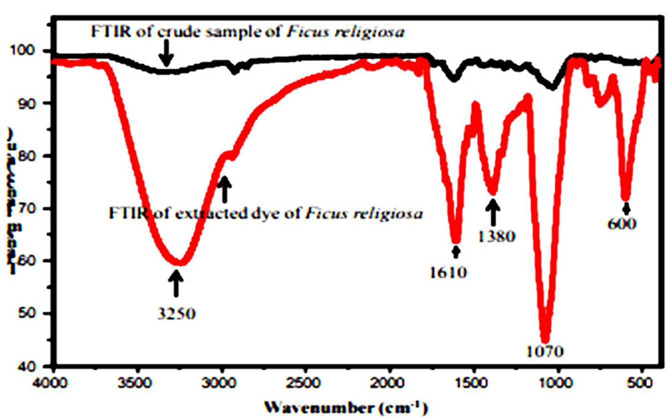

Figure 11. FTIR spectra of the aqueous dye produced from *F. religiosa* bark and neat sample (Pandey et al., 2020)

Using infrared spectroscopy, Vadwala and Kola (2017) identified the functional groups in *B. ceiba* bark extracts. Anthocyanin-related compounds were included in the spectra, which showed a significant –OH signals at 3423 cm^{-1}, C=C stretching at 1616 cm^{-1} aromatic, C—H stretching at 1413 cm^{-1}, C—O at 1077 cm^{-1}, C—C—H at 778 cm^{-1}, and C—O—H bending between 450 and 650 cm^{-1}. The lack of a signal in the 1700-1800 cm^{-1} range indicated the absence of carbonyl (C=O) groups.

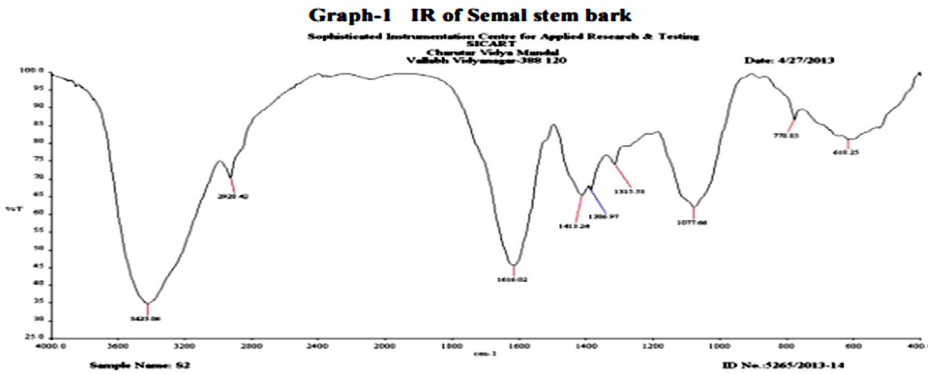

Figure 12. IR spectrum of *Bombax ceiba* (Semal) stem bark Vadwala and Kola (2017)

In a previous study, Pandey et al. (2020) investigated the use of various natural dyes with and without mordants to color a variety of fabrics, including cotton and synthetic fibers. Mordants are needed to improve dye fixing since natural dyes have substantial limitations for textiles. To firther enhance the binding of colors to the fibers, certain auxiliaries, like lemon juice, were used as organic mordants.

5. Conclusion

This study used water and methanol as solvents to successfully extract natural colors from the bark of *F. religiosa* and *B. ceiba*. Major phytoconstituents like tannins, flavonoids, phenols, alkaloids, saponins, and terpenoids were found through phytochemical screening. Functional groups including O—H, C=O, C—O—C, and C—H were confirmed by FTIR analysis, showing structurally active chromophores in charge of dye absorption and binding. When compared to samples without mordants, the application of copper sulphate and ferrous sulphate mordants greatly increased color intensity and fastness. The extracted dyes also shown a good affinity for cotton fabric. Overall, these plant based dye physicochemical properties and dyeing capabilities demonstrate their potential as viable, biodegradale, and efficient substituents for synthetic dyes in textile applications.

6. Recommendation:

The following are suggestions for upcoming researchers;

- To increase dye yield and purity, investigate environmentally friendly extraction techniques.

- Optimize the pH, temperature, and kind of solvent used in dye extraction.
- Evaluate the stability of dyes in various environmental settings.
- To improve colourfastness, try several natural and artificial mordants.
- For thorough dye profiling, use sophisticated analytical methods (HPLC., GC-MS, and FTIR).
- Examine how natural and manmade dyes affect the environment.

Data Availability Statement: Upon reasonable request, the corresponding author will provide the data supporting the study findings.

Author Contributions: Arjun B. and Rupa A. designed the study. Rupa A. and Ramita P. analysed the experimental data, while Arjun B. wrote the text. The final manuscript was reviewed and approved by all authors.

Conflicts of Interest: The authors disclose no conflicts of interest.

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