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FDRE TECHNICAL & VOCATIONAL TRAINING INSTITUTE

SCHOOL OF GRADUATE STUDIES

EXTRACTION OF NATURAL DYE FROM GULMOHAR (DELONIX REGIA) FLOWERS AND ITS APPLICATION ON COTTON FABRIC USING BIO-MORDANT AND COPPER(II) SULFATE WITH OPTIMIZATION OF COLOR STRENGTH AND FASTNESS PROPERTIES OF DYED SAMPLE

BY: NIGUSE AMARE ADELA

MARCH 04, 2026

ADDIS ABABA, ETHIOPA



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Textile and Apparel Fashion Technology Division

MS.C in Textile Technology

Extraction of Natural Dye from Gulmohar (Delonix regia) Flowers and Its Application on Cotton Fabric Using Bio-Mordant and Copper(II) Sulfate with Optimization of Color Strength and Fastness Properties of Dyed Sample

A Thesis Submitted to FDRE Technical &Vocational Training Institute

Faculty of Textile Technology (Department of Textile Technology)

In Partial Fulfillment for the Degree Master of Science of Textile Technology

BY: Niguse Amare Adela

Advisor: Gurumurthy B.R. (PhD)

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DECLARATION

I hereby declare that the work which is being presented in this study entitled "extraction of natural dye from gulmohar (delonix regia) flowers and its application on cotton fabric using bio-mordant and copper(II) sulfate with optimization of color strength and fastness properties of dyed sample" is my original work carried out under the supervision of Gurumurthy B.R.(PhD). It has not been presented for a degree of any other university and all source of materials used for this thesis is accordingly acknowledged.

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Gurumurthy B.R. (Ph.D)	_____	_____

ABSTRACT

Natural dyes generated from plant sources have received a lot of attention since they are more environmentally friendly, biodegradable, and have a smaller ecological impact than synthetic colors. Among these natural sources, Delonix regia flowers show great promise as eco-friendly dyes for textile applications. The primary goal of this research was to extract natural dyes from Gulmohur flowers and assess their potential for dyeing cotton fabric. The study also sought to explore the color strength and fastness of colored fabric utilizing neem-based bio-mordants and copper(II) sulfate as mordants. In this research, Gulmohur flowers were collected, dried, and pulverized before undergoing Soxhlet extraction to obtain the dye. The maximum dye yield of 22% was achieved at an extraction temperature of 90°C for 5 hours. Cotton fabric was selected as the textile substrate, and the extracted dye was applied under optimized dyeing conditions of 15% dye concentration, 85°C dyeing temperature, and 70 minutes dyeing time. Neem bio-mordant and copper(II) sulfate were used to improve dye fixation and enhance color performance. Standard testing procedures were used to assess the dyed textiles' color strength and fastness qualities. The color strength (K/S value) of the dyed fabric reached 10 with neem bio-mordant and 9.5 with copper (II) sulfate, according to the data. Neem bio-mordant and copper (II) sulfate had wash fastness ratings of 4/5 and 4, respectively, and light fastness values of 7 and 6. Wet rubbing fastness was assessed at 4/5 for both treatments, whereas dry rubbing fastness was rated at 5 for both mordants. Additionally, UV–visible spectroscopy and Fourier Transform Infrared (FTIR) analysis were used to characterize the extracted dye and dyed fabrics in order to determine the chemical characteristics and functional groups in charge of dyeing performance. Response Surface Methodology (RSM) and statistical analysis were used to optimize dyeing parameters such temperature, dye concentration, and dyeing duration in order to attain optimal dyeing performance. The results showed that Gulmohur flower dye, especially when combined with neem bio-mordant and copper (II) sulfate under ideal circumstances, created noticeable color strength and good fastness qualities on cotton fabric. This study concludes that Gulmohur flower dye and neem bio-mordant have great promise as an eco-friendly and sustainable substitute for synthetic dyes in cotton textile applications.

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ABBREVIATIONS

MLR: Material Liquor Ratio

ISO: International Organization of Standardization

ETIDI: Ethiopia Textile Industry Development Institute

EFTVTI: Ethiopia Federal Technical and Vocational Training Institute

OWF: On Weight of Fabric

K: Absorption

S: Light Scattering

R: Absorbed Reflectance

AATCC: American Association of Textile Chemists and Colorists

FTIR: Fourier Transform Infrared Spectroscopy

ANOVA**:** Analysis of Variance

F-value: Variance

P-value: Calculated probability

K/S: Kubleka-Munk/Color Strength

a*: Redness (a*−ve) /Greenness (a*−ve)

b*: Yellowness (b*+ve) /Blueness (b*−ve)

L*: Lightness/Darkness (L = 0 black and L-100 White)

℃: Degree Centigrade

%: Percentage

UV: Ultra Violate (UV visible range)

pH: Potential of hydrogen

UV: Ultraviolet spectrophotometer

cm^{-1}: A reciprocal wavelength

CIE: Commission International de l'Eclairage color space

CO_2SO_4: Copper(II) sulfate

GD: Gulmohar Dye

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CHAPTER ONE: INTRODUCTION

1.1. Background of the study

Chemical processing of textiles is significant because it enhances their value. Significant volumes of water, various chemicals, and auxiliaries are consumed in the wet chemical processing of textiles. Additionally, it produces a lot of effluent, which is eventually dumped into the water as pollutants tainted with chemicals and colors that aren't used. Many of the chemicals used in the preparation, dyeing, and finishing of textiles are harmful to the environment because they contaminate soil, water, and the air, harming flora and the fertility of agricultural land. [1].

Natural dyes are colorants derived from plants, animals, or minerals that have been used for thousands of years to color textiles, clothing, and other materials. Unlike synthetic dyes, natural dyes are typically biodegradable, non-toxic, and eco-friendly [2]. Depending on the dyeing method and the raw material, they can yield a broad spectrum of colors, from vivid hues to earthy tones. Historically, natural dyes were the only option available for coloring fabrics until the development of synthetic dyes in the late 19th century. However, with growing concerns about the environmental impact of synthetic dyes, there has been a resurgence of interest in natural dyes in recent years[3].

Using natural dyes also promotes sustainable practices in the textile industry by reducing the use of harmful chemicals and minimizing water pollution. Additionally, natural dyes can create a connection to traditional dyeing techniques and cultural heritage, making them a popular choice for those interested in ethical fashion and slow fashion movements. Natural resources are the source of natural dyes. These are broadly categorized as microbial, plant, animal, and mineral thinning; however, the majority of natural thinning comes from plants [4].

Current ecological understanding requires rekindling interest in natural coloring agents, namely in those who are naturally conscious. Natural colorants are seen as environmentally friendly since they are skin-friendly, renewable, biodegradable, and may even benefit the wearer's health. Most natural fiber types could be colored with natural colorants [2]. Ethiopia has an abundance of natural resources, and with the availability of scientific knowledge, there are many opportunities to investigate and resurrect the use of natural dyes on textiles.

The huge, medium-sized ornamental tree Delonix regia (Gulmohar) has bipinnately complex leaves that resemble ferns. As a semi-deciduous tree, it is mostly found in Madagascar, Africa, Northern Australia, and India. Delonix regia commonly known as Gulmohar in Hindi[6]. It's a flame tree with beautiful red peacock flowers and complex leaves. The majority of the active ingredients are found in the flowers, leaves, and bark [5].

The first step in using natural dye is always to remove the coloring pigment from a dry source. When textile materials are dyed, color is a key factor. It is among the main justifications for buying. Manufacturers include a strong glue into the fiber structure to keep it from fading away rapidly in direct light or from being rinsed out during laundry. [7].

Extraction is the technique of employing particular solvents and a predetermined operating procedure to separate the active components of plant tissue. The leaves, stem, and roots of the plant Delonix regia were extracted. Plant-based colorants are mostly made of flavonoids, which are abundant in anthocyanin and indigoids [8]. The Extraction process of Delonix regia start with flowers will be collect locally and rinse thoroughly with tap water followed by double distilled water to remove all the dust and visible particles, cut in to small pieces and dried at room temperature [9].

1.2. Statement of the Problem

Most synthetic dyes have been widely criticized due to their significant contribution to water pollution and waste disposal challenges. During the manufacture and application of synthetic dyes, large quantities of hazardous chemicals are used and released into the environment, posing serious environmental risks. Moreover, the use of artificial colorants and associated chemicals in textile processing is highly detrimental to human health, particularly causing skin-related problems[10].

Consequently, there is a growing need to develop alternative dyes that are readily available, easy to apply, and environmentally benign, in order to replace synthetic dyes. In response to this need, considerable efforts have been made worldwide to extract eco-friendly natural dyes from various renewable resources and to apply them to textile materials. However, despite the abundance of natural resources in Ethiopia, many plant materials, such as Gulmohur (Delonix regia) flowers, remain underutilized and are often discarded without exploring their potential value.

Gulmohur flowers are abundantly available in Ethiopia and represent a promising source of natural dye. Nevertheless, there is a lack of comprehensive research on the extraction of dye from Gulmohur flowers, which limits the understanding of their potential as a natural dye source for textile applications. Furthermore, limited information is available regarding the color strength and fastness properties of dyes extracted from Gulmohur flowers when applied to textile materials. This research therefore seeks to address these gaps by investigating the extraction, application, and performance evaluation of natural dye obtained from Gulmohur flowers.

1.3. Major research questions

The present study aims to investigate the suitability of dye extracted from Gulmohur (Delonix regia) flowers, using neem leaves as a bio-mordant, for application in the dyeing of cotton fabric. The study further seeks to evaluate the color strength and fastness properties of the dyed fabric. Accordingly, this thesis addresses the following major research question.

1.3.1. The research seeks to address the basic questions are listed below

- How and how much to extract pigment dye yield from Delonix regia flowers?
- What are the optimal conditions (temperature, time, and solvent type) for extracting natural colorant from gulmohar flower?
- What is the impact of dyeing parameters (temperature, time and concentration) on the shade and color retention of gulmohar dye on cotton fabric?
- What are the fastness and strength properties of the dyed material in order to assess its potential as a sustainable and high quality natural dye sources for textile application?

1.4. Objectives of the study

1.4.1. General objective

The overall aim of this study was extraction of natural dye from gulmohar (delonix regia) flowers and its application on cotton fabric using bio-mordant and copper(ii) sulfate with optimization of color strength and fastness properties of dyed sample

1.4.2. Specific objectives

The study's particular goals are listed below.

- To extract pigment and dye yield from gulmohar flowers.

- ❖ To dye cotton fabric by extracted dye yield of Delonix regia flower with mordant and bio-mordant.
- ❖ To characterize the color fastness properties of the dyed material.
- ❖ To evaluate the color strength properties of the dyed material.

1.5. Scope of the research

This research was deals with the exploration of natural dye from Gulmohar plant, which is available in Ethiopia to apply on textile materials especially on cotton fabric with mordant, dye and fibers; getting maximum yield of colorant and reproducible shades; preparing natural dyes in powder or liquid form; improving or exploring dyeing methods or yields; optimizing dyeing conditions; improving dyeablity with natural dye.

In general, the scope of the study involved the following key areas: Overall, this study aims to explore the extraction process of dye from the flowers of the Gulmohur plant, analyze fastness and strength properties of the dyed material, and evaluate its potential as a sustainable and high-quality natural dye source for textile applications.

1.6. Significance of the research

Natural textile dye research is extremely important because of its environmental compatibility, sustainability, and cultural value. Unlike synthetic dyes, which contribute to pollution and health hazards, natural dyes are biodegradable, non-toxic, and renewable, making them an ideal alternative for sustainable textile production. Ethiopia is one of the importers of dyestuffs and chemical products that requires a substantial quantity of foreign currency.

Replacing synthetic dyes with natural ones has major economic, social, and environmental advantages. The study intends to investigate and document locally available natural plants that can be used to extract gulmohar dyes and improve the fastness properties by using neem leaf as bio-mordant and utilized cotton fabric. Furthermore, the project would promote knowledge about the use of these natural dyes in Ethiopia's small-scale textile processing companies.

From the research paper, scientific information will be obtained and this gives a clue for using as an alternative means of Extraction of dye from flower of gulmohar plant and analyze the fastness and strength properties of the dyed material.

- ➢ It can be used for researchers as initials for finding and investigating further study.

- Natural dyes are eco-friendly and sustainable alternatives to synthetic dyes, which often contain harmful chemicals that can be damaging to the environment and human heal.
- farmer/suppliers – Suppling of raw materials to the textile industries as a source natural dye.
- Gulmohur flowers contain natural pigments that can produce a range of vibrant colors, making them valuable for textile dyeing and other applications.
- Country economy – big contribution will be made to the Ethiopian growing economy through improvement of revenues and associated charges by substituting imported dyestuffs.
- Analyzing the color fastness and color strength properties of the dyed material is important to assess the durability and color retention of the dye. This information is crucial for determining the suitability of the dye for various applications, such as textiles, cosmetics, or art materials.
- Researcher – To investigate further studies for further application of natural dyes.

1.7. Hypothesis of the research

It is suggested that extract dye from flower of Delonix regia plant was yield a vibrant and strong color due to the natural pigments present in the flower petals. The dyed material will have good washing fatness properties, resistance to fading, and rubbing. Natural dye extracted from Gulmohar flower will also have environmental friendly properties as compared to synthetic dyes, making it a sustainable and eco-friendly alternative for textile dyeing. When the dye factors like temperature, time, concertation vary as well as the response like color fastness and strength properties vary.

In this study, two types of hypotheses were employed: null hypothesis and alternate (or experimental) hypothesis. The null hypothesis always predicts that no differences will exist between the groups being researched. The alternative hypothesis, on the other hand, predicts that there will be a difference between the groups. Generally, a study hypothesis needs to include a minimum of one independent and one dependent variable.

Hypothesis 1

Hypothesis statement: If the dyeing temperature increases, then color strength and fastness attributes also increase.

- **Alternative hypothesis (H_1)**: The dyeing temperature has a positive relationship and has a substantial impact on the color strength and fastness of dyed fabric.

- **Null hypothesis (H_0)**: The dyeing temperature has no positive relationship and has no substantial effect on the color strength and fastness of the dyed fabric.

Hypothesis 2

Hypothesis statement: If the dyeing time increases, then color strength and fastness properties also increase

- **Alternative hypothesis (H_1)**: dyeing time has a positive relationship and has a significant effect on the color strength and fastness properties of dyed fabric.
- **Null hypothesis (H_0)**: dyeing time has no positive relationship and has no any significant effect on the color strength and fastness properties of dyed fabric.

Hypothesis 3

Hypothesis statement: If the concentration of dye from the flower of gulmohar tree grows, then color strength and fastness attributes also increase

- **Alternative hypothesis (H_1)**: dye concentration has a positive relationship and has a significant effect on the color strength and fastness properties of dyed fabric.
- **Null hypothesis (H_0)**: dye concentration has no positive relationship and has no any significant effect on the color strength and fastness properties of dyed fabric.

Hypothesis 4

Hypothesis statement: If there is available neem as bio-mordant and copper sulfate during the dyeing process increase dye up take of cotton fabric.

- **Alternative hypothesis (H_1)**: Use of bio mordants and copper sulfate significantly enhances the dye up taken of gulmohar flower that extract for cotton fabric.
- **Null hypothesis (H_0)**: Use of bio mordants and copper sulfate does not significantly affect the dye uptake of gulmohar flower that extract for cotton fabric.

1.8. Limitation of the research

Since every study has a limitation which hinders the expected result, those characteristics of design or methodology that impacts or influences the interpretation of the finding from the research are stated here:

- Time and finance constraints for collecting data's in relation to finance for affording the required materials for carrying the study in time.
- Lack of instrument availability for dye extraction and analyze fastness and strength of dyed material.
- Lack of bio-mordant obtained in local market in the form of either powder or liquid.
- Seasonal Availability: The availability of gulmohar flowers is seasonal, which can limit the production of dye from these flowers to specific times of the year. This can affect the consistency and scalability of dye production.
- Standardization of Dyeing Process: The natural dyeing process can be influenced by various factors, including variations in environmental conditions and dye extraction techniques. Standardizing the dyeing process might be challenging, potentially leading to variations in results.
- Addressing these limitations through research, innovation in extraction techniques, and quality testing methods can help overcome challenges associated with extracting dye from gulmohar flowers and analyzing the fastness and strength properties of the dyed material.

1.9. Definition of Terms

- **Extraction: -** is the process of separating the color producing compounds present in the petals of the flower to create a concentrated dye solution that can be used to color fabrics, yarn and other materials.
- **Dye: -** is a color substance that is used to impart color to materials such as fabric, textiles, paper and other surface.
- **Natural dyes: -** are colorants derived from plants, animals, or minerals that have been used for thousands of years to color textiles, clothing, and other materials.
- **Mordant: -** is a substance that is used in the dyeing process to help bind dye to the fabric or material being dyed.
- **Bio-mordant: -** is a natural substance, typically derived from plant sources, that is used in the dyeing process to help fix or enhance the color of the dye on the fabric.
- **Eco-friendly: -** dyes that are produced and used in a way that minimizes harm to the environment and human health.

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

In this chapter about theory of dye, Classification of dyes based on different factors, Natural dyes, Delonix regna, Drying Techniques, Extraction of Dye, Mordant, bio-mordant and Spectrophotometer analysis will be expounded. Natural materials like vegetables, animals, or minerals are used to make natural dyes. Textiles, food, cosmetics, and medications are typically colored using these colors.

This article aims to review the classification of natural dyes based on the available natural dye sources, mordant and its classification, various mordanting techniques, extraction techniques, dyeing techniques, and the benefits and drawbacks of natural dyes[11]. Dye is a decorative material used to color the textiles and fibers we use on a daily basis. Typically, dyes are divided into two categories: natural and synthetic[12].

2.2. Theory of dye

Dyes are the main constituents of color. They are colored substances that can bind to the substrates to which they are applied. They are used to add color to textiles, food items, clothes, and other items to make them stand out and look more beautiful. Color was first used to enhance the beauty of art in the beginning of time, but it has since found many other uses. They are soluble in water and frequently consist of organic molecules [13]. Fabric coloring is the main advancement in the textile manufacturing industry.

2.3. Classification of dyes based on different factors

Theoretical models and knowledge of the electrical origins of color divide dyes into four broad classes based on the sorts of chromogens they contain: (a) donor-acceptor, (b) cyanine, (c) polyene, and (d) $n \rightarrow \pi$ transition. Often, dyes are classified in several other ways as well. Dyes can be categorized as synthetic or natural depending on their origin.

Based on the variety of commercial uses for which they are used, dyes can be categorized as acid, azoic, basic, direct, dispersion, reactive, solvent, sulfur, vat, and mordant dyes. Numerous dyes can be divided into different categories according to their chemical compositions or the makeup of their nuclear structures. Examples of these dyes are xanthen, eurhodin, aniline, phthalocyanine,

triarylmethane, azo, cyanine, diazonium, nitro, and nitroso. Additional classifiable dyes include fluorescent, oxidation, fuel, leather, optical brighteners, leuco, sublimation, smoke, inkjet, and solvent dyes, depending on other unspecified characteristics[13].

Natural dyes are easily applied to a variety of textile substrates and are safe due to their nontoxic and biodegradable nature. They are derived from naturally occurring sources, such as plant, animal, and mineral extracts [14]. Plants are usually the source of natural dyes, such as their flowers, roots, leaves, barks, fruits, wood, etc.

2.4. Natural dyes

Dyes are the main constituents of color. They are colored substances that can bind to the substrates to which they are applied. They are used to add color to textiles, food items, clothes, and other items to make them stand out and look more beautiful. Color was first used to enhance the beauty of art in the beginning of time, but it has since found many other uses. They are soluble in water and frequently consist of organic molecules [13].

Natural dyes can be used to dye practically any natural fiber[15]. Fabric coloring is the main advancement in the textile manufacturing industry. Natural colorants are primarily recognized for their use in dyeing wool, cotton, and silk textiles, as well as for coloring leather in prehistoric times. The natural bases are free of azo-compounds, inexpensive, non-allergic, biodegradable, and environmentally beneficial [16].

Many natural colors derived from plants have been extracted in the past. The natural sources of coloration are various plant parts, such as the roots, leaves, branches, stumps, core wood, bark, wood shavings, flowers, fruits, hulls, and husks [4]. Natural materials like vegetables, animals, or minerals are used to make natural dyes. Textiles, food, cosmetics, and medications are typically colored using these colors.[17]

Interest in using natural colors has increased due to growing environmental awareness and the negative effects of dangerous synthetic dyes. It is still restricted, though, to manufacturers of high-end environmentally friendly textiles. Adopting a more extensive commercial use of natural dyes is contingent upon securing improved fastness properties and shade repeatability. Once crude oil is cracked, petroleum compounds can be used to make synthetic hues. Perkin discovered the first synthetic dye and it was called mauveine or aniline purple. There are various ideas that explain

how the colors of dyes correspond with their structures [13]. Nearly all synthetic pigments are produced in factories using petrochemical bases and hazardous chemical processes that pose a risk to the environment [16]. The need to release these hazardous byproducts into the sky or as effluents pollutes the surrounding area [18].

2.4.1. Types of Natural Dyes

Depending on where natural dyes come from, there are three types of natural dyes sources[14][19]. These are mention as follows.

A. **Plant natural dye:** Many natural dyes and stains, which produce a variety of colors like red, yellow, blue, black, brown, and combinations of these, were mostly derived from plants**.** Under extraction of dye from different parts of plant would use such as fruit, leaves, flower, root and barks. More than 450 taxa are known to make dyes in India, with about 2000 plants producing dyes, of which 150 have been used for various dyeing applications.
B. **Animal natural dye:** In the extraction of dye pigment from various animal could use such as carmine, Cochineal, hexaplex truncus, polish cochineal, tekhlet and tryian purple. A major source of natural coloring includes molluscs, murex snails, cuttlefish, shellfish, insects, etc. The dyes made from insects are lac and cochineal. Red dyes called cochineal colors are derived from insects that inhabit cactus plants.
C. **Mineral natural dye:** Dyes of a mineral origin come from either pure inorganic chemicals or particular mineral natural resources. Among the mineral dyes are clay, ochre, malachite, chrome-yellow, iron buff, and narkin yellow. These dyes are frequently utilized in a number of historic structures and paintings. One significant one is ochre, which is derived from an impure earthy iron ore or ferruginous clay, typically yellow (limonite) or red (hematite).

2.4.2. Advantages and disadvantages of natural dyes

The practice of natural dyeing has seen a resurgence in recent years. This is primarily due to the fact that natural colorants have some advantages over synthetic ones. Below is a list of some of these benefits[20].

Advantage of natural dyes

- The colors that are organically dyed are smooth, glossy, and calming to the human eye.

- They generate a variety of colors. Synthetic dyestuffs cannot produce completely new hues, but a slight change in the dyeing method or the use of several mordants with the same dye can.
- Natural dyes naturally harmonize and provide uncommon color concepts.
- Vegetable-based natural dyes are interchangeable and biodegradable, in contrast to the non-renewable raw ingredients that make up synthetic colors.

Disadvantage of natural dyes

- It is challenging to create a standard recipe for using natural dyes. There is total doubt about the results, which differ. periodically, geographically, and among different crops.
- It's an expensive process that calls for expert craftsmanship. Due to the use of costly mordants and poor color yield, more dyestuffs and longer dying times are required, which significantly lengthens the process.
- There is still much to learn about the poor scientific foundation of this field of study.
- The absence of accurate technical information regarding dyeing and extraction methods.
- When exposed to the sun, sweetness, and air, the colored fabric may change color. Since the precise chemicals present in each part at any given time are still unknown, this cannot be altered.
- With a few exceptions, almost all-natural dyes need mordants to adhere to the fabric substrate. A significant amount of the mordant is left in the residue after dying.

2.5. Delonix regia

Under ideal circumstances, Delonix regia can grow to a height of over 15 meters and a circumference of 2 meters[21]. It is deciduous in areas with prolonged winters. declared the dry seasons. The huge, vivid red flowers, which measure 10 cm across, are borne in corymbs along or at the tips of branches. Their coloring ranges widely in intensity, from orange-vermillion to rich scarlet. The majority of Delonix regia's common names are derived from the color of its blossoms [8].

The Fabaceae family includes the flowering plant species Delonix regia (Bojer ex Hook.). Because of its gorgeous red blossoms, it is known in Bangladesh as the flame tree, or Krisnachura[22]. The plant Delonix regia is a great source of antioxidants and carotenoids. The biological activities of

the plant include anti-diabetic, anti-cancer, anti-rheumatoid, anti-arthritic, anthelmintic, and antioxidant properties. Textiles can be dyed naturally with the flowers of Delonix regia. The dyes found in Delonix regia flowers were extracted using a variety of pH media and mordants.

The cotton, silk, and wool textiles were treated with the dye. Better outcomes with regard to washing and sunlight fastness were seen for the dyed materials. Additionally, different plant components were utilized as natural dyes to color silk fabrics [23]. Delonix regia is a group of flowering plants that are members of the Fabaceae family's Caesalpinioideae subfamily. This genus includes trees native to Madagascar and East Africa. The most famous species is Poinciana (D.regia)[24].

The occurrence of *Delonix regia* originates from Madagascar. Nowadays, it can be found in most tropical and subtropical regions of the world. It is unique in a number of nations, Ethiopia include [25]. Delonix regia is a readily accessible raw material. During the months of April through July, there is an excess of flowers that are squandered on the nation's streets. This flower's petals are a golden pot full of various compounds like phenols and flavanoids, as well as pigments like anthocyanins and carotenoids[26]. In June 2018, three stands of delonex regia trees were cut on the University of Ibadan's main campus in Ibadan, Nigeria[27]. The delonex regia tree's big, flamboyant, mostly crimson or orange-red blossoms are an important characteristic and highly decorative[28].



Figure 2. 1 Delonix regia flower

2.5.1. Chemical of Structures delonix regia

Delonix regia is a plant that contains a variety of chemical compounds, some of which are isolated from different portions of the plant[22].

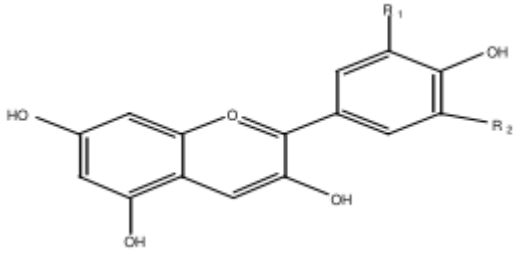


Figure 2 .2 Anthocyanins of gulmohar flower

2.6. Drying Techniques

The majority of the aqueous medium used to extract the colors come from natural sources. Natural dye extracts are frequently processed utilizing popular techniques including spray drying, vacuum drying, and freeze drying to get them into powder or concentrate form [4].

2.6.1. Spray drying technique

Spray drying is the most utilized approach to turning natural color extracts into powder, because it is straightforward and cost-effective.

2.6.2. Drying under a vacuum

Dye molecules should be sufficiently stable for heating, since dry powder is subjected to dry heat from warm air to follow this drying procedure.

2.6.3. Freeze drying technique

By reducing the pressure from the frozen extract, water is sublimated as the natural color extract congeals. Equipment is expensive and operation costs are higher, but heat sensitive dyes may also be turned into dry powders when the procedure is carried out at low freezing temperatures.

2.7. Extraction of Dye

The process of extracting a material or many chemicals from another substance is known as extraction. Numerous technological applications, including textile dyeing, biotechnology, the food and pharmaceutical sectors, and environmental protection, depend heavily on this process. These days, a lot of research is being done on new methods of extracting natural dyes from natural materials, such as using enzymes, microwaves, and ultrasonics, because they are far more effective than more conventional methods [2].

This study attempted to find a cost-effective, sustainable, and environmentally beneficial way to extract dye from these lost blossoms in order to color various fabrics. Natural dyes have seen a resurgence in popularity due to manufacturers' and consumers' rising awareness of the need to utilize eco-friendly products. The use of natural materials in textile material dyeing and printing processes contributes to a decrease in air pollution brought on by synthetic dyes. For a variety of textile materials, natural dyes can be derived from a wide range of natural sources, including plants, animals, insects, minerals, etc [7].

2.8. Method of extraction

The several kinds of extraction techniques for natural dyes were listed below.

2.8.1. Aqueous extraction

Aqueous extraction is a traditional method for extracting colors from plants and other materials. It involves soaking the colored materials in water and adding salt, acid, alkali, or alcohol to improve efficiency [31][29].It's one of the simplest and most traditional ways to extract color from naturally

occurring sources. With the exception of the heat needed during the boiling process, its environmentally benign method keeps it popular [10].

2.8.2. Solvent extraction

When adding solvent to raw materials in a Soxhlet apparatus—a steam-heated extractor—it is necessary for hard woody raw materials. For extraction, a variety of solvents are utilized, including acetone, chloroform, ether, n-hexane, alcohol, etc. In usual, the process takes four hours, but in order to make the process environmentally friendly, solvent usage must be concentrated [10].

2.8.3. Ultrasonic extraction/Microwave Energy

This technique uses Ultra-Sound Energy at lower temps and durations. Increases the product's quality in terms of textile coloring and the extraction of dye from natural dye sources as a result. [10].

2.8.4. Supercritical fluid extraction

Supercritical Fluid Extraction Techniques were developed in response to issues with the enormous energy needed to boil the raw materials, as well as issues with the use of solvents and other compounds. Here, a solvent that is safe, clean, affordable, nontoxic, combustible, and environmentally benign is used—carbon dioxide, for example. However, the method is not widely accessible to regional artisans who utilize natural colors. As a result, choosing necessary and secure extraction techniques became crucial to the use of natural pigments. As a result, the investigation used the conventional aquatic procedures [10].

2.9. Mordanting

Mordants are substances that create a complex between the dye and the fabric substrate to fix color on textiles. Mordants facilitate the development of chemical bonds that bind and tie dyes onto textiles. a link between the fiber and the dye that results in the capacity to color and stain, which can improve the dye fastness feature. Using several mordants, the performance of the mordants created multiple color shadows [16]. Since most natural dyes are not very similar to textile fibers, especially cellulosic ones, they must undergo an additional step called mordanting [4]. The three forms of mordants are metal salts or metallic bite, oil bite and tannins. Due to the mutagenic, carcinogenic, and allergenic effects of textile chemicals and textile dyestuffs, the use of hazardous materials in the textile finishing sector has come under close scrutiny.[30]

2.9.1. Metallic Mordants

For dying natural fabrics with natural dye, metal mordant is typically employed. Traditional dyers used metal salts of iron, copper, tin, chrome, and aluminum as their bites.

2.9.2. Oil Mordants

It is attached to the cotton material by creating a complex with the oil mordant and then blends it with madder to achieve the color of Turkey Red Oil (TRO).

2.9.3. Tannins or tannic acid

Tannic acid and tannins are used as the main mordants for cotton and cellulosic fibers since they have minimal affinity for metallic mordants. Cotton takes longer to color than wool or silk because it lacks the amino and carboxylate groups that give coloring molecules a sticky surface. For this reason, cotton needs to be mordanted. Natural dyes lack substance and are typically applied to fabrics using metallic salt or other mordants that have a significant affinity for both the coloring agent and the substrate. In the prehistoric era, alum, vinegar, ammonia, and salt were employed as binder to help the dye stick to the cotton.

These dyes are also regarded as skin-friendly because they don't irritate the skin or cause any other issues of that kind [7]. Using a spectrometer, the shade depth was measured in order to verify the K/S value. A rubbing test was conducted under both wet and dry conditions to assess the color fastness to abrasion. Once, the physical qualities of the fabric were evaluated using naturally extracted dye [16].

2.10. Bio-mordants

A significant quantity of metal salts remain in leftover dye baths, which are released into wastewaters without any treatment, according to research investigations conducted in the past on the use of metal salts to increase the colorimetric and fastness qualities of colored textile materials.[31]. The application of bio-mordant agents is similar to that of metallic mordants[30]. It was advised to use bio-mordants to improve the dyeing process' quality. [32].

An additional source of natural dye was bio-waste and by-products from different industries and agriculture. However, due to the absence of amino and carboxyl groups in cotton's molecular structure, cotton was unable to bind to dye molecules correctly. Therefore, in order to set the

dyestuff in or on the textile material, a mordant was used during the natural dye dyeing process. According to their characteristics, bio-mordants which are primarily derived from vegetal sources were employed. For example, plants that hyper accumulate aluminum were substituted for alum mordants, plants rich in copper were substituted for copper mordants, and certain plants were rich sources of tannin.[33]. Mordants promote fastness and increase exhaustion by forming chemical connections with the fabric and dye.

The same dye can be used to create a variety of color tones by using mordants. To set, or bind, dyes on textiles, a mordant or dye fixative forms a complex with the dye and adheres to the cloth. Metal mordants in textile dyeing surpass environmental emission restrictions even when handled sparingly. They are still widely used in the business, nevertheless. This is due to the fact that natural dyes are very well fixed to textile fibers by metal mordants. Nevertheless, handling metal mordants while they are being mordanted may be harmful to human health. Utilizing bio-mordants—which are made of organic materials to solve these issues [34].

The goal of mordanting is to create environmentally friendly hues and tones. The use of bio-mordants (Prina extract, valex powder, pomegranate rind, rosemary, thuja leaves, gallnut extract, and chlorophyll-a) as a safe and effective alternative to metal mordants has been the subject of extensive research recently, with positive results [17]. The application of bio-mordant agents is similar to that of metallic mordants.

The investigation revealed that the investigated bio-mordants interacted differently with the dye's coloring components, which are mentioned such as Pomegranate peel, Acacia, Tannic acid($C_{76}H_{52}O_{46}$), Myrobalan, Turmeric, Oak, Henna powder, Lemon, Aloe vera, Sumac, Banana, Neem. Tea, Moringa, Onion skin etc. Natural bio-mordants are mentioned[30].

2.10.1. Neem (Azadirachta indica L.)

While neem extract has been used as a natural dye source in some studies, used neem as a bio-mordant in their research. In their study, they used the extract they isolated from natural dye in Arjun bark to dye cotton fabric with natural dye and neem (Azadirachta indica), zeera (Cuminum cyminum), elaichi (Elettaria car- damomum), and harmal (Peganum harmala) extracts as bio-mordants [21].

neem was used as a natural bio-mordant in three techniques: pre-mordanting, simultaneous mordanting, and post-mordanting while dyeing. The use of bio-mordants in the natural dyeing of cotton fabric was recommended due to their biocompatibility and non-toxicity, as well as outstanding color fastness and adequate antibacterial qualities[35].

2.10.2. Chemical structures of neem

Neem also includes tannin as the principal coloring ingredient (Fig. 1), which can be used to dye fabrics as bio-mordamt. Neem has not, as far as the authors are aware, been thoroughly investigated as a natural tannin dye source for cotton coloring. This study was comprehensive, beginning with colorant isolation with microwave assistance, optimizing dyeing factors and the bio-mordanting process, and concluding with an assessment of color properties[36].

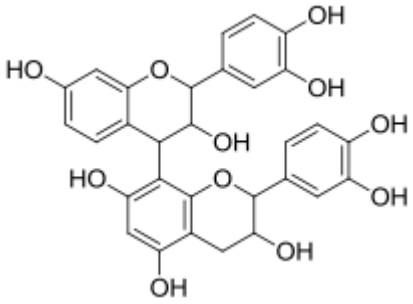


Figure 2. 2 chemical structure of neem

2.11. Spectrophotometer analysis

It is known that the color was measured in various parameters i.e. gloss, fluorescence, radiant energy, light transmittance, reflectance, and translucence. Despite being a very powerful tool in the biological and chemical sciences, a spectrophotometer just requires the simple act of shining a light beam through a sample and onto a light meter that has been filtered to a certain wavelength or very narrow range of wavelengths. Put another way, it's used to measure how much light enters a sample material and, by comparing that quantity to the original light intensity that reaches the sample, it indirectly measures how much light the sample absorbs[10].

The ratio of total light absorbed and dispersed S by the substrate, as determined by the Kbelka Munk equation, served as the basis for the color strength (K/S) measurements. Color coordinate values were computed by a computer using reflectance data, which shows: L* is the

lightness/darkness axis (L* = 100 for white and 0 for black). a* = red-green axis (+ a* for red and –a* for green) b* = yellow-blue axis (+b* for yellow and –b* for blue)[15][14]. The colour coordinate value of all dyed samples was measured by the CIE Lab system using a spectrophotometer, with an average of five measurements in Brightness, Opacity, and Color Tester[37][35].

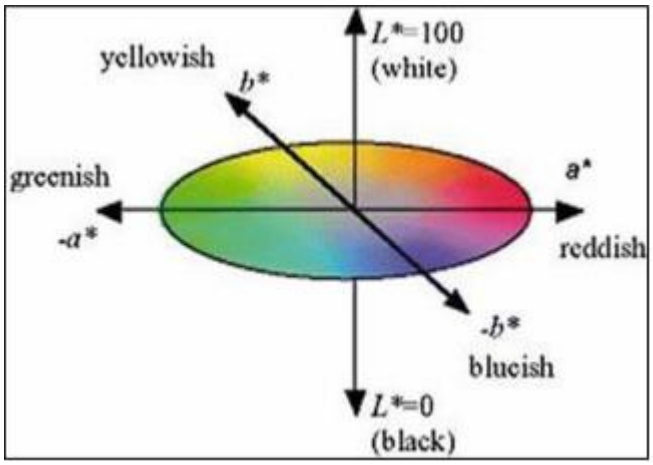


Figure 2. 3 CIE lab color graph

2.12. Fourier transform infrared (FTIR)

FTIR is helpful for confirming the identity of pure substances when used to identify chemical mixtures. Finding functional groups in molecules that vibrate when exposed to specific light wavelengths—either through stretching or bending in various ways is the basis of the technique. Plotting the frequency of light (cm-1) that the sample is exposed to against the intensity of the vibrations creates an FTIR spectrum.[38].

2.13. Colorfastness of natural dyes.

The term "color fastness" refers to the fabric's original color changing or the surrounding material becoming stained following washing. exposure to light, dry cleaning, etc. Changes in the original color depth brought on by exposure to light, washing, dry cleaning, etc. are linked to fading. Light fastness, wash fastness, and rub fastness are the most prevalent forms of color fastness; sweat is the most prevalent issue with clothing[39].

CHAPTER THREE: METHOD AND MATERIAL

3.1. Introduction

The methodology section of this research outlines the systematic approach taken to explore natural dyeing techniques using the flower of gulmohar and neem`s leaf as bio-mordant on cotton fabric while adopting eco-friendly practices. Different solvents and a combination of Soxhlet, water bath, and vacuum pump equipment with the water and ethanol extraction method are used in the extraction process. From this two technique of dye extraction water extraction method is better and preferable because it can be save much more resource.

Taguchi and Box-Behenken experimental designs are employed to optimize extraction parameters, such as time and temperature, for the highest yield percentage of the dye. For the dyeing process, cotton fabric samples are mordanted with copper sulfate and neem as bio-mordant, and Box-Behenken design is used to study the impact of dye concentration, temperature, and time on color strength and color fastness properties. Color measurement, washing fastness, light fastness, and rubbing fastness evaluations are performed using appropriate testing methods to ensure accurate and reliable results.

The study is to optimize the extraction and dyeing procedures to produce vivid and colorfast outcomes while upholding sustainable and environmentally friendly practices by methodically adhering to these approaches. The combination of experimental design and advanced testing methods ensures reliable and meaningful conclusions, contributing valuable insights to the field of natural dyeing techniques and eco-friendly textile practices.

3.2. Materials

3.2.1. Raw materials

The goal of this study was to investigate natural dyeing methods while taking sustainable and eco-friendly solutions into account. Because of its extensive industry use, strong affinity for natural colors, and biodegradability, 100% cotton half-bleached plain weave fabric was selected as the textile substrate.

This is in line with the goal of using eco-friendly methods and examining the dyeing capabilities of the dye extract from the gulmohar flower. The Oromia region of Adama town provided sources

of natural colorant flowers from the gulmohar tree, while the Addis Ababa shola market sold 100% cotton plain weave cloth that had been partly bleached. The fabric's GSM was 140 g/m2.

Table 3.1 Raw material

No	Raw material	Function and where found
1	Flower of delonix regia	Used as a source of dye and collect from local areas especially from either Addis Ababa or Adama.
2	Neem of leaf	Used as a bio-mordant in the process of natural dyeing and helps to bind the dye with the fabric and improves color fastness.
3	Bleached fabrics 100% cotton	Used for dyeing experiment and obtain from local market
4	Tap water	Used for solution preparation and washing process. It found in the work shop

3.2.2. Chemicals and auxiliaries

The extraction and dyeing processes are carried out using water. Wetting agents improve dye or chemical penetration by ensuring consistent liquid-fiber surface contact. To aid in dyeing tiredness, sodium chloride (NaCl) used as an electrolyte to improve dye uptake, binding efficiency between natural dye and cotton fabric including color fixation. Wetting agent used to facilitate interaction between dye solution and cotton fiber like fabric wettability, uniform dyeing and dye penetration. Copper (II) sulfate was chosen as a metallic mordant that used to increase fixation, color fastness, deepens shade and color strength.

Acetic acid is frequently used as PH regulator fixing assistant for cotton fabric dyeing process. Copper (II) sulfate was selected above other heavy metal mordents despite being a metallic mordant because of its comparatively lower toxicity and adaptability with different natural colors. Given that neem is renewable and biodegradable, its potential as a bio-mordant was also investigated. All things considered, the materials selected include 100% research goals for environmentally safe and sustainable textile coloring methods. Industrial soup and sodium carbonate are used for removing the unfixed dye from the dyed sample and performing washing fastness.

3.2.3. Equipment

Table 3. 2 Equipment

No	Equipment	Function and where found
1	Beaker	This versatile apparatus serves several purposes such as confining a chemical reaction, quantifying liquids, heating them over a Bunsen burner flame, or gathering them for a titration test.
2	A laboratory stirrer	Is employed in a container to combine or distribute liquids.
3	Thermo-meter	Determine a substance's, liquid's, or gas's temperature.
4	graduated cylinder	Use measure Liquid volume
5	Dropper	used for droplet liquid to the solution.

3.2.4. Mordant and bio-mordant

Table 3. 3 Mordants

No	Mordants	Function
1	Copper sulfate	Used as synthetic mordants in natural dyeing ability to create strong, vibrant colors on fabric.
2	Neem as bio-mordant	In place of alum used as natural bio-mordants in natural dyeing ability to create strong, vibrant colors on fabric.

3.2.5. Tools and machineries

Table 3. 4 Tools and machineries

No	Tools and machineries	Function
1	Stove	Application of direct heat for the cooking and boiling process.
2	Industrial drying ovens	Can also be applied regulated heat to wet material to be dry
3	Laundry	It is made to perform colorfastness tests for low temperature washing and dry cleaning in accordance with all significant international standards.

4	digital analytical balance	Is a precise weighing device used to measure a substance's mass in a laboratory.
5	absorbance spectrophotometer	Used to gauge a color's intensity. In order to quantify the amount of light that can pass through the sample in comparison to the initial amount of light from the source, the machine beams light through a cell that contains a colorant solution.
6	Soxhlet	Used for dissolve a mixture in a different solubility solvent in order to facilitate the solvent-based compound separation procedure.
7	Volumetric tube	used for measuring and holding of solvent and dye solution
8	Bottle	Used for storing/holding solution of waste beetroot dye
9	Grinder	Used for grinding of dried flower in to powder form
10	Filter paper	used for filtering solid to fine solution particle of dyestuff.

3.3. Methods of the research

3.3.1. Extract flower of gulmohar dye and its procedure for cotton fabric

The gulmohar flowers were carefully prepared for the extraction process by first collecting and washing them thoroughly to eliminate any dirt, soil or contaminants. Once cleaned, the flower then carried out drying process with natural sun light to eliminate moisture content, making them easier to process for powder form, whereas for aqueous taken as it is. These prepared gulmohar flowers were already ready for extraction of their natural colorants, which would be used for dyeing cotton fabric. There were two methods used for the extraction procedure which are powder and aqueous.

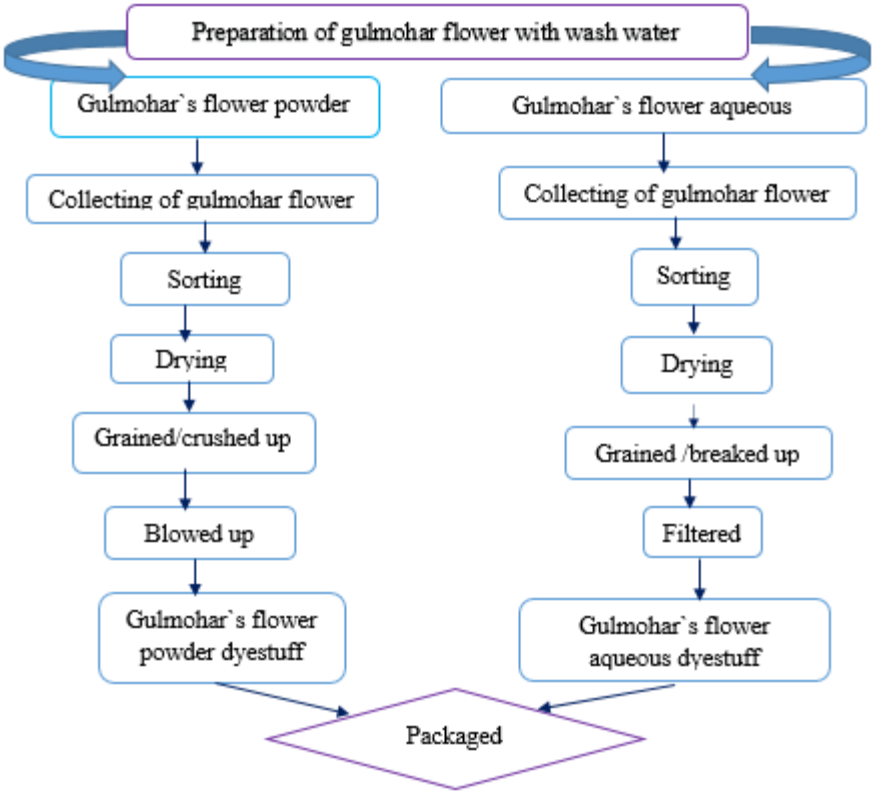


Figure 3. 1 Preparation of gulmohar dye

3.3.2. Extraction of gulmohar flower dye with different solvents

The extraction of gulmohar flower dye was conducted with different solvents such as distilled water and ethanol at the weight of 50gm. Each solvent was chosen based on its ability to dissolve and extract the anthocyanin pigments from the flower material.

Figure 3.6 represents different type of solvent to extract gulmohar`s flower dye.

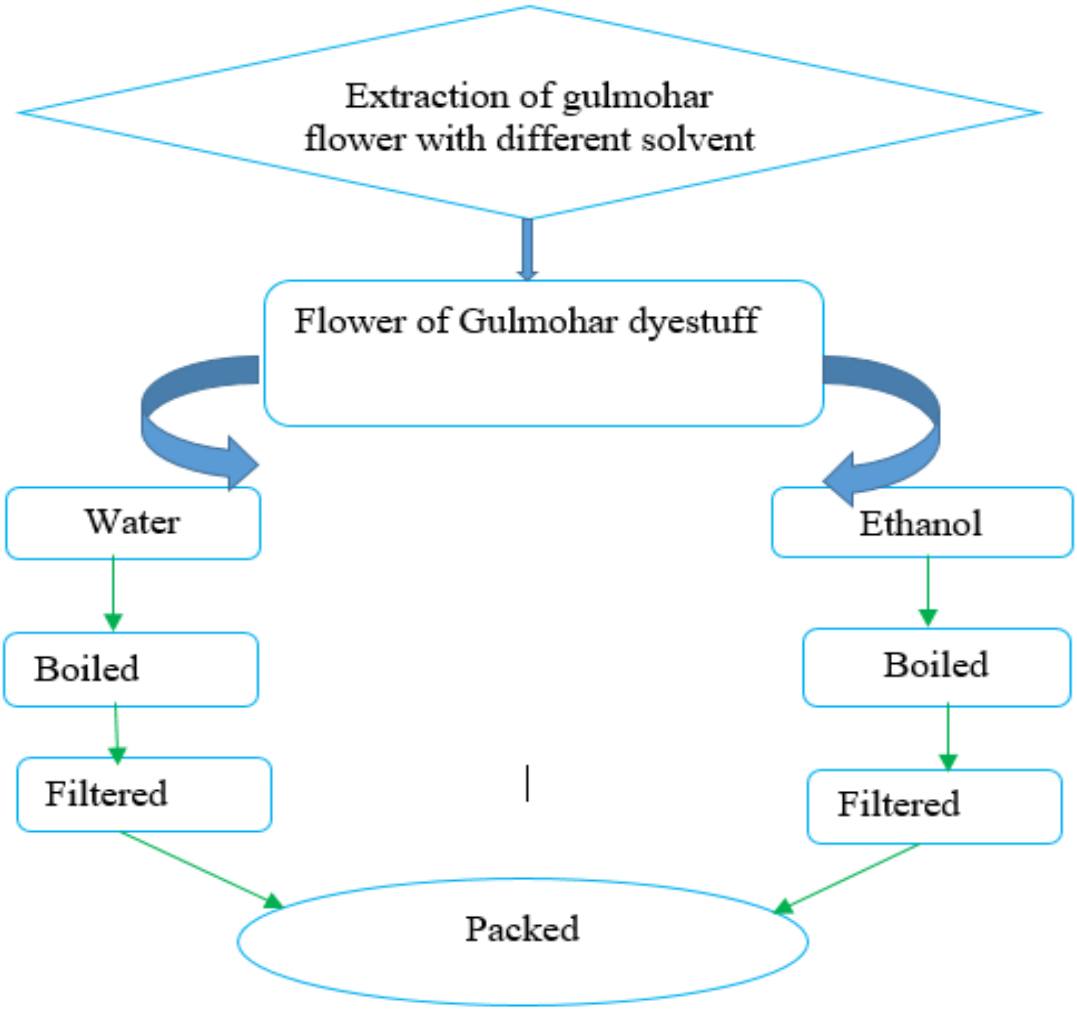


Figure 3. 2 Extraction gulmohar`s flower dye with different solvent

The samples were heated with the solvents at specific temperatures and times to obtain measurable dye yield. The resulting extracted dye were filtered and tested for their suitability in dyeing cotton fabrics with the aim of determining the most effective solvent to find vibrant and sustainable colorants.

3.3.2.1. Extraction of dye from gulmohar flower in Soxhlet methods with water solvent

During extraction of dye from gulmohar flower in soxhlet method with respect to water solvent that needed the compatible combination of deferent instrument and material which are listed below in ordered to obtain better dye yield extraction. The Soxhlet method extraction consists of several key important components and entrances such as:

- Soxhlet Extractor Apparatus: all important device which are needed must be available in various sizes and materials, the extractor apparatus holds the sample and allows for continuous extraction.
- Siphon Mechanism: A characteristic feature, the siphon facilitates the solvent's continuous circulation, critical to the extraction process.
- Sample Holder/filter paper: normally, a cellulose thimble keeping the solid sample for extraction. In some cases, a reusable, transparent glass sample holder is used but in this experiment the better choose was filter paper used to filter gulmohar dye.
- Condenser: The Allihn condenser, combined with a cold water re-circulator, helps to condense the solvent and directs it back into the sample.
- Heating Mantle: The heating mantle heats the ethanol in a round bottom flask.
- Round bottom flask: used for hold the ethanol solvent and lastly remains gulmohar dye.
- Vapor pressure: used to vaporize ethanol and facilitated cooling system of well-organized soxhlate extraction method.
- Grant digital water bath/thermostatic circulator: used for controlling and maintaining to have stable temperature and provides precise heating for a round bottom flask The resulting ethanol vapor rises to the Allihn condenser to extract flower of glumohar dye.
- Flask holder/clump: used for supporting the flask
- Weight balance: used for weighing of materials before and after extraction process carried out in ordered to know how much dye yield obtained.
- Spoon: used for pouring the powder of gulmohar flower.
- water: used for as a solvent.
- Gulmohar flower with a powder form: used for as extract dye material.
- Digital oven drying machine: used for drying residual extracted material to be dry.
- Silicon paper: used for put up wet extracted material to stay in digital oven dry machine due to its high heat resistance without burning.

The flower of gulmohar tree were initially collected from Adama town. The extraction process for obtaining color from the flower of gulmohar tree involves several detailed steps to ensure an efficient and effective extraction of the natural dye. Flowers of gulmohar tree were first collected and thoroughly cleaned to remove any dirt or impurities. After drying under the sun light, the flowers are conditioned to stabilize their state. The actual extraction was carried out by using

Soxhlet apparatus with a 1:10 material to liquor ratio (dye plant to water). Place 50g of dried Gulmohar flower powder in a thimble (filter paper) inside the Soxhlet extractor and add 500ml of distilled water in the round-bottom flask (RBS) then connect the Soxhlet setup with a condenser after that place the RBS in the water bath set to 90℃ at the end start the heating and reflux process. Allow the water to cycle through Soxhlet extractor. The dye was extracted from the flower of gulmohar powder into the solvent over multiple cycles duration of time 3-5 hr.

A Soxhlet apparatus used to remove a component with limited solubility from a solid mixture. By using this approach, a condenser and a flask are placed between a specific pieces of glassware. The solid is periodically washed by the refluxing solvent, which extracts the desired component into the flask. Colorant identification was done via Soxhlet extraction. This operation employed water as a solvent and added Gulmohar flower powder to the thistle of a Soxhlet extractor. The instrument's temperature was kept much below the solvent's boiling point. It took multiple solvent cycles to extract every component from the plant sections. The dye yield can be calculated by the following equation

Dye yield (%) = $(\frac{\boldsymbol{A-B}}{\boldsymbol{A}}) \times \mathbf{100}\%$ ……. Eq (1)[40]

Where letter **A** represent mass(g) of gulmohar flower in powder form before extraction and letter **B** represent mass(g) of gulmohar flower in powder form after extraction process was carried out.

In sox let method dye extraction, 50gm of gulmohar powder were used before extraction and 39gm of gulmohar powder obtained after extraction process completed within parameters of 5hr and 90°C. In case of those input and output could be calculated how much dye yield occurred based on equation one.

Dye yield of gulmohar flower (%) = $(\frac{\boldsymbol{A-B}}{\boldsymbol{A}}) \times \mathbf{100}\%$

= 50gm-39gm $(\frac{\boldsymbol{50gm-39gm}}{\boldsymbol{50gm}}) \times \mathbf{100}\%$

= 22%



Figure 3. 3 Extraction of dye from gulmohar flower by using Soxhlet method with water solvent

3.3.2.2. Extraction of dye from gulmohar flower in Soxhlet methods with ethanol solvent

In soxhlet method during extraction of dye from gulmohar flower with ethanol solvent needed deferent all necessary steps and material that the one described above under water solvent was similar but the unique features are listed as follows:

- Ethanol: used for as a solvent.
- Time: To optimize the dye extraction, various parameters were investigated. Three different extraction times, namely 2hr, 3hr, and 4hr, were explored.
- Temperature: The optimum temperature for the extraction of the dye from the flower of Gulmohar tree was also investigated. The extraction process was conducted at three different temperatures: 50°C, 60°C, and 70°C. Each temperature level was chosen to examine its influence on dye extraction efficiency.

The dye yield that found with respect to ethanol solvent can be calculated by the given formula equation one. In soxhlet method dye extraction, 50gm of gulmohar powder are used before extraction and 42gm of gulmohar powder obtained after extraction process completed at a

parameters 4hr and 70°C. In case of those input and output can be calculated how much dye yield occurred based on equation one.

Dye yield of gulmohar flower (%) = $(\frac{A-B}{A}) \times \mathbf{100}\%$

= 50gm-39gm $(\frac{50gm-42gm}{50gm}) \times \mathbf{100}\%$

= 16 %

Based on this research experiment indicates that soxhlet method with water solvent dye extraction was best preferable than ethanol solvent because it could have much amount of dye yield percentage and no need of high investment cost.



Figure 3. 4 Extraction of dye from gulmohar flower in Soxhlet method with ethanol solvent

Parameters for extraction process soxhlet method with water solvent

3.3.2.3. Time

The Soxhlet extraction method was used to extract the color from the flower of Gulmohar tree. Several factors were examined in order to maximize the dye extraction. Three different extraction times, namely 3hr, 4hr, and 5hr, were explored. Cotton samples were dyed in the extracted materials following each extraction, and the yield % was calculated. In order to ensure the most

effective extraction procedure, the extraction period that produced the highest dye % was chosen for more research based on the results.

3.3.2.4. Temperature

The optimum temperature for the extraction of the dye from the flower of Gulmohar tree was also investigated. Three distinct temperatures were used during the extraction procedure: 70°C, 80°C, and 90°C. Each temperature level was chosen to examine its influence on dye extraction efficiency. It was possible to discover which temperature produced the best results by calculating the yield % for each temperature. The temperature plays a critical role in facilitating the extraction of colorants from the flower and determining the overall effectiveness of the extraction process.

3.3.3. Extraction of bio-mordant from neem leaf in Soxhlet methods with water solvent

Mordant is a substance help to facilitate the reaction occurring between dye and fiber that adheres through fiber to adhere itself to fiber molecules and molecules of dye fixing itself into mordant. In natural dyeing, neem leaf extract works well as a bio-mordant and provides a sustainable substitute for artificial metal-based mordant. It enhances the binding affinity between natural dyes and textile fibers, improving colorfastness and dye uptake. It is an environmentally friendly option for natural dyeing because of its antibacterial qualities, which also increase fabric longevity. Optimizing extraction conditions, pH levels, and treatment duration can maximize its effectiveness in sustainable textile applications.

The general procedure, input and parameters used to extract the dye from the flower of gulmohar tree using in soxhlet method with water solvent which mentioned on the above are the same as those used to separate color of neem leaf powder and use it as bio-mordant instead of copper selphate, so the only specific is described as follow.



Figure 3. 5 Extraction of dye from gulmohar flower by Soxhlet method with water solvent

All of the laboratory processes for extracting/ separating gulmohar dyes and neem as bio-mordant listed on the above and supported by photo images ultimately result in a mixture of dye and solvent in round flask. Therefore, this result can be separated into powder for by evaporating the solvent using a distillation system. However, it is possible to pack the extracted dye or bio-mordant either in liquid or powder form along with the clarifying ingredients.

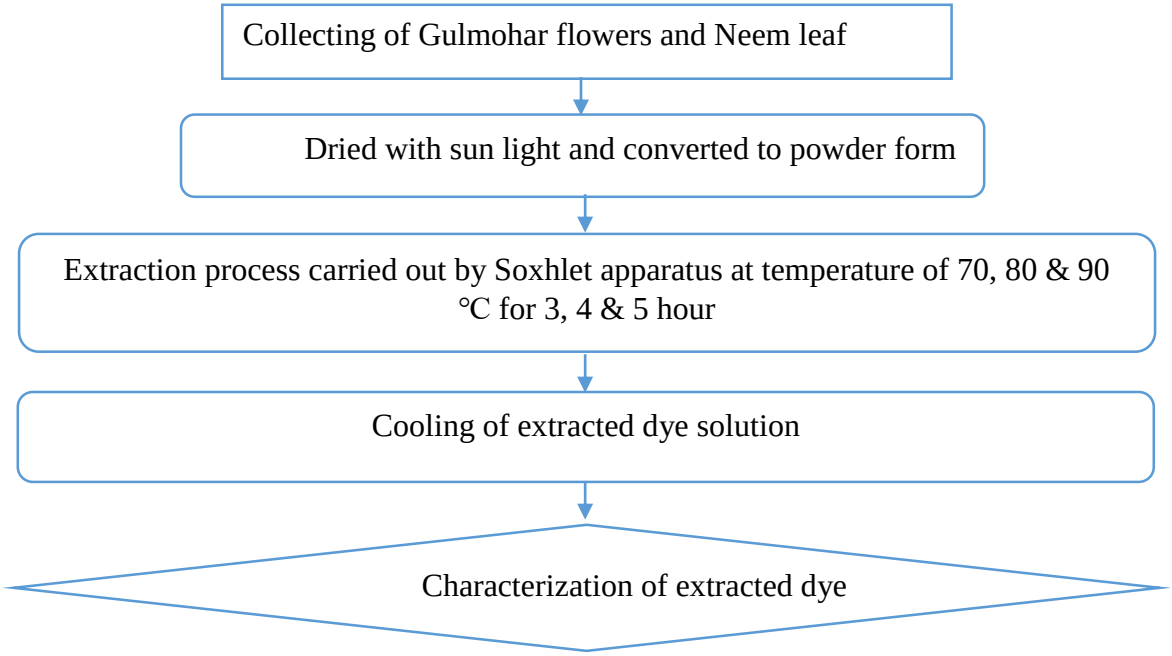


Figure 3. 6 Flow chart of dye extraction process

3.4. Mordanting Methods

The real dyeing process begins with the mordanting stage. Mordant binds itself to the molecules of fiber when it is heated with the fiber. After that, the dye molecule binds to the mordant. When the same dye is mixed with different mordants, different colors result. Iron and alum are excellent, safe mordants. Both the weight of the fabric to be colored and the percentage of chemicals are critical factors. The specific chemicals to be used for each type of mordant, together with their quantity and a specified temperature that must be maintained for a certain amount of time, must be properly followed. This also applies to the steps that must be taken both before and after mordanting. The selected fabric samples were mordanted with one of the aforementioned mordants using the pre-mordanting method, i.e. prior to dyeing[41]. There are three ways of mordanting methods for applying dyes and mordants.

- **Pre-mordanting**: where dyeing comes after applying the mordant.
- **Post-mordanting:** where the dyeing process is completed before the mordanting step.
- **Meta/ Simultaneous mordanting: -** where mordant and dye are mixed together and applied.

3.4.1. Bio-mordanting Methods

Bio-mordants are natural substances that are used in the dyeing process to help fix the color of the dye to the fabric. Bio-mordants work by forming a chemical bond between the dye molecules and the fabric, which helps to make the color more permanent and resistant to fading. Bio-mordants are considered more environmentally friendly than synthetic mordants, as they are biodegradable and less harmful to the environment. Neem mordant is a bio-mordant derived from the neem tree (Azadirachta indica).

Neem mordant is made by extracting the active compounds from neem leaves or seeds and using them in the dyeing process to help fix the color of the dye to the fabric. Using neem mordant in the dyeing process can result in unique color variations and add an extra layer of functionality to the dyed fabric. Additionally, neem mordant is considered environmentally friendly and biodegradable, making it a sustainable choice for eco-conscious textile artists and dyers.

3.4.2. Mordanting Procedure

having a strong affinity between dye and cotton fabric during reaction process mordanting technique was essential. Copper sulfate ($CuSo_4$) a traditional metallic mordant and neem leaf as a bio-mordant (natural mordant) were the two mordants utilized in order to facilitate dye affinity. Copper sulfate and neem mordant was used at a 2% concentration. The fabric samples were submerged and cooked on a hot plate for 30 minute after the mordanting solution was carefully prepared to guarantee a uniform solution.

3.5. Dyeing recipe

A dye obtained through extraction process as described on the above that can be applied onto cotton fabric, all the important conditions for the process must be met, which are listed below as follows.

3.5.1. Key input to perform dyeing process

- Cotton fabric weight 4gm
- Liquor ratio 1:30 (1gm of fabric to 30ml of water solvent)
- Mordant: neem leaf (natural mordant) and Cu_2So4 (synthetic mordant)
- Dye: gulmohar flower extract using 15% owf

A. Major source

Table 3. 5 Major source

Item	Value
Fabric weight	4g
Liquor volume	$\frac{4g \times 30ml}{1g} = 120ml$
Neem (bio-mordant)	10% owf , $\frac{10 \times 4g}{100}$ =0.1g
Gulmohar dye	15% owf , $\frac{15 \times 4g}{100}$ =0.6g

B. Basic parameters

Table 3. 6 Basic parameters

Temperature(°C)	55	70	85

Time(minute)	40	55	70
Concentration(%)	5	10	15

C. Dye bath concentration

To find the dye concentration in the dye bath is used as the weight relative to liquor volume

- Concentration $=\frac{\text{mass of raw material for dye (gm)}}{\text{Volume of Solution (mL)}}$ …… Eq (2)
- Concentration of gulmohar flower dye%= $\frac{\text{flower of gulmohar in powder form (gm)}}{\text{Liquor volume (mL)}}$
- Concentration of gulmohar flower dye%= $\frac{0.6\ (\text{gm})}{120\ (\text{mL})}$ = 0.005×100= 0.5% for deep shade

Therefor 0.5% dye concentration is presented in the dye bath.

D. Auxiliary and quantities

Table 3. 7 Auxiliary and quantities

Auxiliary	Typical dosage
Wetting agent	1% owf, $\frac{1\times4g}{100} = 0.04g$
Acetic acid(CH_3COOH)	2ml
Salt(NaCl)	8g/l
Copper sulfate	2% owf, $\frac{2\times4g}{100} = 0.04g$
PH adjust	6
Soap	2g/l



Figure 3. 7 Preparation of dyeing recipe

3.6. Dyeing Process

The extracted dye with the highest dye yield percentage achieved during the extraction process was used to apply color on cotton fabric with pre-mordant method. Dye concentration, dye temperature, and dye duration were among the dyeing parameters that were meticulously established. Using a water bath dyeing equipment, the dyeing was done in an alkaline medium with a consistent material to liquor ratio of 1:30. The cotton garment was dyed using the exhaust dyeing method with three distinct dye concentrations, namely 5%, 10%, and 15% (owf) shade.

Different dyeing times of 40 minutes, 55 minutes, and 70 minutes were examined, and the dyeing temperature was adjusted to 55°C, 70°C, and 85°C. The purpose of varying these parameters was to study their effects on the performance characteristics of the dyed fabric.

After the completion of the dyeing process, the samples were rinsed with cold water to remove any unattached dye. To improve the dyed fabric's color fastness, a soaping step was then carried out with 3 gm/L non-ionic soap at 55°C for 10 minutes. The dyeing process was finally finished by air drying and cold rinsing. This systematic study of temperature, concentration, and time during the dyeing process would provide valuable insights into the optimal conditions for achieving high-quality, colorfast dyed cotton fabric using the extracted dye from the flower of gulmohar tree. The research aims to determine the best combination of parameters that will result in vibrant and durable colors on the cotton fabric while ensuring an environmentally friendly and sustainable dyeing process.



Figure 3. 8 Water bath dyeing machine

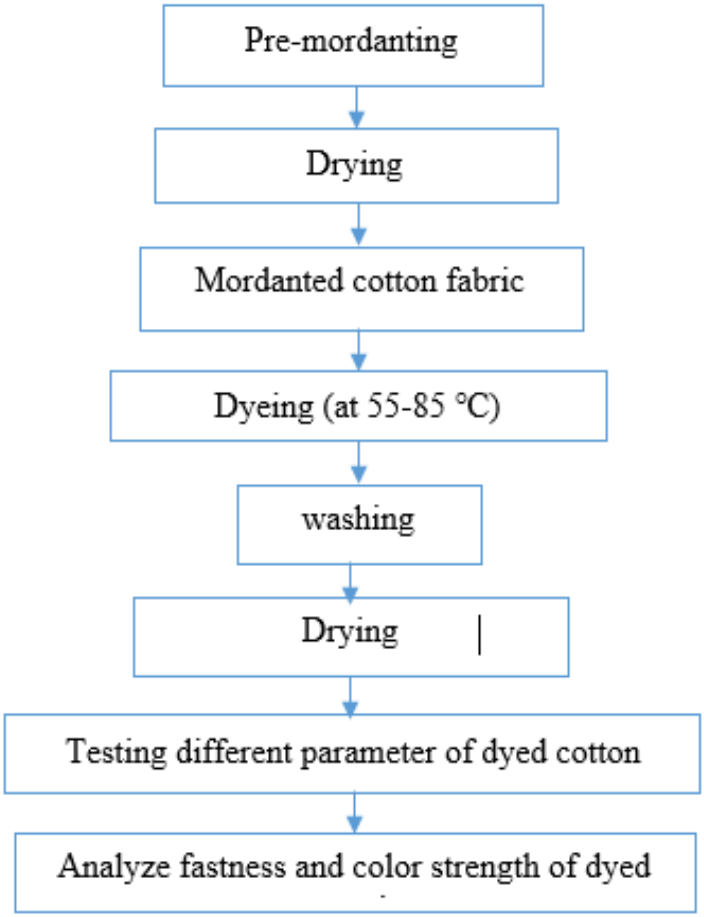


Figure 3. 9 Flow chart of experimental procedures

3.7. Sample plan

The samples of cotton fabric were dyed by using extracted dye that obtained from flower of Gulmohar tree along with neem leaf as bio-mordant, copper sulfate metallic mordant and without mordant. The research population could have made up of 27 dyed samples that an ultimate goal would be tested for performance and then optimized.

3.8. Variables

The majority of the factors suggested in this study are connected to the experimental work because the research was done based on investigation process. The variables in this study are technically specified and can be divided into two categories: dependent or response variables were getting staining, rubbing fastness, abrasion, color strength, washing fastness on dyed cotton fabric and

independent variables or factors, that change the result of specimens by using as input/raw materials were rise dye concentration, dyeing time, and dyeing temperature.

3.9. Method of analysis

To enhance the eco-green dyeing process gulmohar flowers would be used to dye cotton fabric that has been mordanted by using neem leaf as a bio-mordant. In this study deferent outcome was examined how this technique affects the fastness characteristics and color strength value of cotton materials that have been dyed. Determine the response variable and independent variable of the experimental run and analyzing the performance of the Mordanted fabric using a spectrophotometer. In addition to measuring the color strength and color fastness of the bio-mordanted fabric and the color strength of the un-mordanted fabric would served as a control. Lastly, sketch the results and analyze the differences between the bio-mordanted cloth and the mordanted fabric with copper sulfate. Minitab software would be used for the data analysis.

3.10. Design of experimental plan

To effectively improve the extraction and dyeing procedures in this study we used two experimental design techniques that was Taguchi and Box-Behenken design. We employed the Taguchi design for the extraction phase, utilizing two variables with three levels each: extraction temperature and extraction time. Finding the ideal temperature and time combination to optimize the extracted dye's yield % was the goal. By selecting the L9 orthogonal array, we conducted nine experimental runs covering all possible combinations of time and temperature, minimizing the number of trials required while obtaining meaningful results. The yield % of the extracted dye served as the response variable in this stage.

Next, we investigated the effects of three factors: dye concentration, dyeing temperature, and dyeing time using the Box-Behenken design, a response surface methodology. To effectively investigate their effects on the color strength and color fastness characteristics of the dyed cotton fabric, each factor was assessed at two levels. The Box-Behenken design allowed us to fit a second-order polynomial model to the experimental data, enabling us to predict the optimum levels of factors that yield the highest color strength and best color fastness. In order to minimize the total experimental effort and efficiently cover the spectrum of factors and interactions, we conducted 15 experimental runs during this phase.

The combination of Taguchi and Box-Behenken experimental designs contributes significantly to the optimization process, as it allows us to efficiently evaluate multiple factors and interactions with a minimum number of experimental runs. We can efficiently analyze the results, determine the ideal settings for the extraction and dying processes, and attain the intended performance attributes of the dyed cotton fabric by using Minitab software for data analysis. The successful implementation of these experimental designs enhances the reliability and efficiency of our research, leading to meaningful conclusions and valuable insights into the eco-green dyeing approach using the flower of Gulmohar tree and Neem leaf as bio-mordant.

3.10.1. Phase 1-Expermental design for extraction

The taguchi approach entails using a robust design of test to reduce variation in a process. The main objective is to provide high quality product at low cost. Independent variables were time and temperature with three levels while the response variable were yield percentage.

Table 3. 8 Factor and level for extraction

Factor	Description	Level		
A	Temperature(℃)	70	80	90
B	Time(hr)	3hr	4	5h

Table 3. 9 Experimental observation for extraction of gulmohar dye

Exp no	A	B	Yield%
1	70	3	12
2	70	4	13
3	70	5	17
4	80	3	15
5	80	4	16
6	80	5	20
7	90	3	18
8	90	4	19
9	90	5	22

3.10.2. Phase-2 Experimental design plan for dyeing

The independent variables were dye concentration, dyeing temperature and dyeing time with two levels while the response variables were color strength and color fastness.

Table 3. 10 Factors and level for dyeing

Factor	Factors Name	Min	Max
A	Dye concentration(owf)	5	15
B	Temperature (℃)	55	85
C	time (min)	40	70

Table 3. 11 Experimental design box and Behenken(BBD) for dyeing

StdOrdr	RunOrdr	PtTye	Blocs	concentration(%)	temprature(℃)	time(min)
14	1	0	1	10	70	55
4	2	2	1	15	85	55
12	3	2	1	10	85	70
8	4	2	1	15	70	70
11	5	2	1	10	55	70
1	6	2	1	5	55	55
13	7	0	1	10	70	55
10	8	2	1	10	85	40
6	9	2	1	15	70	40
9	10	2	1	10	55	40
7	11	2	1	5	70	70
2	12	2	1	15	55	55
15	13	0	1	10	70	55
3	14	2	1	5	85	55
5	15	2	1	5	70	40

3.11. Testing of dyed sample

3.11.1. Washing fastness test

The ISO 105-C03 standard, a commonly used technique for testing the colorfastness of textiles to domestic washing, was used to evaluate the washing fastness of the dyed materials. In order to evaluate the fabric's color retention following exposure to different washing conditions, a washing machine was used to replicate repeated washing cycles. It simulates real washing conditions (detergent, temperature, mechanical agitation) and evaluates: to identify color change of the test

specimen and color staining on adjacent fabrics. In this study, a specified type of washing machine was utilized for conducting the washing fastness evaluation. However, to ensure consistency and reproducibility, it is essential to mention the specific type of washing machine employed. The choice of washing machine type can influence the agitation and washing conditions, thus affecting the test results.

Composite specimens were made by preparing the dyed cotton fabric samples and Stitching is done along all edges together with composite specimen that constructed between two pieces of multifiber or single-fiber adjacent fabrics (cotton, wool, nylon, polyester, acrylic, acetate) bleached cotton fabric samples for comparison. Following ISO 105-C03 criteria, these composite specimens were then washed in the washing machine. The composite specimen and a prepared solution comprising 2g/l sodium carbonate and 5g/l non-ionic detergent were added to the washing machine. The washing machine was run for 30 minutes at a predetermined temperature of 60°C. The composite specimens were taken out after complete washing cycle was finished, gently agitate and then rinsed for 2 minute in a cold water.

Finally, dry the sample (typically by hanging it at room temperature in still air). Washing fastness is evaluated using two types of assessments based on the standard grey scale for loss of shade depth that original (unwashed) fabric is compared visually with the washed specimen as well as judged under standard lighting (e.g., D65 light) in a color assessment cabinet lastly rated from Grade 5 (No Change) to Grade 1 (Severe Change) and staining(Transfer onto Adjacent Fabrics) by means of adjacent multifiber/paired fabric is evaluated for staining even though compared the stained sample with the unstained original adjacent fabric at the end rated from 5 (No Staining) to 1 (Heavy Staining.

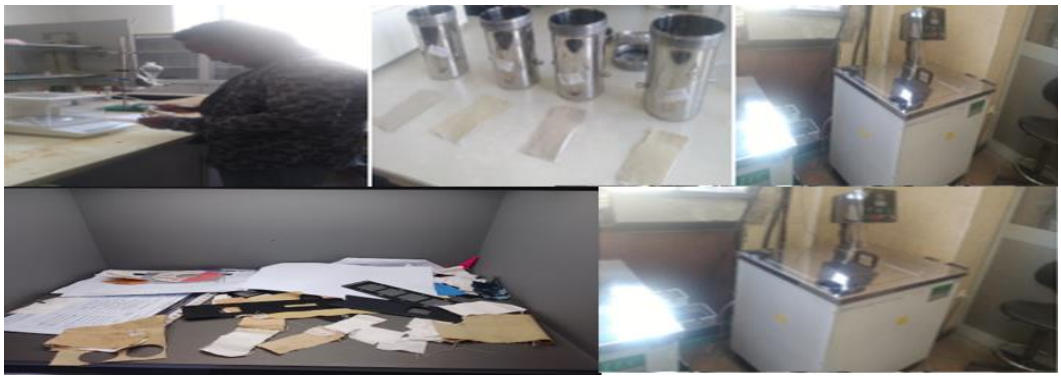


Figure 3. 10 Washing fastness test

3.11.2. Color strength measurement

The depth or intensity of color on a material that has been dyed is referred to as color strength. Richer, deeper colors are indicated by higher color strengths, while lighter colors are indicated by lower color strengths. In this study the reflectance of the dyed samples was measured using UV–Vis Reflectance Spectrophotometer. The UV–Vis Reflectance Spectrophotometer is a suitable instrument for color measurement as it can accurately capture the spectral reflectance of the samples. However, to provide a thorough explanation of the color measuring method, it is vital to describe the spectral range (wavelength range) employed for color measurement.

Each sample's reflectance (R) was measured over the visible wavelength range, and K/S values were derived at the wavelength of maximum absorption (λmax) using the range of wavelengths at which the instrument detects reflectance is determined by the spectral range, and it is important to make sure that the chosen range encompasses the pertinent section of the visible spectrum.

The color strength of the dyed samples was reported as the K/S value. The K/S value is a widely used metric in colorimetric and represents the ratio of light absorption (K) to light scattering (S) of a material at a given wavelength. It measures the color intensity of the dyed sample by indicating how much light the material absorbs and scatters. A higher K/S value indicates a higher color strength, meaning that the material exhibits a more intense and vibrant color.

Understanding how the K/S value relates to the color depth or intensity of the dyed fabric is essential to elaborating on its significance. A higher K/S value suggests that the fabric absorbs more light at a particular wavelength, resulting in a deeper and more concentrated color. Conversely, a lower K/S value indicates lighter or less intense coloration. The **K/S value** is a measure of color strength or the concentration of dye on a material and is calculated using the Kubelka-Munk equation. Let me explain carefully.

$$\mathbf{k/s} = \frac{(1-R)2}{2R} \quad \text{..... Eq(3) [42]}$$

Where:

R = reflectance of the dyed sample at the wavelength of maximum absorption (λmax).

K = absorption coefficient (how much light is absorbed).

S = scattering coefficient (how much light is scattered).

3.11.3. Rubbing fastness evaluation

An automatic Crock meter a common and trustworthy technique for figuring out how resistant textiles are to rubbing was used to evaluate the rubbing fastness of the dyed cotton fabric samples. Reliable assessment of rubbing fastness is made possible by the use of an automatic Crock meter, which guarantees steady and regulated rubbing conditions. In this study the rubbing fastness evaluation was performed using a white rubbing nylon of 5cm*2cm for both dry and wet rubbing. The rubbing procedure was carried out by sliding the rubbing nylon back and forth over the fabric surface for a predetermined number of times while the dyed fabric samples were set on the automatic Crock meter.

The fabric samples underwent ten back-and-forth rubbing strokes with the white rubbing nylon during the dry rubbing process. After that, the samples were examined to see if the rubbing had stained on the white nylon. In a similar manner, samples of dyed fabric were rubbed after the white nylon fabric had been moistened. Ten cycles of the wet rubbing procedure were also carried out. The results of the rubbing fastness evaluation were then analyzed according to the staining of the white nylon fabric as a result of rubbing on the dyed fabric samples.



Figure 3. 11 Automatic crockmeter machine

3.11.4. Light fastness evaluation

The light fastness of the colored fabric samples was determined using the ISO 105-A02 method, which is a widely accepted standard for measuring textile resistance to fading caused by light exposure. In order to evaluate the colorfastness of the dyes and replicate real-life conditions, the

dyed cloth specimens were exposed to controlled light. Following exposure, evaluations were given on a scale that usually ranged from 1 (poor) to 8 (excellent). The degree of color change was visually evaluated by comparing the exposed samples with unexposed controls using the grey scale for color change.

In this study, a specialized light box was utilized to assess light fastness. However, in order to assure consistency and reproducibility of results, it is necessary to specify the precise light source utilized in the light box. Xenon arc lamps, which closely resemble natural sunshine, are a common light source used in lightfastness testing.

The dyed cloth sample were meticulously prepared to a size of 10mm*20mm and subjected to a controlled light source in the light box. The fading effects on the dyed materials are largely determined by the light exposure circumstances, such as irradiance (light intensity) and exposure period. As a result, it is critical to define the exact irradiance and exposure time used during the light fastness test. In order to evaluate any color changes or fading, the color of the colored fabric sample was monitored during the exposure period and compared to standard patterns or color reference scales. The ISO 105-A02 technique uses a standardized evaluation scale to rate colorfastness based on the degree of fading.

3.11.5. Abrasion testing processes of cotton dye fabric

The Martindale abrasion tester instrument was used to test the abrasion of sample dyed with cotton fabric. Samples of dyed cotton fabric were conditioned for at least 24 hours at 20 ± 2 °C and 65 ± 2% relative humidity. Standard sized circular specimens with the dyed side facing the abradant were cut and placed on the specimen holders. The process was carried out between the revolving wheel, which has a standardized abrasive surface, or abrading against the surface of the specimen to determine the status, durability, and resistance of the treatment, and the finished sample. As shown in Figure 3.12 the processes of abrasion testing of cotton fabric dyed with gulmohar`s flower dye.



Figure 3. 12 Abrasion testing processes of cotton dye fabric

3.11.6. UV-visible spectroscopy analysis

A UV spectrophotometer is also defined as an analytical instrument that is used to quantify and investigate visible wavelengths absorbed with transmitted light that passes through a given sample.

Jenway UV-Vis Spectroscopy (OSA, UK) was used to examine the absorption spectra of the dye that was produced from the flower of Gulmohar tree. To determine the maximum absorbance at a particular wavelength (λ max), the examination was carried out within a scan range of 300 to 600 nm. This research offers crucial details regarding the dye's absorption properties, which aid in choosing suitable dyeing conditions and comprehending the extracted dye's behavior. A vital tool for perfecting the dying procedure and getting the right color on the cotton cloth is UV-visible spectroscopy.



Figure 3.13 Ultraviolet-visible spectrophotometer tester in (AASTU)

3.11.7. FT-IR Analysis

The chemical groups and morphological structure of polymers is examined with a Fourier transform infrared tester (FTIR) that is available at AASTU, and its model is IS50ABX, USA to identify the dye was extracted from the flower of gulmohar tree as well as dyed cotton. In order to get important insights into the binding mechanisms during the dyeing process, the main goal was to examine the interaction between the dye, fiber, and mordant. The extracted dye was put into the sample compartment of the spectrometer's Smart Collector Diffuse Reflectance Infrared Fourier Transform Spectroscopy (DRIFTS) (SHIMADZU FTIR-8400S) attachment for this analysis.

The samples' reflectance spectrum was measured, yielding vital information for enhancing fabric colorfastness and dyeing effectiveness. FTIR is called analysis/spectroscopy used for identify chemical characteristics, the major functional groups available in the natural dye to confirm the molecular composition of matters. The standard unit of FT-IR is wavenumber.



Figure 3. 14 Fourier transform infrared testing

CHAPTER FOUR: RESULTS & DISCUSSIONS

4.1. Results and discussions

The research's results and discussion section provides a thorough analysis and interpretation of the data gathered from the experiments carried out on the dyeing of cotton fabrics using the gulmohar tree's flower. Various mordants, such as copper sulfate and neem as a bio-mordant, were applied to improve the dyeing process. Bio-mordants, derived from natural sources, play a crucial role in improving dye fixation while reducing the environmental impact compared to synthetic mordants. The process of extracting gulmohar dye was methodical, aimed at producing a stable and effective dye solution.

This section aims to explore and explain the outcomes of the experiments, focusing on color strength, color fastness properties, and other performance characteristics of the dyed fabrics. The data obtained from color measurements, washing fastness evaluation, rubbing fastness evaluation, FT-IR test and UV-Visible Spectroscopy test would be analyzed to understand the effects of dye concentration, dyeing time, and dyeing temperature on the dyed fabrics' performance.

The findings from this study provide valuable insights into the potential of gulmohar`s flower as a sustainable natural dye source for cotton fabric. The discussion will also compare the results of dyed fabrics with different mordants to identify the most effective eco-green dyeing approach. This part is very important for coming to useful conclusions and learning more about how natural dyeing techniques could be used to make textiles in a more environmentally friendly way.

4.2. Extraction of dye

Dye extraction is the process of isolating and concentrating color-producing compounds from gulmohar's flower in powder form by dissolving them in a water solvent, followed by the soxhlet procedure.

4.2.1. Yield percentage vs. extraction factors

The yield of dye denotes the quantity of dye acquired following the completion of the extraction procedure. The yield percentage is calculated using a standard formula, which involves subtracting the amount of seed before extraction from the amount of seed after extraction and then dividing it by the initial amount of seed. In this study, the dye yield corresponds to the purified dye rather than the crude form. [1]

By determining the dye yield percentage, we can assess the efficiency of the extraction process in obtaining the purified dye from the flower of gulmohar tree. This information is valuable for optimizing the extraction method and ensuring that the resulting dye is of high quality and suitable for use in various applications. Moreover, understanding the yield percentage allows us to make informed decisions about the quantity of dye that can be obtained from a specific amount of raw material, contributing to sustainable and cost-effective dye production practices.

Table 4. 1 Yield Vs extraction parameters

Temperature (°C)	Time (hour)	Yield (%)
70	3	12
	4	13
	5	17
8o	3	15
	4	16
	5	20
90	3	18
	4	19
	5	22

4.2.1.1. Effect of extraction temperature on dye yield

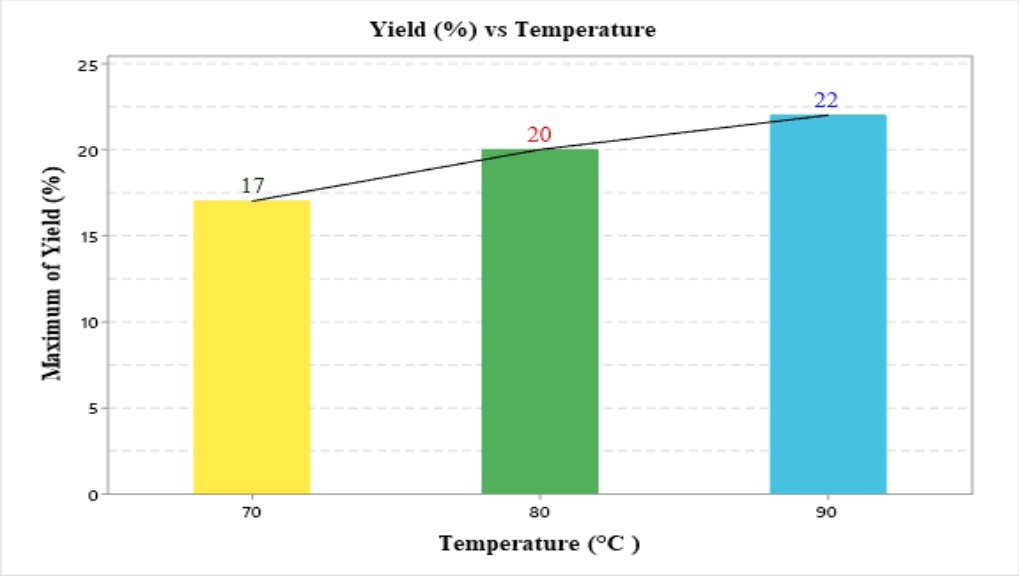


Figure 4. 1 Yield% Vs Extraction Temperature for 5 hours

The impact of extraction temperature on dye output from Delonix regia (Gulmohar) flower extract at a fixed extraction time of five hours is displayed in Figure 4.1. The results demonstrate a positive

correlation between temperature and dye generation. The equivalent extracted dye yield increased from 17% to 22% when the extraction temperature was raised from 70°C to 90°C. The yield was comparatively low at 70°C, probably because there wasn't enough thermal energy to properly break down cellular structures and liberate pigments. Elevated temperatures significantly accelerate the extraction kinetics by weakening plant cell walls and accelerating the transfer of dye molecules into the solution, as evidenced by the maximum yield (22%) at 90°C.

Overall, the graph shows that temperature plays very important role in dye extraction efficiency. The increasing trend indicates that, within the investigated range, higher temperatures enhance extraction performance without causing thermal degradation of the pigments. This result is showing that higher temperatures improve solute solubility and diffusivity, which in turn improves the recovery of natural dyes. Therefore, the fixed extraction duration of five hours, 90°C can be regarded as the ideal temperature for optimizing dye yield.

4.2.1.2. Effect of extraction time on dye yield

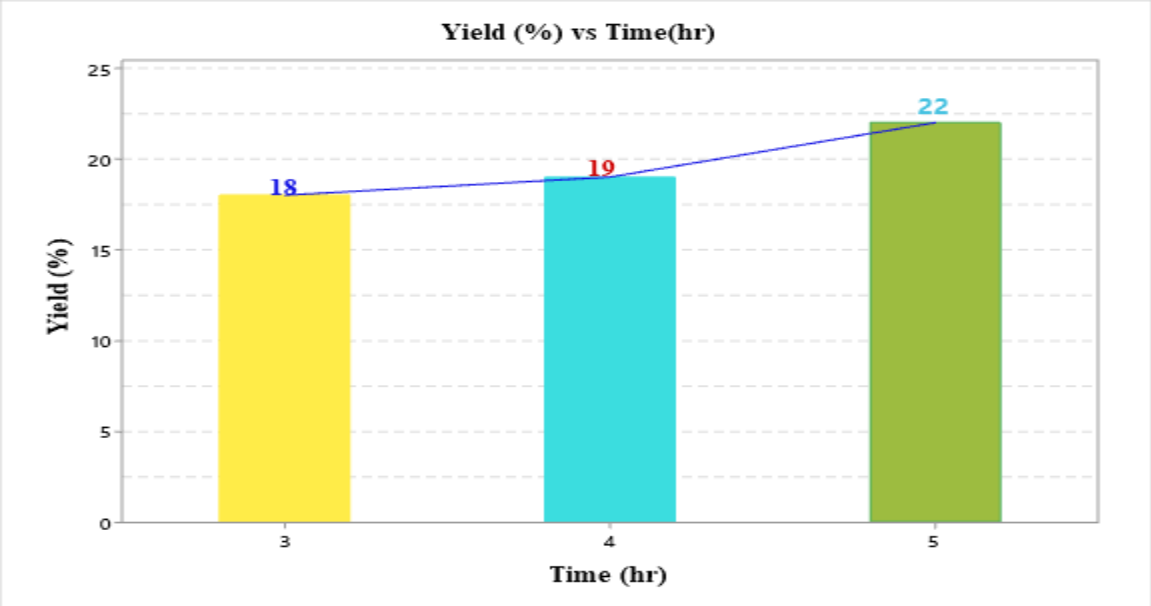


Figure 4. 2 Yield% Vs Extraction Time for 5 hours

Figure 4.2 shows the effect of extraction time on dye output from Delonix regia flower extract at a constant extraction temperature. As the extraction period is increased from three to five hours, the results demonstrate a consistent rise in dye production. At 3 hours the dye yield obtained 18%

and gradually improved to 19% at 4 hours lastly at five hours the maximum yield of 22% was attained, indicating that longer exposure times and pigment diffusion into the extraction liquid.

The general pattern indicates that extraction time is important for increasing dye yield because it lengthens the time the plant material and solvent are in contact, which improves mass transfer. However, there was a more noticeable increase between 4 and 5 hours, while the increase between 3 and 4 hours was comparatively minor. Five hours seems to be the best extraction period within the tested range because it yields the maximum yield without showing any signs of pigment degradation or extraction efficiency plateauing.

Additionally, it is crucial to understand that the gulmohar flower's dye production percentage is greatly influenced by the interaction between extraction temperature and time. The statistical study demonstrates the significant combined effect of extraction temperature and time (P value < 0.05). These findings highlight the necessity of carefully adjusting both extraction time and temperature to produce the best dye yield %, resulting in a more efficient and productive natural dye extraction method. Moreover, understanding the relationship between extraction time and yield percentage provides valuable insights for establishing precise extraction protocols, contributing to the development of eco-friendly and sustainable dyeing practices.

4.3. Statistical analysis, modeling and validation for yield percentage

In this investigation statistical analysis was performed to understand how the extraction temperature and duration affect the yield % of the dye. The impact of those parameter on the extraction of dye yield was assessed by Statistical analysis (ANOVA). Both parameters demonstrated a highly significant influence ($p < 0.05$), suggesting that process conditions have a major impact on yield.

The relationship between temperature, time, and yield was described using a regression model, and prediction equations were created using the model coefficients. The coefficients in the regression equation represent the strength and direction of the relationships between the variables and response. The reliability of the model for predicting dye extraction performance was finally confirmed by validation experiments carried out under the anticipated optimal circumstances, which revealed close agreement between experimental and predicted yield values.

4.3.1. Justification of Regression Coefficients based on model variable and response

Table 4. 2 Extraction variables temperature and time

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	16.889	0.111	(16.580, 17.197)	152.00	0.000	
Temperature (°C)						
70	-2.889	0.157	(-3.325, -2.453)	-18.38	0.000	1.33
80	0.111	0.157	(-0.325, 0.547)	0.71	0.519	1.33
90	2.778	0.157	(2.342, 3.214)	17.68	0.000	*
Time (hr)						
3	-1.889	0.157	(-2.325, -1.453)	-12.02	0.000	1.33
4	-0.889	0.157	(-1.325, -0.453)	-5.66	0.005	1.33
5	2.778	0.157	(2.342, 3.214)	17.68	0.000	*

Each factor's importance was assessed using the statistical markers T-value, P-value, SE (standard error), and 95% confidence intervals. When all predictor variables are at their reference levels, the baseline dye production is represented by the constant coefficient (16.889). The model is statistically credible and the baseline yield is significantly different from zero, as indicated by its exceptionally high T-value (152.00) and P-value of 0.000.

4.3.1.1. Effect of temperature

With a highly significant P-value of 0.000, the coefficient for 70°C is 2.889, suggesting that this temperature significantly reduces yield when compared to the reference condition. This implies that lower temperatures restrict dye molecules' solubility and diffusion, which lowers extraction efficiency. The effect is not statistically significant at 80°C, as indicated by the coefficient of 0.111 and the associated P-value of 0.519. On the other hand, the coefficient for 90°C (2.778) has a positive T-value (17.68) and is highly significant (P-value 0.000), suggesting that this temperature significantly increases dye yield. Better dye extraction is facilitated by increased cell wall breakdown at higher temperatures and improved pigment solubility.

4.3.1.2. Effect of extraction time

The yield significantly decreased during three hours, as indicated by the coefficient (-1.889) and its P-value (0.000). In a similar vein, 4 hours has a significant P-value of 0.005 and a negative coefficient of -0.889, indicating that it similarly produces lower yields than the ideal time. Conversely, 5 hours shows a considerable positive contribution to dye output with a highly

significant and positive coefficient (2.778). Longer extraction times greatly increase dye release, as confirmed by the confidence interval (2.342 to 3.214), which is probably caused by longer solvent penetration and diffusion.

4.3.2. Regression equation

$$\text{Yield}(\%) = 16.889 - 2.889\ \text{Temperature (°C)}_70 + 0.111\ \text{Temperature (°C)}_80 + 2.778\ \text{Temperature (°C)}_90 - 1.889\ \text{Time (hr)}_3 - 0.889\ \text{Time (hr)}_4 + 2.778\ \text{Time (hr)}_5 \quad \text{eq(1)}$$

4.3.3. Analysis of variance

The findings of the Analysis of Variance (ANOVA) used to assess the impact of extraction temperature and extraction duration on the yield of dye extracted from Delonix regia (Gulmohar) flowers are shown in Table 4.3.

Table 4. 3 Analysis variance at extracted yield

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Temperature (°C)	2	48.2222	56.81%	48.2222	24.1111	217.00	0.000
Time (hr)	2	36.2222	42.67%	36.2222	18.1111	163.00	0.000
Error	4	0.4444	0.52%	0.4444	0.1111		
Total	8	84.8889	100.00%				

4.3.3.1. Significance of temperature

A Sequential Sum of Squares (Seq SS) of 48.2222, or 56.81% of the overall variation in dye production, is explained by the temperature factor. The high Adjusted Mean Square (Adj MS = 24.1111) and exceptionally big F-value (F = 217.00) clearly imply that extraction temperature is a major cause of variation. The associated P-value (0.000) is well below the 0.05 significance level, indicating that temperature has a significant impact on dye production. This demonstrates that fluctuation in temperature effects pigment solubility and diffusion, making it a vital parameter in optimizing the extraction process.

4.3.3.2. Significance of extraction time

Extraction time has a Seq SS of 36.2222, accounting for 42.67% of the total variation, making it the second greatest contributor. Additionally, the very high F-value (163.00) and Adj MS (18.1111) demonstrate that extraction time has a statistically significant impact on dye production and High significance is once again confirmed by the P-value (0.000). The conclusion that longer extraction times greatly improve solvent penetration and mass transfer, leading to a larger dye yield, is supported by this data.

4.3.3.3. Error term

Just 0.4444 SS, or 0.52% of the overall variability, is explained by the error term (residual). This incredibly low figure suggests that the results were mostly unaffected by measurement error, experimental noise, and uncontrollable factors. The model matches the data quite well with little random variation, according to the low Adj MS (0.1111).

4.3.3.4. Overall model performance

The ANOVA findings clearly reveal that both extraction temperature and extraction time have a substantial impact on dye production. The total variability in dye yield was 84.8889, and the controlled factors (temperature and time) accounted for 99.48% of the variation. Temperature adds slightly more variance than time, but together, they explain virtually all of the variability in the extraction process. These results confirm how crucial it is to maximize dye recovery efficiency from Delonix regia flowers by optimizing both parameters.

4.3.4. Model summary

The model summary statistics used to assess the precision, dependability, and predictive capacity of the regression model created for dye yield as a function of extraction temperature and extraction time are shown in Table 4.4.

Table 4. 4 Model summary of extracted dye yield

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.333333	99.48%	98.95%	2.25	97.35%	52.47	11.65

4.3.4.1. Standard error of regression (S)

As table 4.4 shows that there is very little residual variation between the observed and projected yield values, as indicated by the standard error value (S = 0.3333). A low S value confirms the high precision of the fitted regression equation by indicating that the model predictions closely match the real data.

4.3.4.2. Coefficient of determination (R-sq)

The two predictors, extraction temperature and extraction time, based on table 4.4 account for the whole variation in dye yield, according to the model's R-sq value of 99.48%. This incredibly high R-sq shows that very little variability remains unexplained and therefore the model has strong explanatory power.

4.3.4.3. Adjusted (R-sq(adj))

Based on table 4.4 indicated that even after taking the number of predictors into consideration, the modified R2 value (98.95%) stays extremely near to the R2 value. The closeness of R^2 and adjusted R^2 suggests high model stability.

4.3.4.4. Press statistic

Another indicator of predictive accuracy is the Prediction Error Sum of Squares (PRESS = 2.25), which table 4.4 shows that the model performs well under cross-validation and generates little prediction error. This supports the finding that the regression model has a high degree of reliability.

4.3.4.5. Predicted R^2

Based on table 4.4 shows that the model's ability to predict fresh observations that were excluded from the fitting process is indicated by the projected R2 of 97.35%. The model can consistently generalize outside of the training dataset, as evidenced by this high value, which shows great prediction ability.

4.3.4.6. Information criteria (AICc and BIC)

Table 4.4 indicates that the model yielded comparatively low values for the Bayesian Information Criterion (BIC = 11.65) and the Corrected Akaike Information Criterion (AICc = 52.47). Lower AICc and BIC values show a better mix of model fit and simplicity. These results indicate that the

chosen model is efficient, eliminates excessive complexity, and yields a statistically optimal solution.

4.3.5. Interaction plot for yield percentage vs temperature

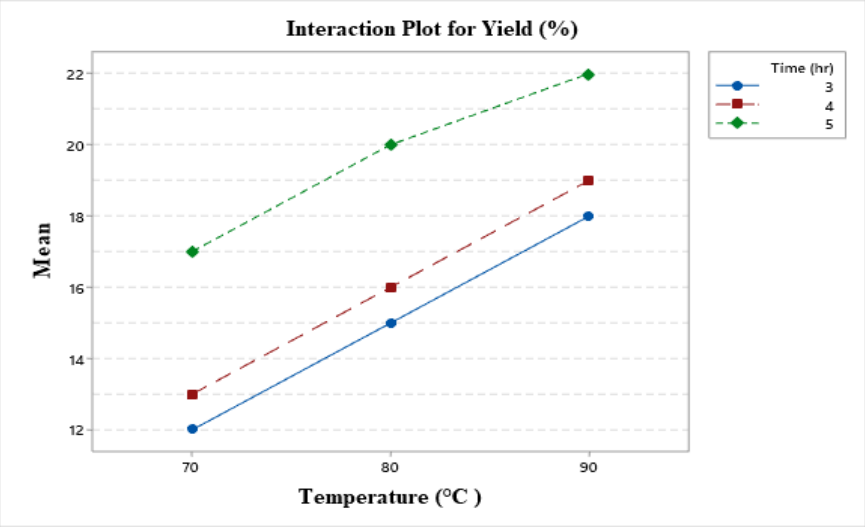


Figure 4. 3 Interaction plot for yield percentage vs temperature

Figure 4.3 shows the interaction plot for yield % as a function of temperature and extraction time, demonstrating how the combined effect of temperature and time effects dye extraction efficiency from delonix regia flower. The plot shows three independent lines for extraction durations of 3, 4, and 5 hours, as well as the average yield (%) obtained at each temperature level (70°C, 80°C, and 90°C).

Temperature has a significant beneficial impact on extraction efficiency; at 70°C, yields are the lowest time levels, while extraction yields are consistently highest at 90°C. This implies that higher temperatures increase the solubility of dye chemicals and encourage quicker diffusion from the plant matrix into solvent. Furthermore, the slopes of the three lines show that longer extraction times provide better yields at all temperature levels. At 90°C, for example, the yield gradually rises from 18% (3 hours) to 19% (4 hours) and then to 22% (5 hours). This means that extended contact between the solvent and plant material aids in the mass transfer of dye molecules.

The yield is increased by both parameters separately, and the temperature-related enhancement is comparable at different extraction times. Practically speaking, the interaction plot shows that the maximum dye production was obtained at the highest tested settings, which are 90°C and 5 hours.

This informs process optimization and encourages the choice of higher operational settings to maximize extraction efficiency.

4.3.6. Response optimization of yield percentage

Table 4. 5 Parameters of optimization for yield percentage

Response	Goal	Lower	Target	Upper	Weight	Importance
Yield (%)	Maximum	12	22		1	1

The optimal processing conditions that maximize the natural dye extraction yield were identified using the optimization parameters shown in table 4.5. Together, the optimization parameters show that the extraction procedure seeks to maximize dye yield within the experimental temperature and time constraints.

4.3.6.1. Response and goal setting

Based on the table 4.5 indicated that the yield percentage (%) was the response chosen for optimization. The chosen optimization aim was "Maximum," since the main goal of the extraction procedure is to remove as much dye as possible from the raw material.

4.3.6.2. Lower and target limits

Based on table 4.5 the lowest yield attained throughout the experimental trials, a lower bound of 12% was set. The yield values below this bottom limit are deemed to be operationally undesirable. The desired or anticipated yield under enhanced or optimized extraction circumstances was represented by the goal value, which was set at 22%. Since the model itself calculates the achievable maximum yield based on the regression equation and design space, the "Upper" number was purposefully left blank. The goal is to maximize.

4.3.6.3. Weight assignment

The response was given a weight of 1, as table 4.5 indicating meaning that every deviation from the goal is handled consistently. This indicates that the optimizer attempts to maximize yield in a balanced way under all possible circumstances rather than placing extra attention on small or large deviations. Since yield is the only response in this optimization, a weight of 1 is suitable and sufficient; a greater weight would make the optimizer more sensitive to departures from the target.

4.3.6.4. Importance level

Additionally, table 4.5 show that the relevance level was set to 1, indicating that the optimization process gives yield percentage standard priority. Higher importance values in multi-response optimization signify that a particular response is more crucial than others. Setting significance to 1 guarantees that the optimizer concentrates just on maximizing yield without imposing needless ranking or bias because there was only one primary response in this study.

4.3.7. Response optimization of yield

Table 4. 6 Solution response optimization of yield

Solution	Temperature(°C)	Time(hr)	Yeild(%) Fit	Composite desirability
1	90	5	22.4444	1

The optimized solution produced by the Minitab Response Optimizer to maximize the dye extraction yield is shown in table 4.6. The algorithm assesses every possible combination of temperature and extraction time within the experimental design space based on the previously established optimization criteria (Goal = Maximum; Lower = 12%; Target = 22%; Weight = 1; Importance = 1). It then determines the ideal factor settings that yield the highest predicted yield.

4.3.7.1. Optimized factor settings

In table 4.6 indicated that Optimized factors were defined as temperature 90°C and time 5hr. While longer extraction times enable adequate contact between solvent and biomass, higher temperatures increase molecular mobility and disturb plant cell structures.

4.3.7.2. Predicted yield at optimum condition

Under table 4.6 shows that these ideal conditions, the anticipated yield is 22.444%. This value shows that the system successfully hit the intended performance barrier because it is extremely near to the target yield (22%) specified in the optimization parameters. The estimated yield is the expected average output of the extraction procedure when carried out under the prescribed circumstances.

4.3.7.3. Composite desirability

Based on table 4.6 indicated that the value of composite desirability was 1. A flawless solution in relation to the specified optimization goals is indicated by a desirability rating of 1. A desirability

of 1 indicates that the optimal factor combination is statistically ideal for maximizing yield since values closer to 1 in multi-response optimization indicate highly satisfactory outcomes.

4.3.7.4. Interpretation and implication

The optimization results based on table 4.6 show that temperature and extraction time have a significant impact on the extraction process, with maximum yield attained at the highest tested levels of each factor. This indicates that the extraction kinetics are still increasing at 90°C and 5 hours, suggesting that further increases beyond the experimental range could result in further improvements. However, it is also necessary to assess practical factors like energy consumption, thermal degradation, or equipment limitations.

4.3.8. Multiple response prediction of yield percentage

Regression Equation in Un coded Units

Yield (%)=-15.11 + 0.2833 Temperature (°C) + 2.333 Time (hr)…….Eq(2)

Table 4. 7 Multiple response prediction of yield percentage

Variable	Setting			
Temperature (°C)	90			
Time (hr)	5			
Prediction	Fit	SE Fit	95% CI	95%PI
Yield	22.0556	0.548098	(20.7144, 23.3967)	(19.6378, 24.4733)

In order to estimate the dye yield based on table 4.7 shows that the ideal extraction conditions of 90°C temperature e and 5hours extraction time, multiple response prediction was used. The fitted yield value of 22.06% produced by the prediction model represents the anticipated extraction efficiency under these given circumstances. The corresponding standard error of the fit (SE Fit = 0.5481) indicates low estimation uncertainty and strong model stability.

The range in which the true mean yield is anticipated to fall, assuming repeated trials under identical conditions, is shown by the 95% Confidence Interval (20.71%, 23.40%). A broader range is provided by the 95% Prediction Interval (19.64%, 24.47%), which takes into consideration the inherent variability of upcoming individual observations. The model provides accurate and dependable predictions, as demonstrated by the narrow intervals. Overall, the findings indicate

that 90°C and 5 hours are excellent extraction parameters for optimizing dye yield, and there is substantial statistical evidence to support the projected value's resilience.

4.4. Characterization of the extracted dye

Coloring compounds of the gulmohar flower were characterized using FTIR Spectrometry and UV-Vis Spectrophotometry. FTIR Spectrometry was used to characterize cotton fabric dyed with gulmohar flower and neem leaf as a bio-mordant, as well as cotton fabric dyed with gulmohar flower dye mordanted with copper (II) sulphate.

4.4.1. FT-IR analysis on extracted gulmohar flower dye test results

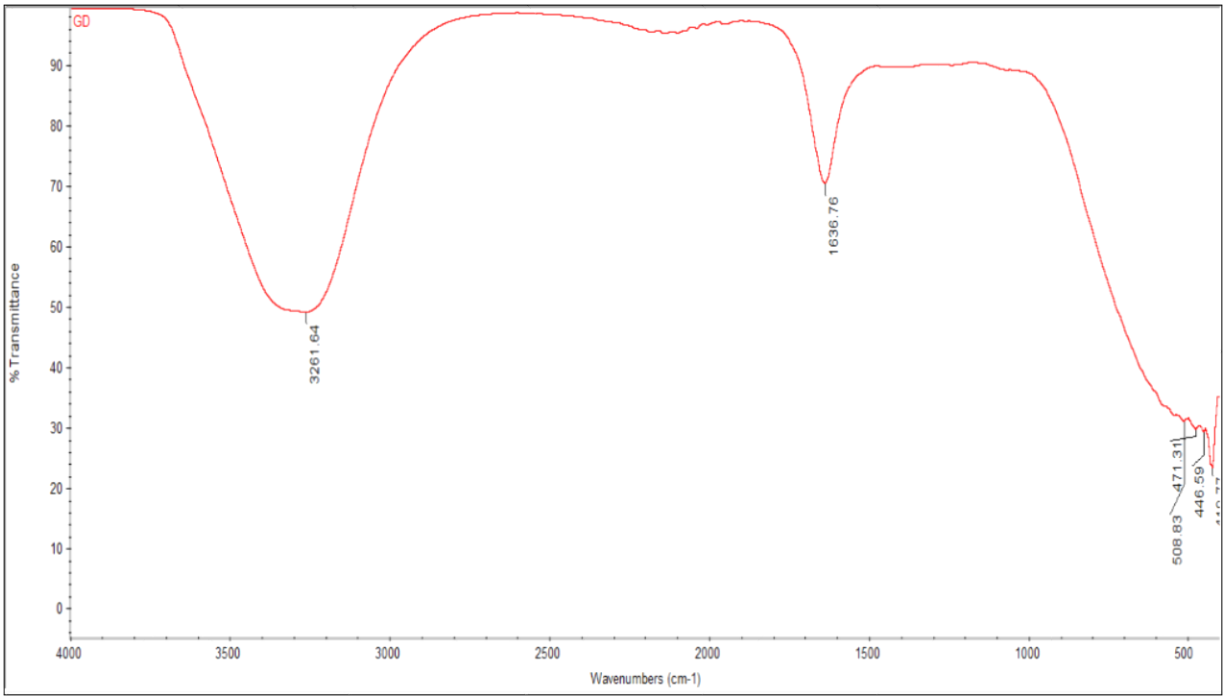


Figure 4. 4 FT-IR analysis on extracted dye test results

The letter GD appeared on FT-IR graph represent gulmohar dye. The numbers on the FT-IR graph indicated: X-axis numbers for wave numbers(cm^{-1}), Y-axis for transmittance of IR light and number near peaks exact peak position used identify functional group. The several characteristics absorption bands showed on the above graph which help to identify the major functional groups present in the gulmohar dye. Based on the visible peak indicated that broad peak, deep band near 3280-3300cm^{-1} indicate presence of hydroxyl(-OH) group. It consisted flavonoids, phenolic compounds and plant based polyphenols.

This confirm that extracted dye contain polyphenolic natural pigments. Medium band around 1630-1650cm^{-1} assigned to (C=O) stretching or carbonyl group. This peak was typical natural dye such as flavonoid, anthocyanin and chaconnes. Band near 1400-1500cm^{-1} assigned to aromatic C=C peaks in this region indicted aromatic ring structure and benzene like rings. Peak near to 1100-1200cm^{-1}assigned to C-O-C linkage, phenolic esters and flavonoid glycosides. Small peak 800-900cm^{-1} indicated to aromatic C-H bending. This confirms the presence of substituted aromatic rings. These functional groups support the suitability extract for textile dyeing due to its chromophores' groups and ability to bind with natural fibers.

4.4.1.1. Olefin Functional Groups of extracted dye

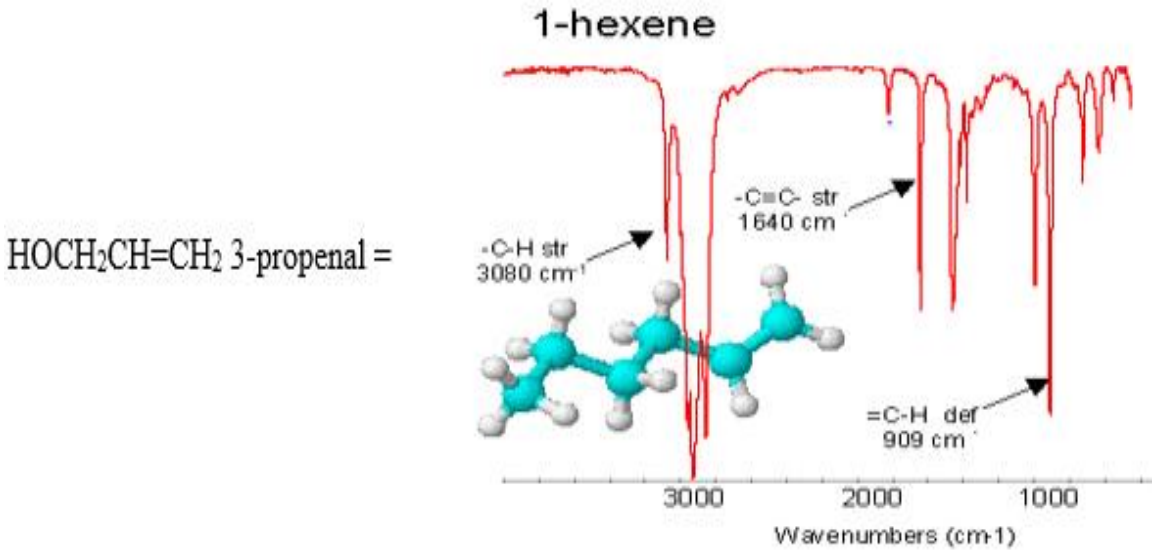


Figure 4. 5 Olefin functional groups for 1-hexene

The FT-IR spectra of the gulmohar dye reveals characteristic absorption bands demonstrating the presence of olefin (alkene) functional groups. Unsaturation within the molecule is shown by the peak at around 3080 cm^{-1}, which is the C–H stretching vibration of the vinyl (=C–H) group. The presence of an olefin double bond is further confirmed by a significant absorption around 1640 cm^{-1}, which represents the C=C stretching of the alkene functional group. Furthermore, the =C–H out-of-plane deformation, which is characteristic of terminal alkenes, is responsible for the band at 909 cm^{-1}.

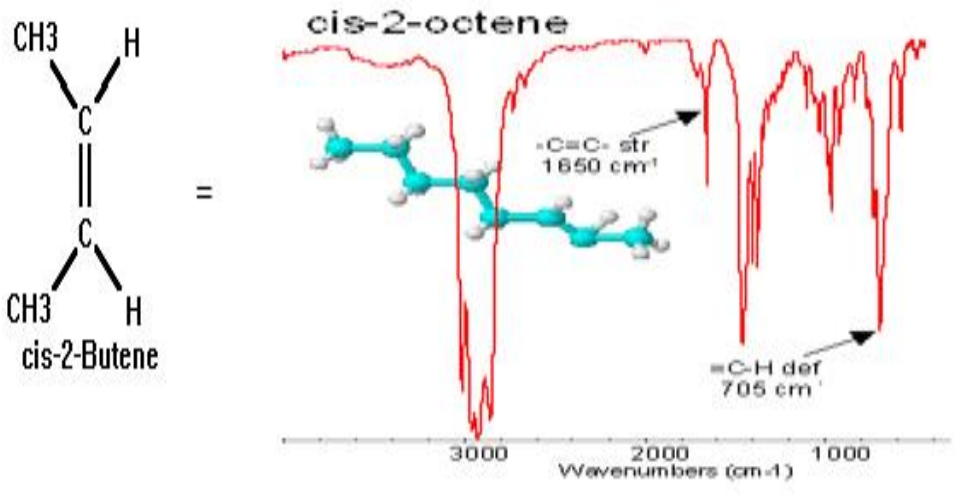


Figure 4. 6 Olefin functional groups for Cis-2-octene

The FT-IR spectrum of cis-2-octene shows unique absorption bands, which confirms the presence of olefinic (alkene) functional groups. The C=C stretching vibration, which is typical of internal alkenes like cis-2-octene, is represented by the absorption peak at about 1650 cm^{-1}. Furthermore, the out-of-plane distortion of =C–H, a common sign of cis-substituted double bonds, is represented by the band around 705 cm^{-1}. When combined, these characteristics confirm the cis-configuration of the C=C bond and the existence of an internal olefin group.

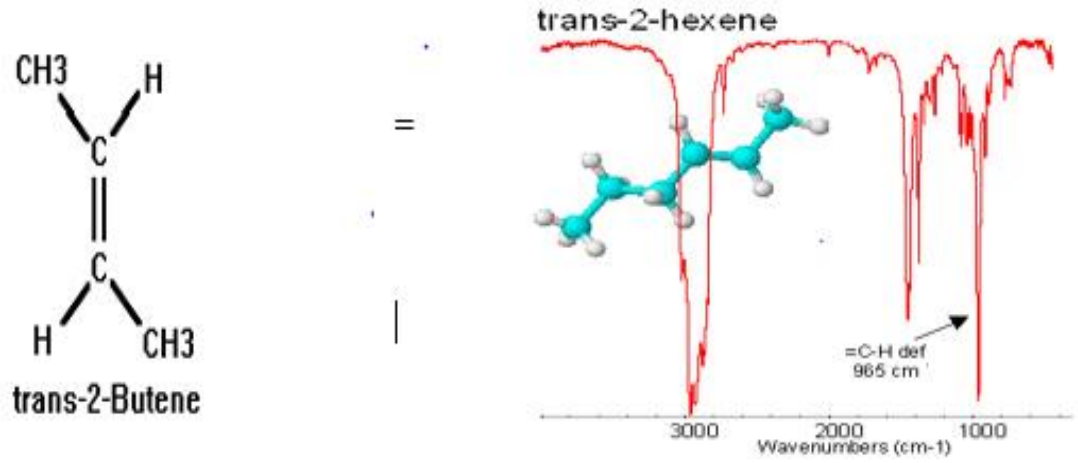


Figure 4. 7 Olefin functional groups for transe-2-hexene

Trans-2-hexene's FT-IR spectra shows distinctive peaks that verify the existence of olefinic (C=C) functional groups. Trans-substituted alkenes can be identified by their out-of-plane =C–H deformation, which is represented by the strong absorption band around 965 cm^{-1}. Trans-isomers

are easily distinguished from their cis counterparts by this peak. The presence of an interior double bond is supported by additional signals related to C=C stretching that usually show up in the area between 1640 and 1680 cm^{-1}. Overall, the spectrum characteristics support trans-2-hexene's olefinic structure.

4.4.1.2. Aliphatic ether compounds of extracted dye

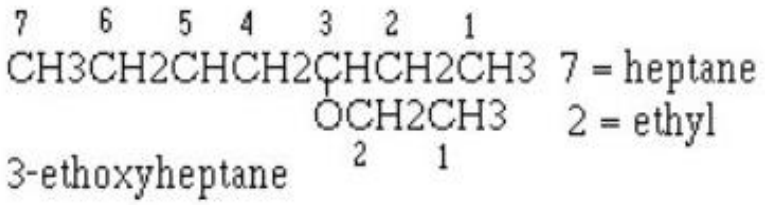


Figure 4. 8 Aliphatic ether compounds

The presence of an aliphatic ether (R–O–R') functional group is confirmed by the FT-IR properties of 3-ethoxyheptane. Aliphatic ethers often show a significant C–O–C stretching vibration in the area of 1050–1150 cm^{-1}, which is the key diagnostic band for ether bonds. There is no broad absorption about 3200–3600 cm^{-1} because ethers lack O–H groups, which supports the lack of alcohol functionality. The remaining peaks are aliphatic C-H stretching about 2850-2960 cm^{-1}, corresponding with the lengthy hydrocarbon chains of the heptane and ethyl groups. Overall, the spectrum characteristics unmistakably show that 3-ethoxyheptane, an aliphatic ether functional group, is present.

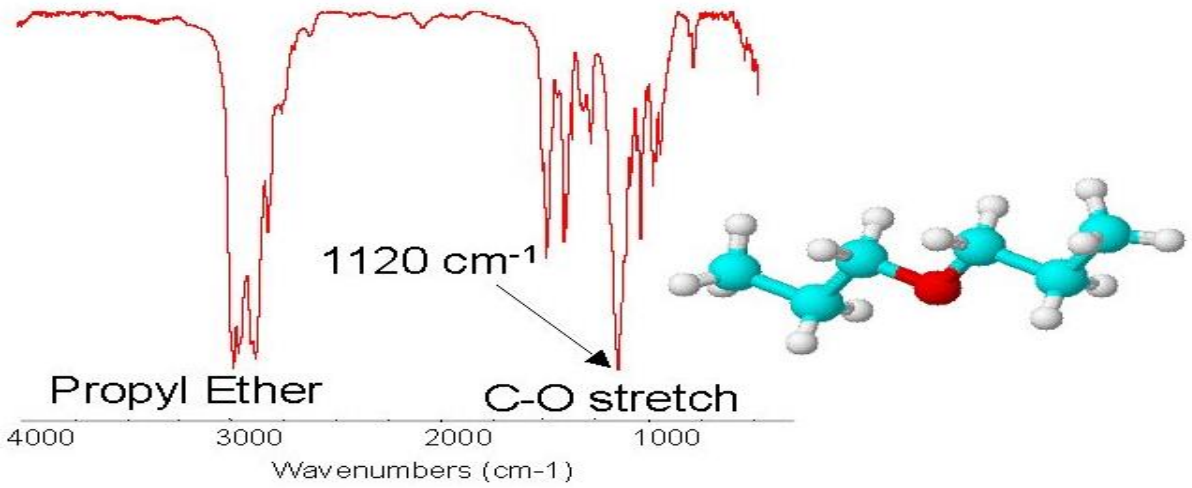


Figure 4. 9 Spectral interpretation of propyl ether

The FT-IR spectra of propyl ether shows a strong absorption band at 1120 cm^{-1}, which corresponds to the C-O-C stretching vibration and verifies the presence of an ether functional group. Additionally, the spectra display distinctive aliphatic C–H stretching bands in the 2850–2960 cm^{-1} range, which are consistent with propyl alkyl chains. The absence of a significant O-H stretching band at 3200-3600 cm^{-1} suggests the chemical is an ether rather than an alcohol. Overall, the reported spectrum characteristics support propyl ether's aliphatic ether structure.

4.4.1.3. Aliphatic groups

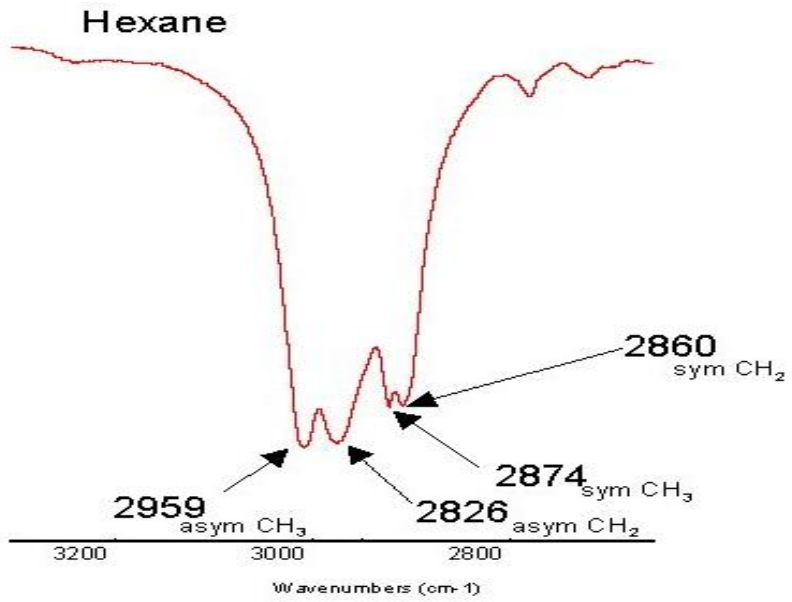


Figure 4. 10 Aliphatic functional groups

Hexane's FT-IR spectra shows distinctive absorption bands that attest to the existence of aliphatic (alkane) functional groups. Strong peaks at 2959 cm^{-1} and 2874 cm^{-1} indicate asymmetric stretching vibrations of CH_3, while bands at 2926 cm^{-1} and 2860 cm^{-1} indicate asymmetric and symmetric stretching of CH_2 groups, respectively. A saturated hydrocarbon structure is further shown by the lack of absorption in areas linked to heteroatoms or unsaturation. Together, these spectrum characteristics confirm that hexane is an aliphatic alkane.

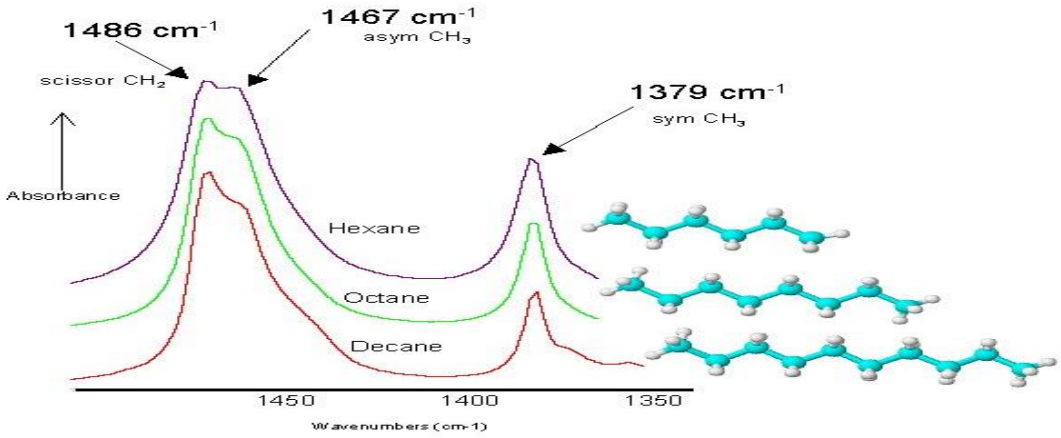


Figure 4. 11 CH_3 deformation absorptions

The presence of alkyl methyl groups is confirmed by the distinctive CH_3 deformation (bending) absorption regions in the FT-IR spectra. The absorption between 1467-1466 cm^{-1} is ascribed to the asymmetric bending vibration of CH_3. The band at roughly 1379 cm^{-1} corresponds to the symmetric bending (umbrella) vibration of CH_3 groups. The changes in chain length and methyl group environment are reflected in the differential in band intensity between hexane, octane, and decane. The diagnostic deformation absorptions of aliphatic hydrocarbons give reliable evidence for the existence of CH_3 functional groups.

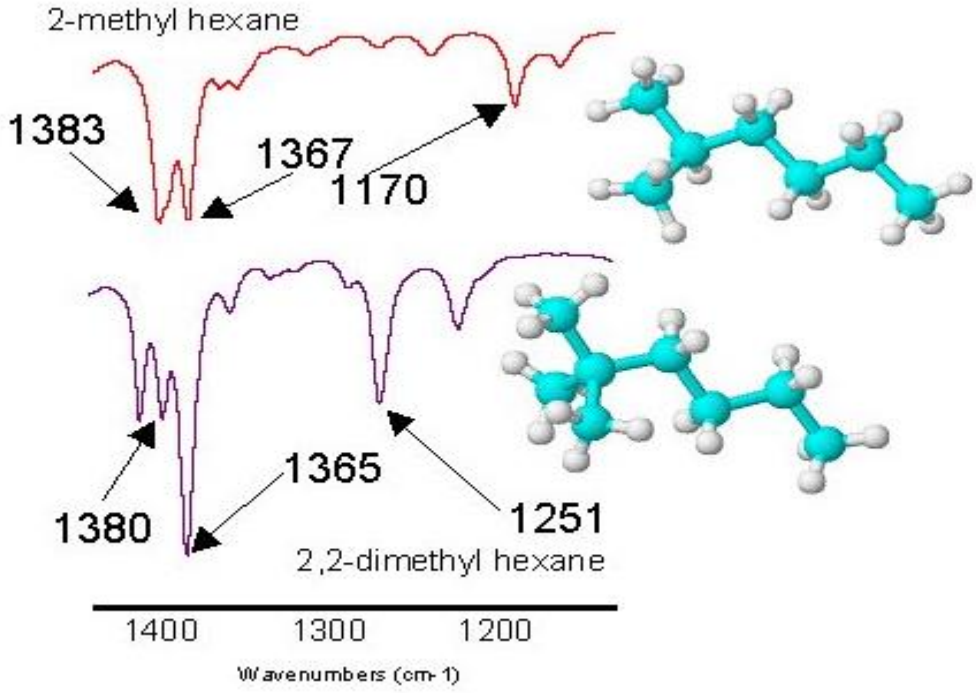


Figure 4. 12 Deformation absorption band splitting

The FT-IR spectra clearly reveal deformation absorption band splitting caused by alkyl group bending vibrations in branched aliphatic hydrocarbons. The presence of a methyl-substituted alkane is indicated by the bands seen in 2-methylhexane between 1383 cm^{-1} and 1367 cm^{-1}, which correspond to the symmetric and asymmetric bending (deformation) vibrations of CH_3 groups. In contrast, 2,2-dimethylhexane exhibits stronger splitting with deformation bands at 1380 cm^{-1}, 1365 cm^{-1}, and 1251 cm^{-1}, indicating greater molecular symmetry and branching.

Alkane branching, in which various methyl environments result in numerous bending vibrations, is characterised by this separation of deformation bands. Thus, the FT-IR results demonstrate that deformation band splitting can be employed to differentiate structural isomers of aliphatic hydrocarbons.

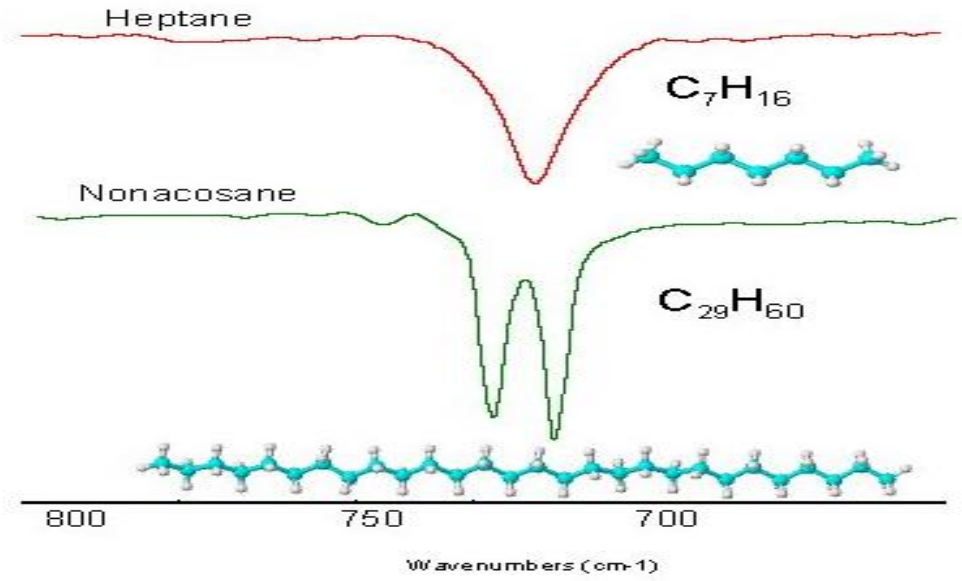


Figure 4. 13 -$(CH_2)_n$ -rocking absorption

In the range of roughly 720–730 cm^{-1}, the FT-IR spectra exhibit a distinctive –$(CH_2)_n$–rocking absorption band that is indicative of long, linear aliphatic hydrocarbon chains. Nonacosane ($C_{29}H_{60}$) has a strong and well-defined band due to longer methylene unit sequences, while heptane (C_7H_{16}) has a weaker band due to the shorter chain length. The presence and relative length of saturated aliphatic chains are confirmed by this rocking vibration, which is caused by the collective motion of nearby –CH_2– groups.

4.4.1.4. Alcohol functional groups

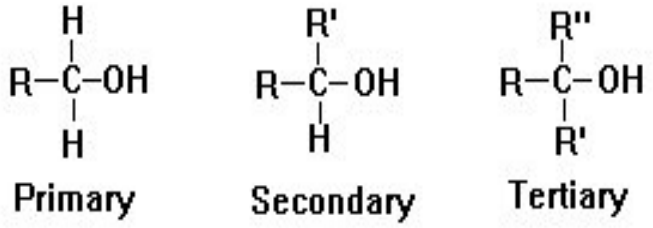


Figure 4. 14 Alcohol chemical properties

The FT-IR spectra of alcohols displays unique absorption bands that represent their chemical composition as primary, secondary, or tertiary alcohols. The O–H stretching vibration is responsible for a broad and intense absorption in the 3200–3600 cm^{-1} range, which indicates the hydrogen bonding characteristic of alcohols. The C-O stretching vibration in the 1000-1260 cm^{-1} range varies in position and strength depending on whether the alcohol is primary, secondary, or tertiary, due to differences in molecular structure and substitution. Together, these spectral characteristics verify the existence and categorization of alcohol functional groupings.

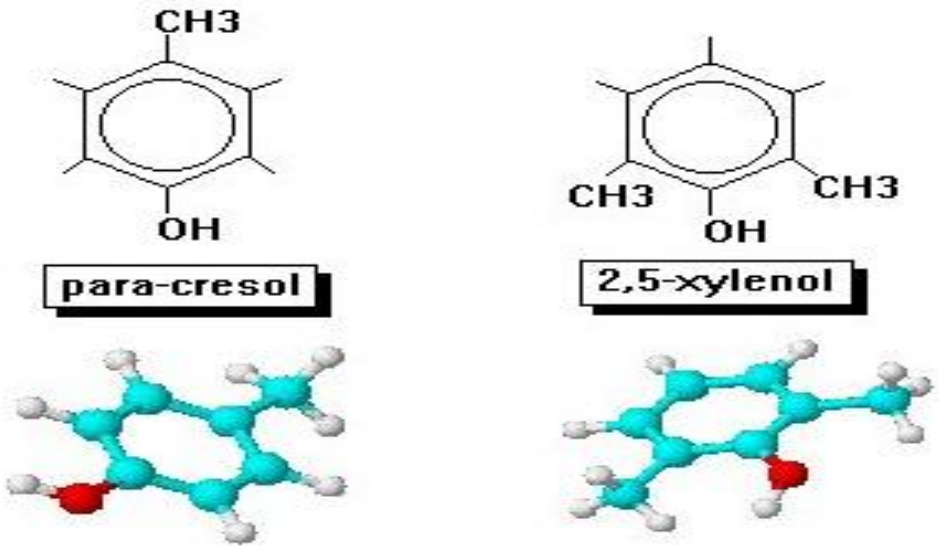


Figure 4. 15 Phenol Chemical Properties

Phenolic substances like p-cresol and 2,5-xylenol have distinctive absorption bands in their FT-IR spectra that validate their phenol functional groups. The broad band at 3200-3600 cm^{-1} corresponds to the O-H stretching vibration of the phenolic group, which is often expanded due to hydrogen bonding. The presence of a benzene ring is indicated by aromatic C=C stretching vibrations at 1500-1600 cm^{-1}, while the phenolic group's C-O stretching vibration is found at 1200-

1260 cm^{-1}. Together, these spectral characteristics confirm the phenolic structure and related chemical characteristics.

4.5. Cotton fabric mordanting

Pre--mordanting process was promoted to facilitate the dye uptake and fastness properties of cotton fabric samples were treated with neem leaf bio-mordant and copper(II)sulfate respectively based on all Key input to perform dyeing process that mentioned on methodology part and followed by dyeing process carried out with extracted flower of gulmohar dye. For the sake of comparison expected cotton fabric dyed with flower of gulmohar dye along with neem leaf as a bio-mordant had a greater color strength than Copper(II) sulfate mordanted one.

4.6. Dyeing process with extracted dye from flower of gulmohar tree

After extraction of the dye performed and then dyeing process had carried out. The dyeing parameters such as dye concentration, dyeing temperature and dyeing time while the PH were alkali media and material to liquor ratio was constant 1:30. Cotton fabric were dyed by natural dyeing method using 5%, 10% and 15% (o.w.f) shade at 55°C, 70°C and 85°C dyeing temperature with a dyeing time of 40 min, 55min and 70min to study the effect of temperature, concentration and time on the performance characteristics of dyed fabric. After completion of dyeing, the samples were rinsed with cold water followed by soaping using 3 gm/L non-ionic soap at 55°C for 10 minutes. Then finally cold rinsing and drying using air dry was carried out.

4.7. Result of color strength in computer color matching instruments

The transferred color on to **cotton** fabric is measured and mentioned by color strength, also known as k/s value. In this study, the color strength (K/S) result of dyed cotton fabric samples with the flower of gulmohar`s flower and mordanted with neem leaf as bio-mordant and Copper (II) sulfate were measured using UV–Vis Reflectance Spectrophotometer. The summarized results obtained from lab test are mentioned in Table 4.8, which also includes color indices (L*, a*, b*) for each dyeing condition.

Table 4. 8 Summary table for color strength and color indices test result

Sample code	Temperature(℃)	Time in(min)	Concentration (%)	Type of Mordant	K/S	Color indices		
						L*	a*	b*
	55	40	5	Neem	2.34	75.78	4.42	6.98
				Cu_2SO_4	2.17	74.83	3.87	6.89
			10	Neem	3.23	74.74	4.44	6.86
				Cu_2SO_4	3.22	74.42	3.76	5.89
			15	Neem	4.38	74.76	4.65	6.36
				Cu_2SO_4	3.21	74.19	4.23	5.89
		55	5	Neem	3.34	74.89	4.89	5.99
				Cu_2SO_4	3.12	73.97	3.98	5.97
			10	Neem	6.01	68.77	4.18	4.87
				Cu_2SO_4	5.71	67.79	3.96	4.98
			15	Neem	6.17	66.72	3.78	4.79
				Cu_2SO_4	6.04	65.89	3.79	3.97
		70	5	Neem	4.09	64.98	2.89	3.99
				Cu_2SO_4	3.93	63.75	2.51	3.81
			10	Neem	7.54	65,96	2.75	3.79
				Cu_2SO_4	7.13	64.97	2.97	3.98
			15	Neem	8.21	62.98	2.87	4.47
				Cu_2SO_4	8.12	63.9	2.95	3.98
	70	40	5	Neem	3.05	74.78	4.22	6.88
				Cu_2SO_4	2.47	74.73	3.82	6.79
			10	Neem	3.28	74.54	4.34	6.36
				Cu_2SO_4	3.64	74.42	3.76	5.95
			15	Neem	4.78	74.26	4.45	6.36
				Cu_2SO_4	3.23	73.99	4.13	5.87
		55	5	Neem	3.75	74.19	4.87	5.99
				Cu_2SO_4	3.42	73.87	3.88	5.57
			10	Neem	6.06	68.67	4.16	4.77
				Cu_2SO_4	5.81	67.75	3.92	4.98
			15	Neem	6.47	66.52	3.68	4.79
				Cu_2SO_4	6.05	65.19	3.71	3.87
		70	5	Neem	4.19	64.78	2.87	3.98
				Cu_2SO_4	3.93	63.05	2.41	3.81
			10	Neem	8.24	65.86	2.35	3.72
				Cu_2SO_4	7.16	64.91	2.27	3.38
			15	Neem	9.01	62.94	2.76	4.32
				Cu_2SO_4	8.13	63.9	2.05	3.97
			5	Neem	3.5	74.68	4.12	6.78

	85	40		Cu_2SO_4	3.06	74.83	3.92	6.89
			10	Neem	4.28	74.44	4.14	6.16
				Cu_2SO_4	3.14	74.62	3.96	5.85
			15	Neem	5.18	74.26	4.45	6.36
				Cu_2SO_4	4.73	73.96	4.12	5.83
		55	5	Neem	4.75	74.69	4.77	5.98
				Cu_2SO_4	4.42	73.85	3.85	5.07
			10	Neem	7.06	68.47	4.06	4.57
				Cu_2SO_4	6.81	67.4	3.82	4.98
			15	Neem	8.4	66.32	3.67	4.78
				Cu_2SO_4	7.25	65.18	3.51	3.67
		70	5	Neem	7.89	64.71	2.57	3.98
				Cu_2SO_4	7.13	63.05	2.41	3.82
			10	Neem	9.24	65.26	2.36	3.52
				Cu_2SO_4	9.06	64.31	2.17	3.36
			15	Neem	10	62.84	2.56	4.02
				Cu_2SO_4	9.5	63.9	2.03	3.94

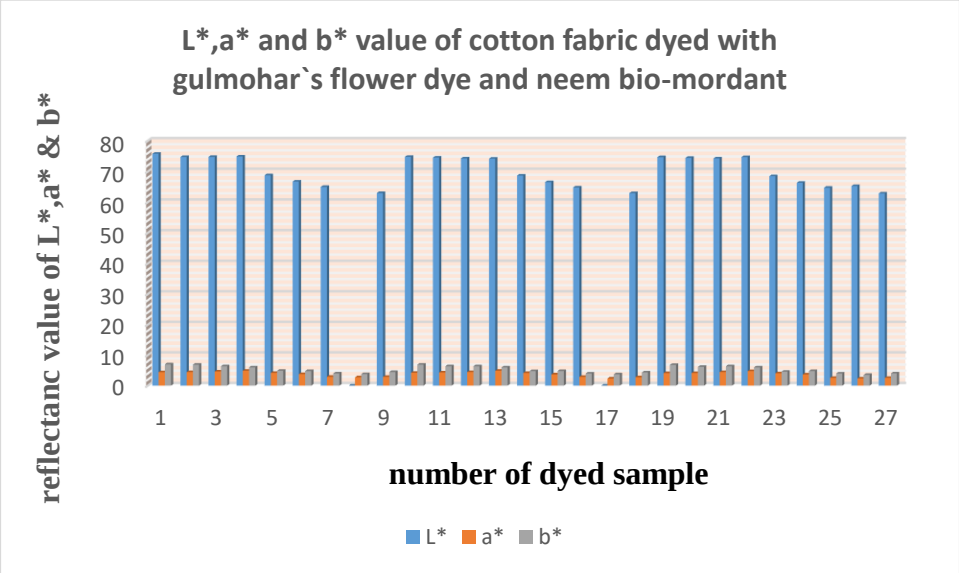


Figure 4. 16 *L, a*&*b value graph with neem mordant

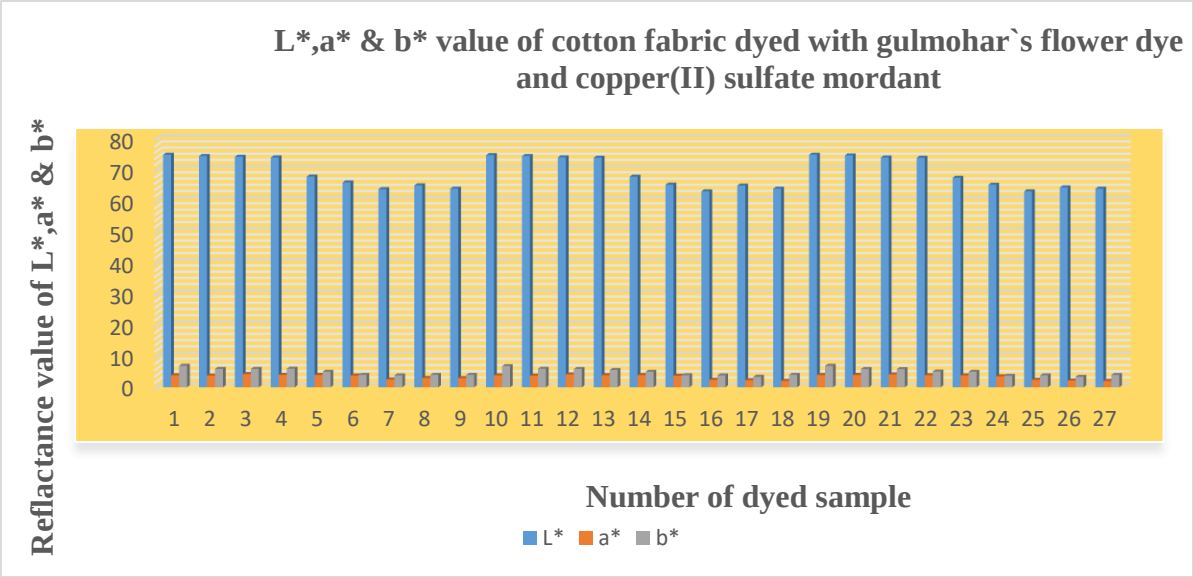


Figure 4. 17 *L, a*&*b value graph with copper(II) sulfate mordant

4.7.1. Effect of dyeing parameters on color strength value

Table 4.8 summarized the data by comparing the color strength and color index values of cotton fabric dyed with gulmohar's flower dye and cotton fabric mordanted with copper (II) sulfate and neem as a bio-mordant. Compared to copper(II) sulfate mordanted cloth, the bio-mordanted fabric offers the highest color strength. The impact of dyeing parameters on the color strength of dyed fabric is examined in detail below.

In table 4.8 indicated that the color strength (K/S) values of cotton fabrics dyed with different gulmohar flower extracted concentrations. The study investigates the effects of dye concentration, dyeing temperature, and dyeing duration on the dyeing process using two distinct mordants which are neem as a bio-mordant and copper (II) sulfate.

The table value listed below are taken from the summary table 4.8 of color strength and color indices test result obtain with lab test.

4.7.1.1. Effects of dye temperature on color strength value

Table 4. 9 Color strength of cotton fabric dyed with temperature

Sample dyed with neem bio-mordant	Sample dyed with Cu_2SO4

K/S(λmax)	Temperature(^{0}C)	K/S(λmax)	Temperature(^{0}C)
8.21	55	8.12	55
9.01	70	8.13	70
10	85	9.50	85

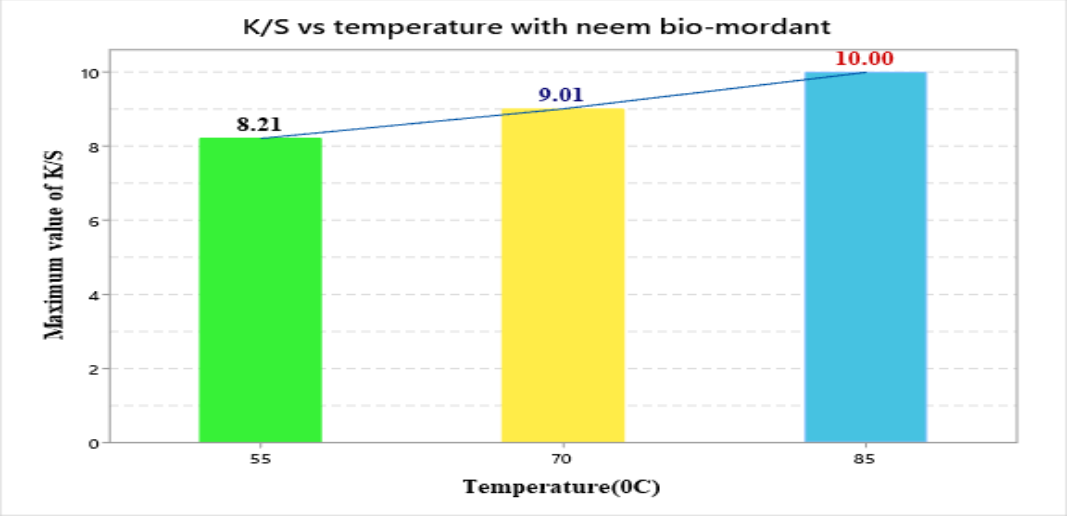


Figure 4. 18 Color strength(k/s) vs temperature(^{0}C) sample dyed with neem bio-mordant

According to the figure 4.18, the color strength (K/S) of the cotton fabric dyed by gulmohar`s flower dye with neem bio-mordant increases gradually with dyeing temperature. A moderate dye absorption is indicated by a K/S value of 8.21 at 55 °C. The K/S increases to 9.01 at 70 °C, indicating improved dye diffusion and a more robust interaction between the dye, bio-mordant, and fiber. At 85 °C, the maximum color strength of 10.00 is reached, indicating that higher temperatures greatly enhance dye absorption and fixation.

Deeper penetration of the dye-mordant complex into the fabric structure is made possible by increased molecular mobility of dye molecules and fiber swelling at high temperatures. Therefore, when employing neem as a bio-mordant, 85 °C is found to be the ideal temperature for obtaining maximal color strength within the examined range.

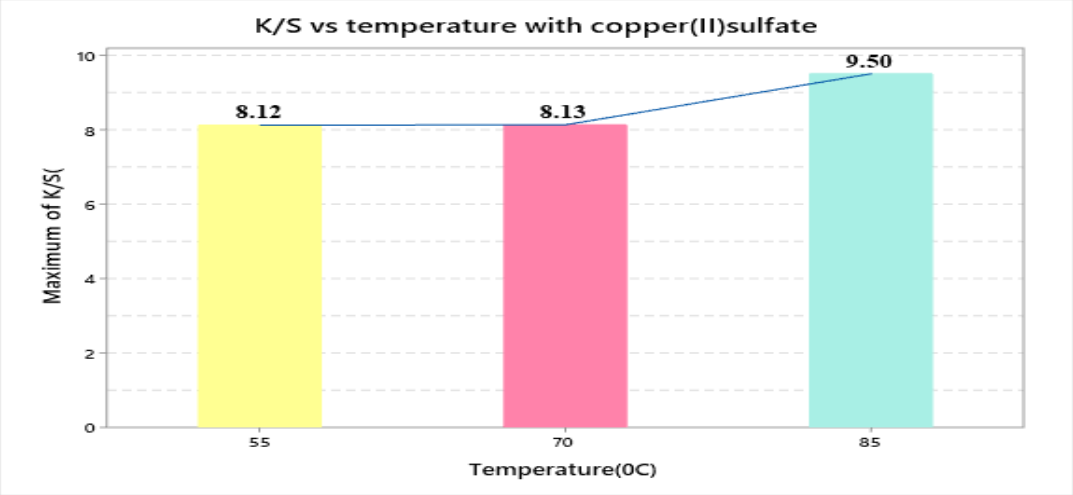


Figure 4. 19 Color strength(k/s) vs temperature sample dyed with copper(II) sulfate

As shown in the figure, the color strength (K/S) of cotton fabric colored with Gulmohar dye in the presence of copper(II) sulfate mordant gradually increases as the dyeing temperature rises. The first dye uptake under relatively mild temperature conditions is indicated by the K/S value of 8.12 at 55 °C. At 70 °C, there is a slight rise to 8.13, indicating that moderate temperatures only slightly improve dye–fiber interaction. However, the maximum K/S value of 9.50 is reached at 85 °C, where there is a noticeable rise in color strength.

This behavior is explained by greater cooperation between the metal mordant, dye molecules, and cellulose at higher temperatures, enhanced dye diffusion, and increased fiber swelling. As a result, when copper(II) sulfate is employed as a mordant, 85 °C is found to be the ideal temperature within the studied range for obtaining the maximum color strength of Gulmohar dye on cotton cloth.

4.7.1.2. Effects of dye time on color strength value

Table 4. 10 Color strength of cotton fabric dyed with time

Sample dyed with neem bio-mordant		Sample dyed with Cu_2SO4	
K/S(λmax)	Time (min)	K/S(λmax)	Time (min)
5.18	40	4.73	40
8.4	55	7.25	55
10	70	9.5	70

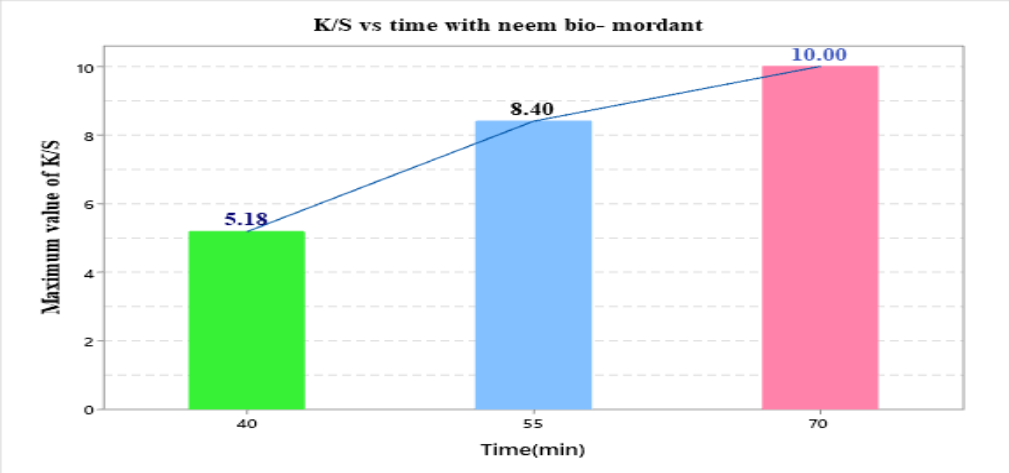


Figure 4. 20 Color strength(k/s) vs time sample dyed with neem bio-mordant

The color strength (K/S) of cotton fabric colored with Gulmohar dye in the presence of neem bio-mordant is shown in the figure as a function of dying time. The K/S value is comparatively low (5.18) at a shorter dying time of 40 minutes, suggesting restricted dye transport and fixing on the fiber surface. The color strength increases dramatically to 8.40 when the dying duration is extended to 55 minutes, indicating improved interaction between the dye–mordant complex and the cellulose matrix. The maximum K/S ratio of 10.00 is reached after 70 minutes, indicating that longer dyeing times encourage better fixing and increased dye uptake.

This rising trend demonstrates that longer dying times provide enough time for the natural dye to diffuse and bond when neem bio-mordant is present. Therefore, 70 minutes is thought to be the ideal dyeing time within the researched range for achieving the highest color strength on cotton fabric colored with Gulmohar dye using neem bio-mordant.

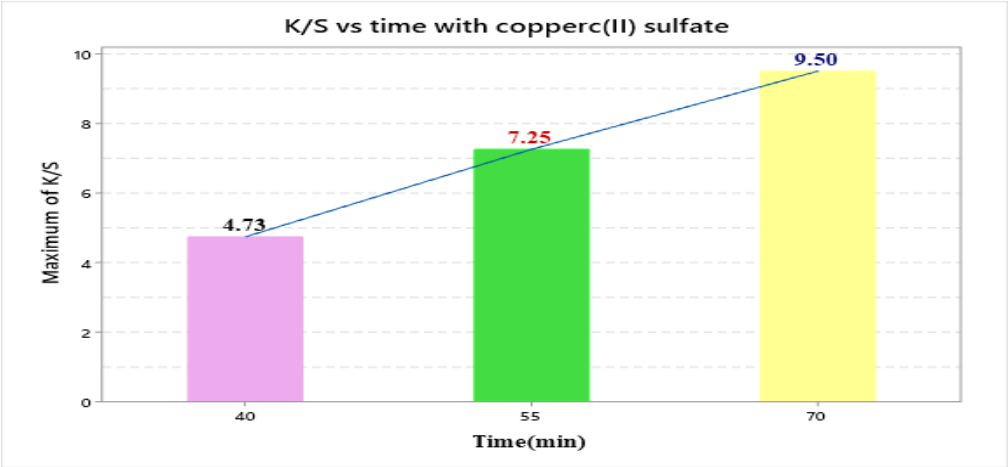


Figure 4. 21 Color strength(k/s) vs time sample dyed with Cu_2SO_4 mordant

As the figure 4.21 indicated that the effect of dying time on color strength (K/S) of cotton fabric treated with Gulmohar dye in the presence of a copper(II) sulfate mordant. At 40 minutes, a comparatively low K/S value of 4.73 was achieved, indicating insufficient dye diffusion and fixing at shorter dyeing times. The color strength increases significantly to 7.25 when the dying duration is extended to 55 minutes, indicating better interaction between the cotton fiber and the dye-mordant complex. Longer dyeing times improve dye uptake and fixing efficiency, as seen by the maximum K/S value of 9.50 reached at 70 minutes.

This progressive increase confirms that adequate dyeing time is essential for effective diffusion and coordination of Gulmohar dye with copper(II) sulfate mordant on cotton fabric. Hence, 70 min is identified as the optimum dyeing time for achieving maximum color strength under the studied conditions.

4.7.1.3. Effects of dye concentration on color strength value

Table 4. 11 Color strength of cotton fabric dyed with concentration

Sample dyed with neem bio-mordant		Sample dyed with Cu_2SO4	
K/S(λmax)	concentration(%)	K/S(λmax)	concentration(%)
7.89	5	7.13	5
9.24	10	9.03	10
10	15	9.50	15

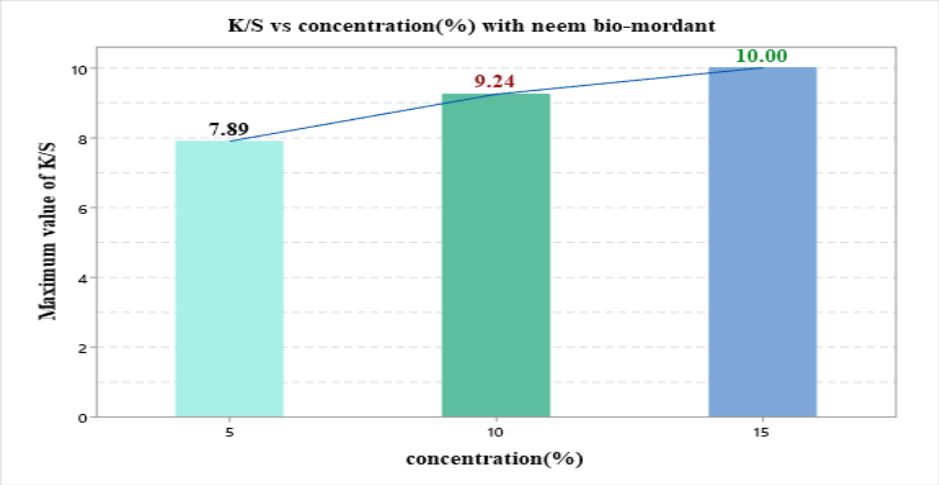


Figure 4. 22 Color strength(k/s) vs concentration (%) sample dyed with neem bio-mordant

The graph shows how the maximum color strength (K/S) of dyed cotton fabric is affected by the concentration of neem bio-mordant (%). As seen, the K/S value progressively improves with mordant concentration, indicating improved dye-fiber interaction.

At 5% concentration, the K/S value is 7.89, indicating that dye uptake is rather poor due to the restricted availability of mordant sites on the cotton fiber. Increasing the concentration to 10% results in a considerable increase in K/S to 9.24, indicating that dye molecules are better fixed due to greater coordination between the dye, mordant, and cellulose structure. The greatest K/S value of 10.00 is recorded at 15% concentration, indicating maximal color strength under the conditions investigated.

The linear increasing trend indicates a positive relationship between neem bio-mordant concentration and color strength, showing that larger mordant concentrations improve dye absorption and retention. This improvement can be ascribed to the development of more binding sites, which enhances the dye-fiber combination.

Although 15% concentration produces the maximum K/S value, concentrations over this level may not be economically or environmentally justifiable due to fiber saturation or mordant waste. As a result, 10-15% neem bio-mordant concentration is deemed ideal for achieving good color strength in cotton fabric dyeing.

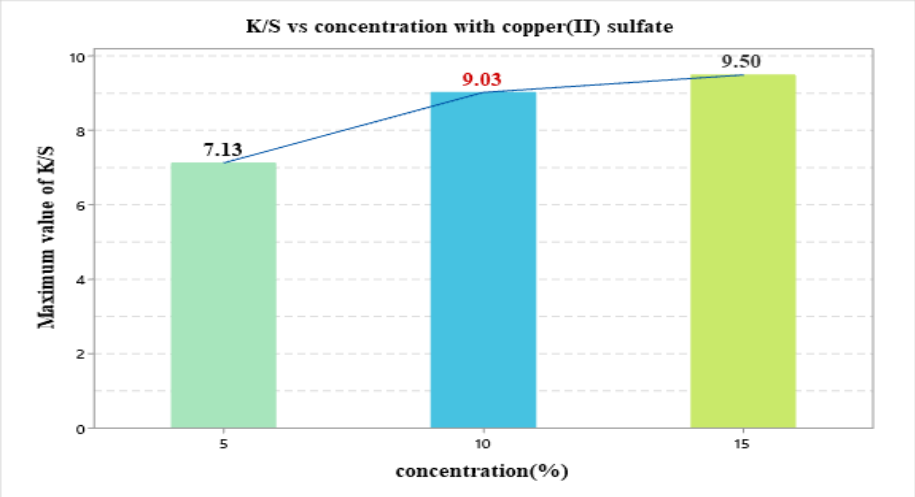


Figure 4. 23 Color strength(k/s) vs concentration (%) sample dyed with Cu_2SO_4 mordant

The figure shows how the concentration of copper(II) sulfate mordant affects the color strength (k/s) of cotton fabric colored with gulmohar dye. The k/s value clearly increases with increasing mordant concentration, indicating better dye fixing on the cotton fiber.

The k/s value is 7.13 at a mordant concentration of 5%, indicating reduced color strength as a result of inadequate mordant–dye–fiber complex formation. The k/s value dramatically increases to 9.03 when the concentration is raised to 10%, indicating improved coordination between the gulmohar dye molecules and cellulose through copper ions. The greatest color strength under the conditions under study is demonstrated by the highest k/s value of 9.50, which is obtained with an additional increase to 15%.

This gradual rise in k/s demonstrates that stronger dye–fiber interactions are encouraged by increasing copper(II) sulfate concentrations, which result in deeper shade development. The slight rise between 10% and 15%, however, indicates that near-saturation of binding sites might happen at greater doses. In order to achieve good color strength on cotton fabric colored with gulmohar dye, a concentration of 10–15% copper(II) sulfate mordant can be deemed ideal.

4.7.1.4. Effect of different mordant types on the colour strength

The colour strength of cotton fabric sample dyed with extracted gulmohar`s flower dye along to neem leaf as bio-mordant and Copper(II) sulphate mordant measured using UV–Vis Reflectance Spectrophotometer.

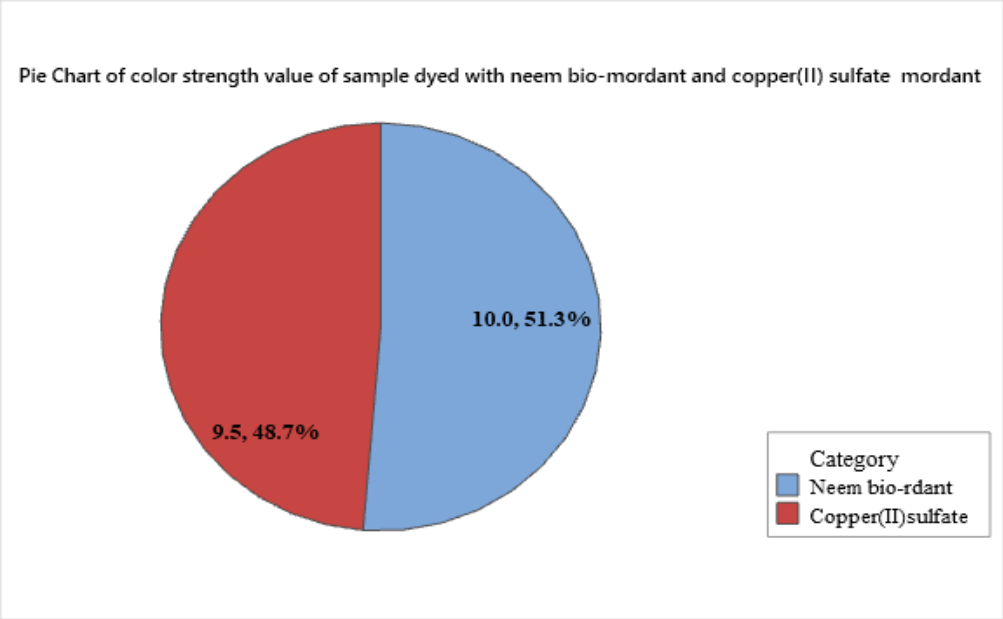


Figure 4. 24 Color strength(K/S) Vs mordant type

The pie-chart result figure 4.24 shows the relative color strength of cotton fabric treated with extracted Gulmohar dye using copper (II) sulfate as a metallic mordant and neem as a bio mordant. The results revealed significant differences in colour strength based on the mordant type. The cloth treated with neem bio-mordant contributes somewhat more to color strength, making up 51.3% (K/S = 10.0) of the total, whereas the sample mordanted with copper (II) sulfate provides 48.7% (K/S ≈ 9.5). This suggests that neem bio-mordant is slightly more effective than copper(II) sulfate at improving dye uptake and color depth on cotton fabric. The findings emphasize neem's potential as an eco-friendly bio-mordant capable of creating color strength that is equivalent or superior to traditional metallic mordants.

These findings suggest that the mordant has a major impact on the dye's color strength and affinity for the cotton fabric. In terms of compatibility and superior color development, bio-mordants like neem leaf in this study—offer advantages over metallic mordants, including copper (I3) sulfate. Understanding these impacts is critical for producing desirable color outputs in sustainable textile dyeing processes, as is evaluating the environmental impact of the mordants used.

4.7.2. Statistical analysis, modeling and validation for color strength

Statistical analysis was used to determine the impact of dyeing parameters such as temperature, time, dye concentration and mordant type on color strength (K/S). To identify important parameters and their interactions, experimental data were examined using the proper statistical tools. Regression analysis uses p-values and coefficients to show you whether correlations in your model are statistically significant and what those relationships are.

Mathematical models were created to characterize the relationship between process factors and K/S values, allowing for the prediction of color strength under various dying conditions. The F value in regression is the result of a test where the null hypothesis is that all of the regression coefficients are equal to zero. Put differently, nothing can be predicted by the model. Model adequacy and reliability were tested using goodness-of-fit metrics and error analysis, indicating that the derived models adequately capture the experimental behavior of color strength.

4.7.2.1. Regression equation for color strength sample dyed with neem bio-mordant

K/S = 5.718 - 0.684 Temperature(°C)_55 - 0.298 Temperature(°C)_70
+ 0.982 Temperature(°C)_85- 1.944 Time(min)_40+ 0.061 Time(min)_55
+ 1.883 Time(min)_70- 1.618 Concentration(%)_5+ 0.381 Concentration(%)_10
+ 1.237 Concentration(%)_15……eq(3)

4.7.2.2. Regression equation for color strength sample dyed with copper(II)sulfate

K/S = 5.244- 0.504 Temperature(°C)_55- 0.373 Temperature(°C)_70
+ 0.878 Temperature(°C)_85- 2.037 Time(min)_40+ 0.159 Time(min)_55
+ 1.878 Time(min)_70- 1.504 Concentration(%)_5+ 0.498 Concentration(%)_10
+ 1.007 Concentration(%)_15……..…eq(4)

4.7.2.3. Analysis of variance of sample dyed with neem bio-mordant

Table 4. 12 Analysis of variance of sample dyed

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Temperature(°C)	2	13.68	10.65%	13.68	6.8417	13.44	0.000
Time(min)	2	65.95	51.34%	65.95	32.9725	64.79	0.000
Concentration(%)	2	38.65	30.09%	38.65	19.3254	37.97	0.000
Error	20	10.18	7.92%	10.18	0.5089		
Total	26	128.46	100.00%				

The findings of the Analysis of Variance (ANOVA) show that the color strength (K/S) of cotton fabric dyed with neem bio-mordant is statistically significantly impacted by dyeing temperature, time, and concentration. The three factors have high F-values and p-values of 0.000 ($p < 0.05$), indicating their significance. Dyeing time is the most significant factor influencing color strength, as seen by its maximum contribution (51.34%), followed by concentration (30.09%) and temperature (10.65%). The relatively low error contribution (7.92%) implies that the model has acceptable experimental precision and reliability.

4.7.2.4. Analysis of variance sample dyed with copper(II)sulfate mordant

Table 4. 13 Analysis of variance sample dyed with copper(II)sulfate mordant

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Temperature(°C)	2	10.48	8.61%	10.48	5.2395	10.20	0.001
Time(min)	2	69.29	56.91%	69.29	34.6469	67.43	0.000
Concentration(%)	2	31.72	26.05%	31.72	15.8603	30.87	0.000
Error	20	10.28	8.44%	10.28	0.5139		
Total	26	121.77	100.00%				

The ANOVA results show that temperature, dyeing time, and concentration have a significant influence on the color strength (K/S) of cotton fabric colored using copper(II) sulfate mordant. All parameters have statistically significant p-values ($p < 0.001$), indicating a considerable effect on color development. The most significant contributor to the change in K/S among the factors examined is dyeing time (56.91%), which is followed by concentration (26.05%) and temperature (8.61%). The low error contribution (8.44%) suggests that the statistical model well describes the color strength behavior and that there is strong experimental consistency.

4.7.2.5. Model summary of sample dyed with neem bio-mordant

Table 4. 14 Model summary of sample dyed with neem bio-mordant

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.713383	92.08%	89.70%	18.5500	85.56%	74.28	76.65

A robust and trustworthy regression model for predicting the color strength (K/S) of cotton fabric dyed with neem bio-mordant is shown in the model summary. The model's high R-sq value (92.08%) and modified R-sq(adj) (89.70%) indicate that it explains the majority of the variability in color strength. The low PRESS value (18.55) and anticipated R-sq(pred) (85.56%) show

minimal overfitting and strong predictive performance. The resulting model's adequacy and robustness for color strength analysis are further supported by the low standard error (S = 0.713) and favorable AICc (74.28) and BIC (76.65) values.

4.7.2.6. Model summary of sample dyed with copper(II)sulfate mordant

Table 4. 15 Model summary of sample dyed with copper(II)sulfate mordant

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.716836	91.56%	89.03%	18.7300	84.62%	74.54	76.91

The regression model has excellent explanatory and predictive power for color strength. The high R2 value (91.56%) and modified R2 (89.03%) show that the chosen factors account for the majority of the variation in K/S. The anticipated R^2 (84.62%) and low PRESS value (18.73) indicate strong prediction performance and minimal overfitting. The model's accuracy is demonstrated by the low standard error (S = 0.7168), and its adequacy and parsimony are supported by the AICc (74.54) and BIC (76.91) values. Overall, the model is statistically valid and appropriate for forecasting the color strength of cotton fabric dyed using copper(II) sulfate mordant.

4.7.2.7. Regression Equation in Uncoded Units sample dyed with neem bio-mordant

K/S = -8.04 + 0.0555 Temperature(°C) + 0.1276 Time(min)
+ 0.2856 Concentration(%)……..eq(5)

4.7.2.8. Regression equation in uncoded Units sample dyed with copper(II)sulfate mord

K/S = -7.67 + 0.0461 Temperature(°C) + 0.1305 Time(min)
+ 0.2511 Concentration(%)……...eq(6)

4.7.2.9. Main effect plot for color strength

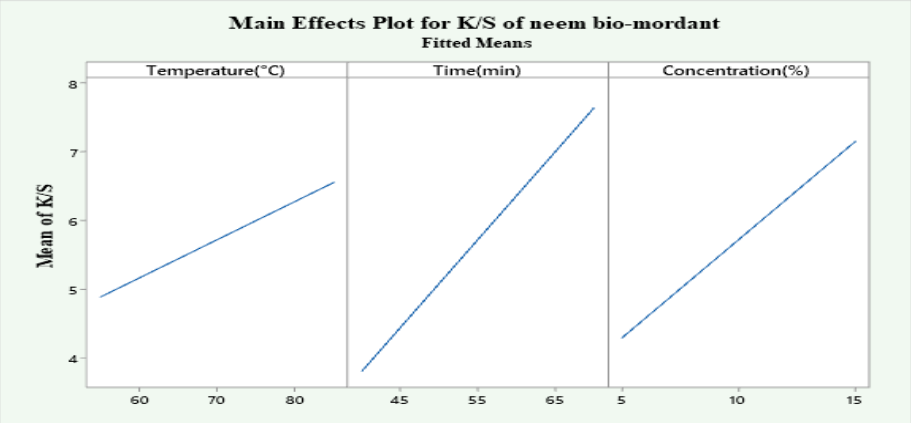


Figure 4. 25 Main effect plot for color strength (K/S)

The main effects figure shows how temperature, time, and concentration individually affect the colour strength (K/S) of cotton fabric dyed with gulmohar dye when neem bio-mordant is present. As the temperature rises, the K/S ratio increases, indicating that dye penetration into the fibre is improved. Time is the most significant factor influencing colour strength, as evidenced by its steepest slope. In a similar vein, higher dye concentration leads to larger K/S values because of increased dye availability. Overall, the plot shows that all three criteria have a considerable and beneficial effect on colour strength, with time having the greatest impact.

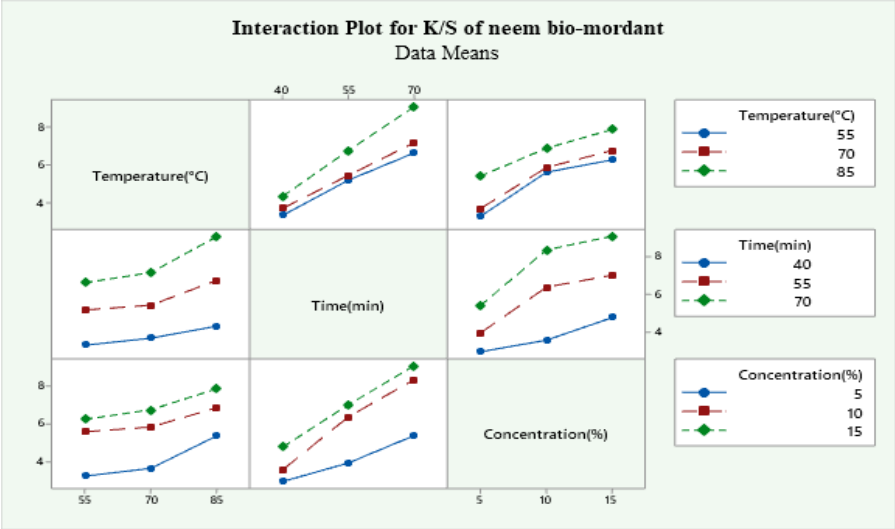


Figure 4. 26 Interaction plot for color strength

The interaction plot shows how temperature, time, and concentration all work together to affect the color strength (K/S) of cotton cloth dyed with gulmohar dye while neem bio-mordant is present. The depicted lines' non-parallel shape suggests that there are substantial interaction effects between the dyeing parameters. The influence of one factor depends on the level of the others, as evidenced by the observation of an increase in K/S when greater temperature is combined with longer dying time and increased concentration. These interactions demonstrate that achieving ideal color strength requires simultaneous optimization of temperature, duration, and concentration rather than altering a single parameter alone.

4.7.2.10. Response Optimization of color strength values

Table 4. 16 Parameters of optimization for color strength

Response	Goal	Lower	Target	Upper	Weight	Importance
K/S neem	Maximum	2.34	10		1	1

The response optimization parameters were set in Minitab to maximize the color strength (K/S) of cotton fabric dyed with gulmohar dye and neem bio-mordant. The response goal was set to maximum, with a lower limit of 2.34 and a target value of 10, to ensure that dye uptake was effectively enhanced. This response was given equal weight (1) and importance (1), indicating that it was considered fairly during the optimization process. These values verify that the main performance criterion used to determine ideal dying conditions was color strength.

Table 4. 17 Solution of optimization for color strength

Solution	Temperature(°C)	Time(min)	Concentration(%)	K/S neem	Temperature(°C)
1	85	70	15	9.89204	0.985906

The maximum color strength of cotton fabric dyed with gulmohar dye using neem bio-mordant is reached at a temperature of 85 °C, dyeing period of 70 minutes, and dye concentration of 15%, according to the optimization findings derived using Minitab. Under these optimized conditions, a high K/S value of 9.89 was projected, along with a desirability value of 0.986, indicating great optimization results. This outcome demonstrates that the chosen process parameters successfully improve cotton fabric's dye fixation and color depth.

Table 4. 18 Multiple response prediction of color strength values

Variable	Setting			
Temperature (°C)	85			
Time (hr)	70			
Concentration(%)	15			
Response	Fit	SE Fit	95% CI	95%PI
K/S of sample	9.892	0.344	(9.180, 10.604)	(8.161, 11.623)

The multiple response prediction analysis evaluates the color strength of cotton fabric dyed with gulmohar dye using neem bio-mordant under optimized conditions of 85°C temperature, 70 minutes of time, and 15% concentration. The model forecasts a fitting K/S value of 9.892, indicating a good color depth. The low SE fit (0.344) indicates strong model precision. While the 95% prediction interval (8.161–11.623) verifies appropriate variability for subsequent observations, the 95% confidence interval (9.180–10.604) shows accurate calculation of the mean response. Overall, the findings support the ANOVA model's prediction accuracy and resilience for optimizing color strength.

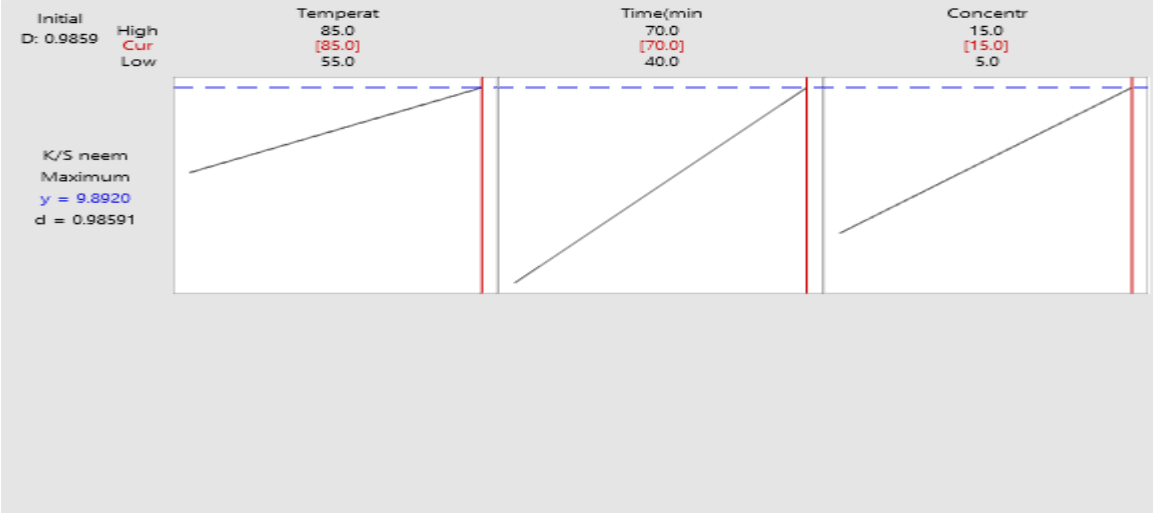


Figure 4. 27 Main effect plot for optimized color strength values

The main effects figure shows the effect of temperature, time, and concentration on the optimal color strength (K/S) of cotton fabric dyed with gulmohar dye and neem bio-mordant. The plot shows that raising the temperature to 85 °C, the time to 70 minutes, and the concentration to 15% causes the K/S to gradually rise, reaching a maximum anticipated value of 9.89 with a high desirability (0.986). The positive slopes indicate that each parameter makes a significant

contribution to color strength enhancement. Overall, the plot verifies the optimal circumstances chosen for attaining maximal dye fixation and color depth on cotton fabric.

4.8. Characterization of the dyed sample with neem mordant

FTIR spectrometry and UV-Vis spectrophotometry were used to characterize the gulmohar flower's coloring components. Cotton fabric dyed using gulmohar flower and neem leaf as a bio-mordant, as well as mordanted with copper (II) sulfate, were characterized by FTIR spectrometry.

4.8.1. FT-IR analysis on dyed sample with neem bio-mordant test results

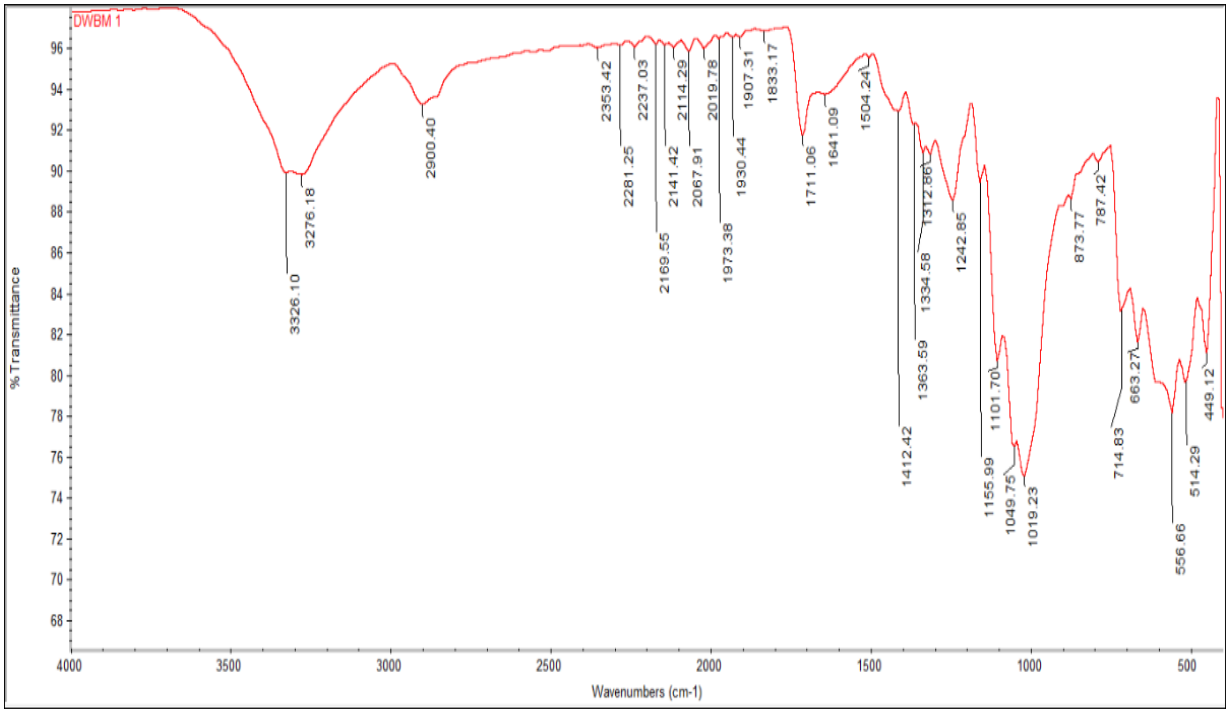


Figure 4. 28 Sample dyed with extracted gulmohar dye with neem leaf bio-mordant test result

The cotton fabric dyed with extracted gulmohar dye in the presence of neem leaf bio-mordant exhibits distinctive absorption bands in the FT-IR spectra, indicating a successful dye–fiber interaction. O–H stretching vibrations are responsible for the broad band at 3300–3400 cm^{-1}, which shows hydrogen bonding between cellulose, dye molecules, and bio-mordant components. Absorptions around 2920–2850 cm^{-1} are indicative of aliphatic group C–H stretching.

The peaks at 1600-1500 cm^{-1} correspond to aromatic C=C stretching, indicating the presence of phenolic components from gulmohar dye and neem extract. Furthermore, C–O and C–O–C stretching vibrations are represented by bands in the 1200–1000 cm^{-1} range, indicating the

development of stable contacts between the dye, bio-mordant, and cellulose matrix. Furthermore, C–O and C–O–C stretching vibrations are represented by bands in the 1200–1000 cm^{-1} range, indicating the development of stable contacts between the dye, bio-mordant, and cellulose matrix.

4.8.2. Chemical properties

Aliphatic ketones have the general structure

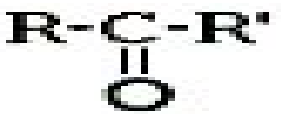


Figure 4. 29 Aliphatic ketones structure

The FT-IR spectra of cotton fabric dyed with gulmohar dye and neem as a bio-mordant reveals absorption bands associated with aliphatic ketone (R-CO-R′) structures. The peak detected between 1715-1730 cm^{-1} is attributed to the C=O stretching vibration, a characteristic of aliphatic ketones. The existence of carbonyl-containing organic molecules formed from neem bio-mordant and natural dye components is supported by additional bands near 2850–2960 cm^{-1}, which correspond to aliphatic C–H stretching. These spectrum patterns show that aliphatic ketone groups contribute to dye-mordant-fiber interactions, which improve dye molecular fixation on cotton fabric.

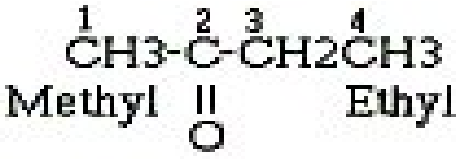


Figure 4. 30 Methyl ethyl ketone

The FT-IR spectrum of cotton fabric dyed with gulmohar dye using neem leaf bio-mordant reveals absorption bands typical of carbonyl structures of the methyl ethyl ketone ($CH_3–CO–CH_2CH_3$) type. The presence of carbonyl functionalities is confirmed by the strong band seen between 1715 and 1725 cm^{-1}, which corresponds to the C=O stretching vibration of a ketone group. Absorptions at 2850-2960 cm^{-1} are due to aliphatic C-H stretching of methyl and ethyl groups. These FT-IR characteristics show that neem bio-mordant and gulmohar dye's ketonic components are successfully bonded to cotton cellulose, promoting stable dye fixing. Common name: Methyl Ethyl Ketone IUPAC: 4 Carbons = butane; 2-Butanone.

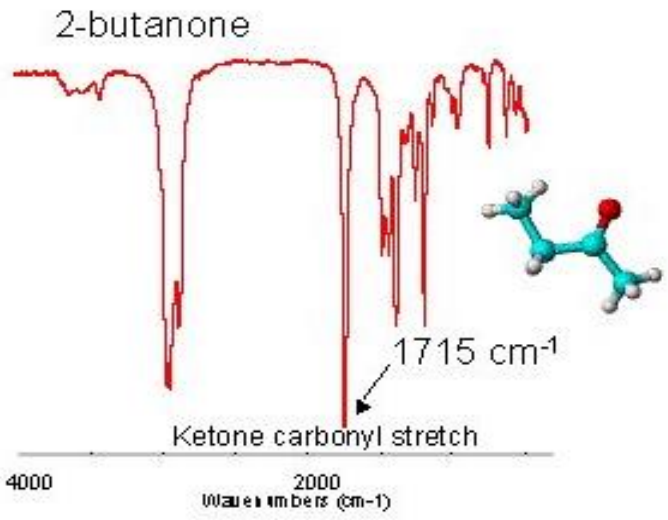


Figure 4. 31 2-Butane spectral interpretation

The C=O stretching vibration of an aliphatic ketone, which is typical of 2-butanone-type compounds, is represented by a strong and sharp absorption band in the FT-IR spectrum at about 1715 cm^{-1}.Aliphatic C–H stretching of methyl and methylene groups is responsible for additional bands in the 2850–2960 cm^{-1} range. These spectrum characteristics reveal the existence of ketonic functional groups derived from gulmohar dye and neem bio-mordant components, demonstrating their successful interaction and fixing on cotton fabric.

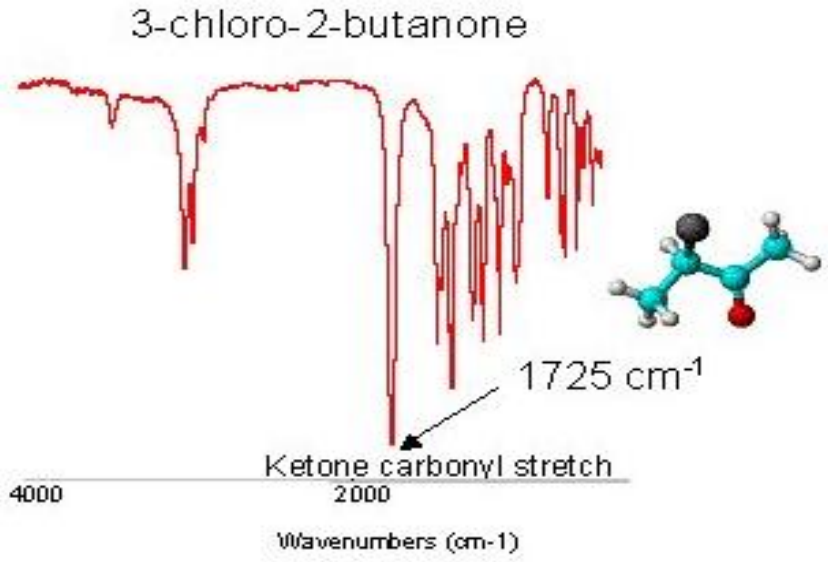


Figure 4. 32 3-Chloro-2-butanone spectral interpretation

The significant absorption band in the FT-IR spectra at about 1725 cm^{-1} is attributed to the aliphatic ketone's C=O stretching vibration, which is typical of compounds of the 3-chloro-2-

butanone type. The chloro substituent's electron-drawing effect accounts for the somewhat greater carbonyl frequency as compared to simple ketones. Aliphatic C–H stretching vibrations are represented by additional absorptions in the 2850–2960 cm^{-1} range. These spectrum characteristics show the existence of halogen-substituted ketonic functional groups formed from gulmohar dye and neem bio-mordant components, indicating their interaction and fixing on cotton fabric.

4.8.3. Aliphatic Functional Groups

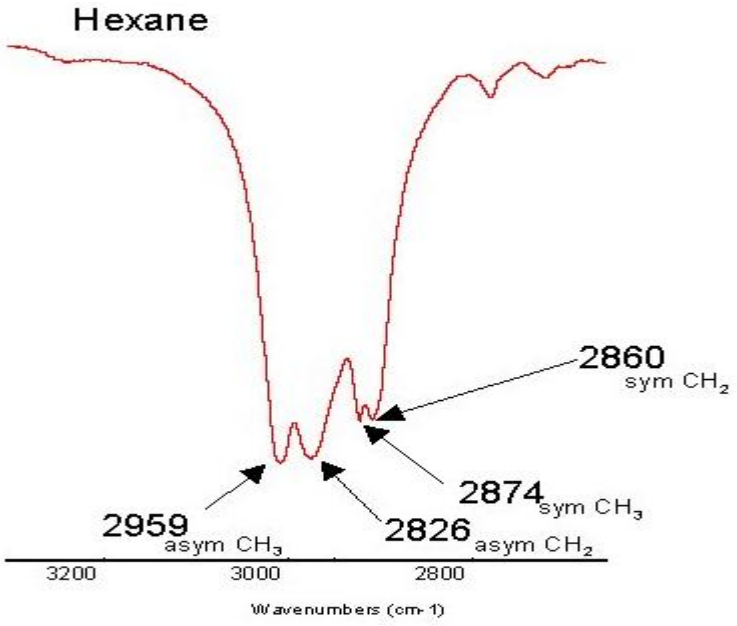


Figure 4. 33 $-CH_3$ and $–CH_2$ stretching absorptions

The existence of aliphatic hydrocarbon groups in the cotton fabric dyed with gulmohar dye and neem bio-mordant is confirmed by the FT-IR spectrum's distinctive $–CH_3$ and $–CH_2$ stretching absorption bands. The absorption at 2959 cm^{-1} is attributed to the asymmetric stretching of $-CH_3$, whereas the band near 2926 cm^{-1} corresponds to the asymmetric stretching of $-CH_2$.The symmetric stretching vibrations of $–CH_3$ and $–CH_2$ are responsible for the peaks seen at around 2874 cm^{-1} and 2860 cm^{-1}, respectively. These absorptions suggest the existence of aliphatic elements from the natural dye and bio-mordant, which facilitates their interaction with the cotton cellulose matrix.

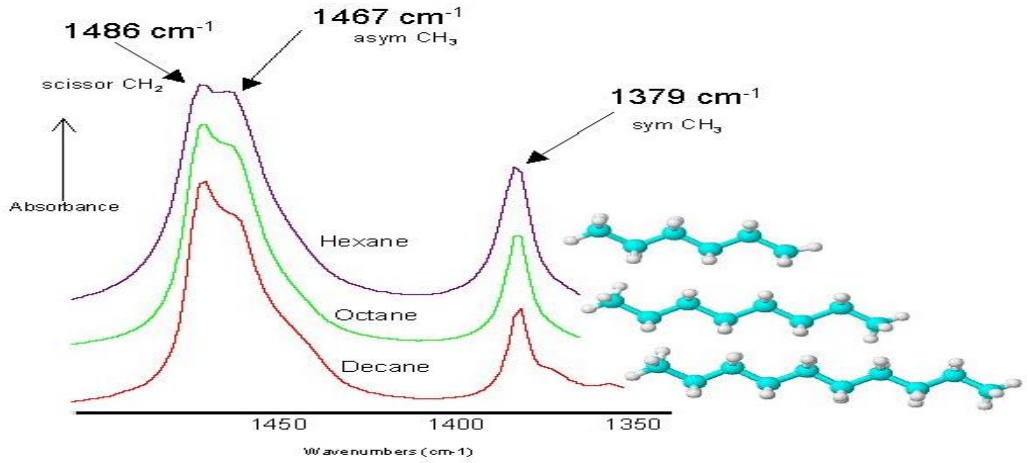


Figure 4. 34 CH_3 deformation absorptions

The presence of alkyl groups is shown by the distinctive CH_3 deformation (bending) absorption bands in the FT-IR spectrum of cotton fabric coloured with gulmohar dye using neem bio-mordant. The absorption near 1467-1486 cm^{-1} indicates asymmetric bending (deformation) of CH_3, while the band at 1379 cm^{-1} indicates symmetric bending (umbrella mode) of CH_3 groups. These deformation absorptions show the presence of aliphatic components from the natural dye and bio-mordant, indicating their effective interaction and fixing within the cotton cellulose structure.

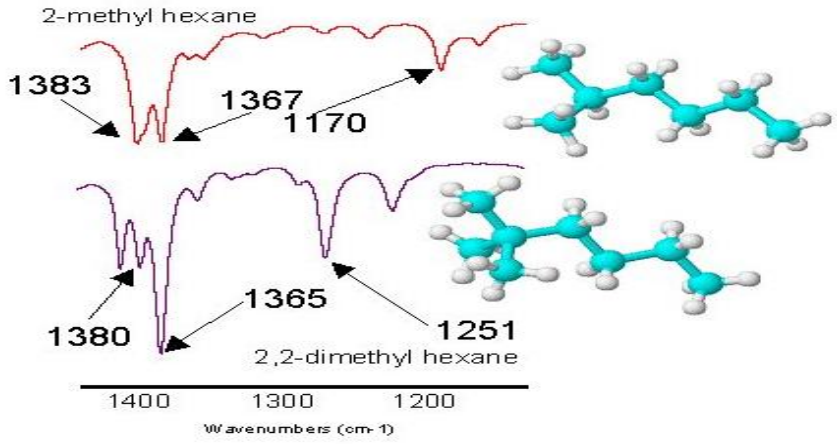


Figure 4. 35 CH_3 deformation absorption band splitting

The FT-IR spectra of cotton fabric colored with neem bio-mordant and gulmohar dye clearly shows CH_3 deformation absorption band splitting, a sign of branching aliphatic structures The symmetric and asymmetric bending vibrations of CH_3 groups are represented by the bands seen

about 1383–1367 cm^{-1}, whilst additional splitting near 1365 cm^{-1} and 1251 cm^{-1} indicates distinct methyl group environments brought on by molecular branching. This splitting behavior confirms the presence of structurally diverse alkyl components from the natural dye and bio-mordant, proving their efficacy in interacting with the cotton matrix.

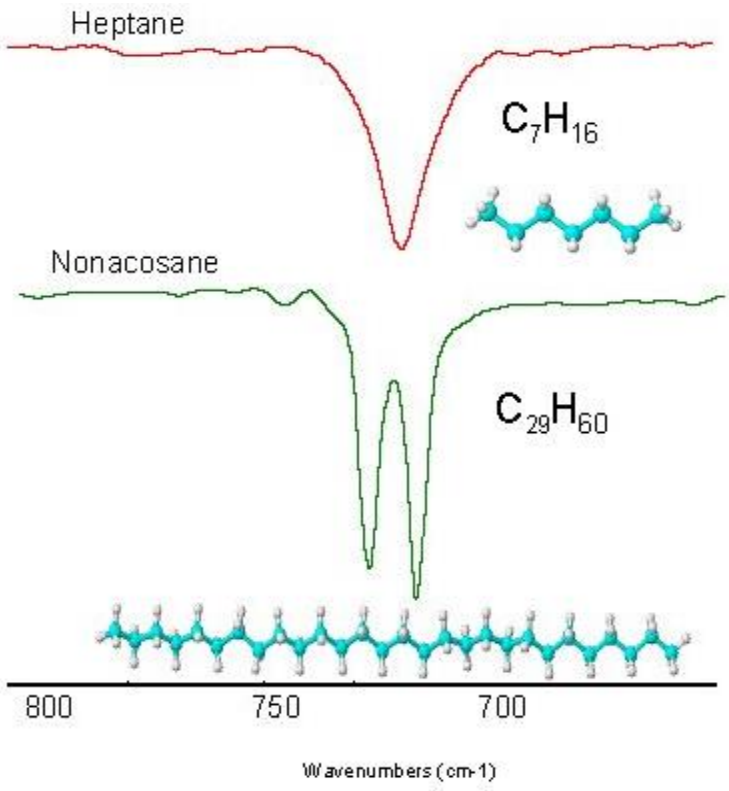


Figure 4. 36 $-(CH_2)_n$ -rocking absorption

A distinctive $–(CH_2)_n–$rocking absorption band in the 720–730 cm^{-1} area of the FT-IR spectrum of cotton fabric colored with gulmohar dye using neem bio-mordant is indicative of long, linear aliphatic chains. This band is caused by the collective rocking vibration of successive methylene ($-CH_2-$) groups and intensifies with increasing chain length, as seen in nonacosane against heptane. This absorption indicates successful interaction and fixing within the cotton cellulose structure, confirming the integration of long-chain aliphatic components from the natural dye and bio-mordant.

4.9. Performance evaluation of cotton fabric dyed sample

As indicated in Table 4.19, a performance evaluation of the dyed samples was carried out to determine their wash and rubbing fastness. The evaluation sought to determine color stability and staining under various situations.

Table 4. 19 summary table for color strength and color indices test result

Temperature(°C)	Time in(min)	Concentration (%)	Type of mordant	Washing fastness							Rubbing fastness		Light fastness
				Color stain						Color change	Dry	wet	
				Wool	acrylic	Polyester	Nylon	cotton	Diacetate				
55	40	5	Neem	3/4	4/5	4	4/5	4	5	3	4	3/4	4
			Cu_2SO_4	3/4	4/5	4/5	3/4	4	5	3	4	4/4	4
		10	Neem	4/5	4	4/5	5	4/5	5	3/4	4	4	4
			Cu_2SO_4	5	5	4/5	4	4/5	5	3	4	3/4	4
		15	Neem	5	4/5	4	5	¾	5	3/4	4	3/4	4
			Cu_2SO_4	4/5	4/5	5	4/5	4/5	5	3	4	3/4	4
	55	5	Neem	4/5	4	4/5	4	5	5	3	4	3/4	4
			Cu_2SO_4	4/5	4/5	4	4/4	4/5	5	3	4	3/4	4
		10	Neem	4	4/5	4/5	5	4/5	5	3/4	4	3/4	4
			Cu_2SO_4	4/5	4	4/5	5	4/5	5	3	4	3/4	4
		15	Neem	4	4	4/5	4	5	5	3/4	4	4	5
			Cu_2SO_4	4/5	4	5	4/5	4	5	3/4	4	3/4	4
	70	5	Neem	4/5	4	4/5	5	4	5	3	4/5	4	4
			Cu_2SO_4	4	4/5	4	4	4/5	5	3	4/5	4	4
		10	Neem	4/5	4	4/5	4	4/5	5	3	4/5	4	4
			Cu_2SO_4	4/5	4	4/5	5	4/5	5	3/4	4/5	4	5
		15	Neem	4	4/5	4/5	4	4/5	5	4	4/5	4	6
			Cu_2SO_4	4/5	4	4/5	4/5	4	5	3/4	4/5	4	5
	40	5	Neem	4/5	4/5	5	5	4/5	5	3/4	4	3/4	4
			Cu_2SO_4	5	4	4/5	4/5	4/5	5	3	4	3/4	4
		10	Neem	5	4/5	5	4	4	5	3/4	4	3/4	5
			Cu_2SO_4	4/5	5	4/5	4/5	4/5	5	3	4	3/4	4
		15	Neem	4/5	4	4/5	4/5	4/5	5	4	4	3/4	5
			Cu_2SO_4	5	4/5	5	4	4	5	3/4	4	3/4	5
		5	Neem	4/5	4/5	4	4	4/5	5	3/4	4	3/4	4
			Cu_2SO_4	4	4/5	4	4/5	4	5	3	4	3/4	4
			Neem	4/5	4/5	4/5	5	4/5	5	3/4	4	3/4	5

70	55	10	Cu_2SO_4	5	4	4/5	4	4/5	5	3	4	3/4	4
		15	Neem	4/5	4/5	4/5	4	5	5	3/4	4/5	4	5
			Cu_2SO_4	4/5	4	5	4/5	5	5	3	4	3/4	4
	70	5	Neem	5	4	4/5	4	4/5	5	3/4	4	3/4	4
			Cu_2SO_4	5	4	4	5	4	5	3	4	3/4	4
		10	Neem	5	4/5	4/5	4/5	4/5	5	3/4	4	3/4	6
			Cu_2SO_4	5	4/5	4/5	4	4/5	5	3	4	3/4	5
		15	Neem	5	4/5	5	4/5	4/5	5	4	4	3/4	6
			Cu_2SO_4	5	4/5	4/5	5	4/5	5	4	4	3/4	5
85	40	5	Neem	4/5	4/5	4	4/5	5	5	3/4	4	3/4	4
			Cu_2SO_4	4/5	4/5	4/5	5	4/5	5	3	4	4	4
		10	Neem	5	5	4/5	4/5	5	5	4	4/5	4	5
			Cu_2SO_4	5	4/5	4	4/5	4/5	5	3	4/5	4	4
		15	Neem	5	5	4.5	4	5	5	4	4/5	4	6
			Cu_2SO_4	5	4/5	4/5	4	4/5	5	4/5	4/5	4	6
	55	5	Neem	5	4	4/5	5	4/5	5	3/4	4	4	5
			Cu_2SO_4	5	4/5	4/5	4	5	5	3	4/5	4	5
		10	Neem	5	4/5	4/5	4/5	5	5	3/4	4/5	4	6
			Cu_2SO_4	5	4	5	4/5	4/5	5	4	4/5	4	5
		15	Neem	5	4/5	4	4	5	5	4	4/5	4	6
			Cu_2SO_4	5	4/5	5	5	4/5	5	3/4	4	4	5
	70	5	Neem	5	5	4	5	4/5	5	4	4	4	5
			Cu_2SO_4	5	4/5	5	4/5	4	5	3/4	4/5	4	5
		10	Neem	5	5	4/5	4/5	5	5	4/5	5	4/5	6
			Cu_2SO_4	5	5	4/5	4	5	5	4	4/5	4	6
		15	Neem	5	5	5	5	5	4/5	4/5	5	4/5	7
			Cu_2SO_4	4	5	4/5	5	4/5	5	4	5	4/5	6

4.9.1. Wash fastness of dyed samples

The dyed cloth samples were washed with soap and sodium carbonate at 60°C for 30 minutes in order to assess their wash fastness. Table 4.19 summarizes the color stain, color change, and wash fastness ratings for various dyeing conditions and mordant types. The dyed samples treated with neem leaf as a bio-mordant and gulmohar flower dye extract showed encouraging wash fastness

properties. On the blue-grey scale for color change, the grades varied from 3 to 4/5, indicating moderate to very minimal wash fastness. This shows that the dyed materials held their color well after washing, with just slight color changes noted in some cases. The use of neem leaf as a bio-mordant appeared to enhance the wash fastness of the colored cotton fabric compared to the dyed samples mordanted with Copper (II) sulfate, which demonstrated very slight wash fastness. However, they had a lower wash fastness than the neem leaf bio-mordanted samples. The Copper (II) sulfate mordant may have caused a film-like surface on the cloth, reducing the dyed fabric's color strength and wash fastness.

Overall, the neem leaf bio-mordant-treated dyed cotton fabric showed commercially acceptable wash fastness ratings, indicating its promise as an environmentally benign and sustainable method of textile dyeing. The colored samples' very slight wash fastness demonstrates the successful fixing of the natural dye onto the fabric fiber using the bio-mordant, resulting in better color stability and resistance to washing-induced fading or discoloration. The wash fastness evaluation's findings are consistent with earlier research on mordant type and color strength.

The use of natural dye extract from the flower of gulmohar tree and neem leaf as a bio-mordant has proven to be a promising strategy for generating both brilliant colors and long-lasting colorfastness in cotton fabrics, making it a viable option for eco-friendly textile dyeing applications rubbing fastness

4.9.2. Rubbing fastness

Table 4.19 shows ratings for color change following wet and dry rubbing. Rubbing fastness is an important indicator of a colored fabric's ability to hold its color when subjected to rubbing or friction, which simulates normal wear and tear. Using various dyeing settings and mordant types, the study assessed the rubbing fastness of cotton fabric dyed using gulmohar tree flower extract.
The dyed cotton fabric samples treated with both neem leaf bio-mordant and Copper (II) selphate mordant showed excellent to very good rubbing fastness.

For dry rubbing tests, the ratings varied from 4 to 5, while for wet rubbing tests, they ranged from 3/4 to 4/5. These ratings indicate minimum to no color transfer or change when subjected to rubbing, highlighting the powerful attachment of the natural dye to the cloth fibers with the aid of the mordants. Regardless of the type of mordant employed, the rubbing fastness results show that

the dyed materials can tolerate normal abrasion, making them appropriate for clothing and textiles that are frequently handled or rubbed without losing their color integrity.

In conclusion, the study shows that cotton fabric samples colored using gulmohar flower extract and either copper (I3) sulfate mordant or neem leaf bio-mordant have excellent to very good rubbing fastness. This suggests that the overall color stability and resistance to color transfer during rubbing are improved by the dye-fiber interaction made possible by the mordant.

The rubbing fastness results are consistent with the previously analyzed wash and light fastness capabilities, offering full insight into the possibilities of using neem leaf bio-mordant as an eco-friendly and effective option for producing durable and colorfast textiles. The findings demonstrate the feasibility of employing natural dyes and bio-mordant in sustainable textile manufacturing, which can lessen the impact on the environment and enhance the functionality of colored textiles.

4.9.3. Light fastness

Lightfastness of cotton fabric colored with Gulmohar dye in the presence of neem bio-mordant was tested to determine color resistance to fading during light exposure. The test was conducted using a controlled light source in accordance with established procedures like ISO 105-A02. Dyed fabric specimens were exposed to artificial light for a set amount of time, along with typical blue wool reference samples.

Although auxochrome can dramatically change the fastness in either direction, a dye or pigment's resistance to chemical or photochemical attack is an intrinsic feature of the dye chromophore. Dye substitution patterns appear to play a major role in determining light fastness. The samples dyed with gulmohar tree flowers, neem leaf as a bio-mordant, and copper sulfate exhibit good to moderate resistance to lightfastness.

The lightfastness rating indicates how well neem bio-mordant works to improve dye-fiber interaction and strengthen gulmohar`s dye resistance to photo degradation on cotton fab. The samples displayed moderate to good light fastness when mordanted with copper sulfate due to the development of a complex with a transition metal that protects the chromophore from photolytic degradation and protons sorbed by the chromophoric group.

4.9.4. Abrasion test results

The Martindale abrasion test was used under standard conditions to assess the abrasion resistance of cotton fabric dyed with Gulmohar flower dye. As table 4.20 indicates that the color change after abrasion was visually and instrumentally examined to establish the natural dye's durability on cotton fabric. A common visual aid for determining the extent of color loss in dyed fabrics following abrasion is the grey scale for color change.

This indicates that the abrasion fastness of cotton fabric is equal to the weight of the cloth both before and after abrasion. During the abrasion test performed taking three times at deferent place from one sample and had to select mean of its value.

Table 4. 20 Abrasion result

No	Weight of dyed cotton fabric sample with flower of gulmohar dye and either neem as bio-mordant or copper (II) sulfate mordanted.			
	Mean Weight before abrasion		Mean weight after abrasion	Result Of rubbing
1	Sample dyed with neem bio-mordant	0.20gm	0.19gm	0.01gm
2	Sample dyed with CO_2SO_4 mordant	0.19gm	0.182gm	0.008gm

Based on this sample the mean weight before abrasion of cotton fabric dyed is equal to 0.19gm, and mean weight after abrasion of is 0.19gm. Abrasion fastness = mean of abrasion before – mean of abrasion after= 0.19gm - 0.19gm = 0 gm

Weight loss formula used as an indicator abrasion fastness which is

- To understand weight loss results:-weight loss= $(\frac{w1-w2}{w1})$ ……..…….. (7)
- Based on the above tested result there is no weight loss explained as followed by two ways:

i. Cotton fabric sample dyed with neem bio-mordant: -

Before tested and after abrasion tested= $(\frac{w1-w2}{w1})\times 100\% \Longrightarrow (\frac{0.20gm-0.19gm}{0.20gm}) \times 100\%=5$

ii. Cotton fabric sample dyed with copper(II)sulphate mordant: -

Before test and after abrasion tested= $(\frac{w1-w2}{w1}) \times 100\% \Longrightarrow (\frac{0.19gm-0.182gm}{0.19gm}) \times 100\% = 4.21 \approx 4$

According to abrasion test result there is some weight loss. Based on this grey scale ratings numerical scale indicates that 1-5 which means 1 represent very severe(worst) 5 assigned to no change or excellent abrasion fastness. Therefore, cotton fabric sample dyed with neem bio-mordant is batter and preferable than sample dyed with copper(II) sulfate.

CHAPTER FIVE:CONCULUSION & RECOMMENDATION

5.1. Conclusion

This study investigated extraction and use of natural dye from the flower of gulmohar tree, as well as the use of neem leaf as a bio-mordant facilitate and increase color uptake in cotton fabric during dyeing process carried out. Natural dyes offer immense commercial potential in the current sustainability context because many synthetic dyes and metallic mordants release a significant amount of dangerous chemicals into the environment during the dyeing process carried out in the textile industry.

Natural dyes are gaining popularity for textile coloration due to environmental concerns, eco-friendliness, and pollution reduction. Natural colors are considered more user-friendly and biodegradable than synthetic dyes. The study analyzed the impact of several dyeing parameters, such as dye concentration, dyeing time, dyeing temperature, and mordant type, on the dyed cotton fabric's color strength and fastness.

The results demonstrated that the flower of gulmohar tree is a hopeful source of natural dye, yielding a vibrant cream-hip color on cotton fabric. The color strength and inclusive performance of the dyed cloth were effectively improved by using neem leaf as a bio-mordant. Dyeing parameters including temperature, duration, and dye concentration affect the color strength (K/S) value in different types of mordanting. Pre-mordanting play important role in enhancing substantivity and improving the binding of natural dyes to textile substrates.

Bio-mordanted cotton samples showed very good color strength values, exceeding those mordanted with Copper (II) sulfate, which can be attributed to the formation of a film on the fabric surface by the metallic mordant. In reality, nature has offered different colors for us to meet delight pertaining to decorate with color art from natural healthy resources. Gulmohar flower dyestuff has done on cotton fabric with different temperature (55°C), time (40min) and dyestuffs' concentration (5%) of M: L ratio 1:30 (for water extraction with diluting the concentration and for light shade of dyeing) and temperature (85°C), time (70min) and dyestuffs' concentration (15%) of M:L ratio 1:30 for deep shades of dyeing.

The investigation indicates that the effect of increasing parameter like temperature, time and dye concentration revealed led to higher color strength, providing deeper shades of color on the fabric.

The experimental results demonstrate that washing fastness (including color change and staining), color strength (measured by K/S value), rubbing fastness, and abrasion resistance exhibited the most favorable outcomes in this study.

The study of fastness properties indicated that neem leaf bio-mordant imparted very good wash fastness to the colored cloth, whereas Copper (II) sulfate mordanted sample exhibited good wash fastness. Moreover, both neem leaf bio-mordant and Copper (II) sulfate mordanted samples exhibited excellent rubbing fastness for dry staining and very good rubbing for wet staining, indicating minimal color change, in addition the sample mordanted with Copper (II) sulfate exhibited fair to good light fastness however the sample mordanted with neem leaf bio-mordant exhibited fair to very good light fastness. In general, the tested specimens demonstrated fair to excellent performance in rubbing fastness, abrasion resistance, color strength (K/S value), and washing fastness (both color change and staining).

Overall, the study shows that employing natural dyes derived from gulmohar tree flowers in conjunction with neem leaf as a bio-mordant can be a practical and sustainable way to color cotton fabric. The dyed materials had brilliant colors, very good color strength, and impressive fastness qualities, making them ideal for sustainable textile applications. By implementing such ecologically friendly techniques, the textile sector may lessen its environmental impact and contribute to a greener, more sustainable future.

In conclusion, this study emphasizes the importance of exploring natural dye sources and bio-mordants to promote the sustainability of textile dyeing processes while retaining the required performance and aesthetics of the end product. It gives useful insights for academics, manufacturers, and stakeholders in the textile industry to adopt more ecologically responsible and sustainable practices, contributing to a more eco-conscious and socially responsible textile sector.

5.2. Recommendation

Based on the data and findings from the research, several recommendations can be proposed to enhance the application of natural dye derived from the flower of gulmohar tree and neem leaves as bio-mordants for dyeing cotton fabric.

Optimize Parameters of extract dye yield and Dyeing process: Further optimization of dye yield parameters, such as extracting temperature and time should be conducted to achieve the desired

dye yield as well as to attain the required color depth and colorfastness attributes, additional dyeing parameters, such as dyeing temperature, dyeing duration, and dye concentration, should be optimized. By adjusting these variables, the dyed fabric's overall performance and color vibrancy can be increased.

Perform a comprehensive Lifecycle Analysis: To fully evaluate the dyeing process's environmental impact, do a detailed lifecycle analysis of the entire process, from dye extraction to application. This analysis will help establish the process's overall sustainability and pinpoint areas for improvement

Investigate Environmentally Sustainable Mordants: Other environmentally friendly bio-mordants that can successfully improve the dye's color strength and fastness qualities should be investigated in addition to neem leaf. Examine bio-mordants sourced from waste materials or agricultural by-products to mitigate environmental impact.

Examine Alternative Natural Dye Sources: While the flower of gulmohar tree has shown promise as a natural dye source, more research into additional natural dye ingredients is needed. Examine diverse plant-derived sources to enhance the spectrum of colors and hues achievable with distinct bio-mordants. In addition, the study's findings will benefit cotton producers, dyers, and manufacturers involved in the trade of natural dyes and biomordants in terms of replacing chemicals in the processing sectors and producing performance textiles.

Increase Production: To assess the feasibility of large-scale dyeing operations, think about increasing the production process if the research was done in a lab. Determine the viability of adopting these techniques in industrial settings while preserving constant color quality and fastness.

Work Together with Stakeholders: Collaborate with textile producers, dye suppliers, and other industry players to increase the use of sustainable dyeing processes. Share research findings and form partnerships to promote the use of environmentally friendly dyeing procedures.

Promote and Sell Eco-Friendly Textiles: Promote fabrics dyed with natural dyes and eco-friendly mordants as environmentally responsible options in light of rising consumer awareness and demand for sustainable products. To draw in eco-aware customers, emphasize the products' eco-friendly features.

Ongoing Research and Improvement: Continue your research and development efforts to enhance the overall efficiency and performance of natural dyeing methods. Investigate novel approaches and technologies that can improve color depth, fastness qualities, and the overall sustainability of the dying process.

By implementing these suggestions, the textile sector may lessen its influence on the environment and help create a greener future by switching to more ecologically friendly and sustainable dyeing methods. Using natural dyes and bio-mordants can result in eco-friendly and socially responsible textile products, addressing the needs of environmentally conscious consumers and creating positive change in the sector.

References

[1] K. K. Samanta, S. Basak, and S. K. Chattopadhyay, “Eco-friendly Coloration and Functionalization of Textile Using Plant Extracts,” 2014, doi: 10.1007/978-981-287-110-7.

[2] H. Helmy, “Extraction approaches of natural dyes for textile coloration,” *J. Text. Color. Polym. Sci.*, vol. 0, no. 0, pp. 0–0, 2020, doi: 10.21608/jtcps.2020.30990.1037.

[3] V. Narayana Swamy, K. N. Ninge Gowda, and R. Sudhakar, “Extraction and dyeing conditions of natural dye from flowers of Plumeria rubra L. on textiles and fastness properties,” *Indian J. Tradit. Knowl.*, vol. 15, no. 2, pp. 278–284, 2016.

[4] D. Hamdy and A. Hassabo, “Various Natural Dyes from Different Sources,” *J. Text. Color. Polym. Sci.*, vol. 0, no. 0, pp. 0–0, 2021, doi: 10.21608/jtcps.2021.79786.1066.

[5] A. Modi *et al.*, “Delonix regia: Historic perspectives and modern phytochemical and pharmacological researches,” *Chinese Journal of Natural Medicines*, vol. 14, no. 1. Chinese Journal of Natural Medicines Editorial Board, pp. 31–39, Jan. 01, 2016. doi: 10.3724/SP.J.1009.2016.00031.

[6] T. Paulzagade, S. K. Mahajan, S. Dubey, and P. Mishra, “EFFECT OF DELONIX REGIA (GULMOHAR) ON COLOURATION OF GOLD FISH CARASSIUS AURATUS,” *Int. J. Trendy Res. Eng. Technol.*, vol. 7, 2023, [Online]. Available: www.trendytechjournals.com

[7] M. Ijaz, “Extraction and Application of Natural Dye from Gladiolus on Cotton and Cotton / Polyester Blend,” vol. 57, no. October, pp. 51–57, 2020.

[8] P. Bhokare, A. Khadke, G. Kuchekar, S. Kulkarni, and C. Pallavi Bhokare, “Comparative study of different extraction technique and phytochemical screening of Delonix regia,” *~ 133 ~ J. Pharmacogn. Phytochem.*, vol. 7, no. 4, 2018.

[9] P. Reddy, S. Ruj, N. Fathima, I. J. Pharm, and B. Sci, “Ecofriendly synthesis of silver nanoparticles using Delonix regia flower extract and its characterization by UV and SEM and in vitro study on its toxicity and antioxidant potential International Journal of Pharmacy and Biological Sciences Ecofriendly synt,” *Biol. Sci. |Open Access |MCI Approv. |UGC*

Approv. Journal| Int. J. Pharm. Biol. Sci., vol. 9, pp. 2230–7605, 2019, [Online]. Available: www.ijpbs.comorwww.ijpbsonline.comwww.ijpbs.comorwww.ijpbsonline.com

[10] L. P. Sanku, I. Rajitha, A. Padma, V. Lakshmi, and J. Hayavadana, "Exploring dye extraction methods and preservatives for natural dyes," *~ 137 ~ Journal of Pharmacognosy and Phytochemistry*, vol. 10, no. 1, 2021. [Online]. Available: www.phytojournal.com

[11] A. Asia and N. World, "Natural dye." pp. 1–6, 2015. [Online]. Available: https://en.wikipedia.org/wiki/Natural_dye

[12] S. Tadkar, "Extraction of Natural Dye," vol. 4, no. 5, pp. 16–21, 2013.

[13] G. Chakraborty and A. Bhattarai, "Polyelectrolyte – Dye Interactions : An Overview," pp. 1–17, 2022.

[14] G. R. Chilukoti, B. Venkatesh, and V. Sai Chandana, "Optimisation of dyeing and mordanting parameters on cotton fabrics treated with allium cepa as a natural dye source," *J. Text. Assoc.*, vol. 79, no. 5, pp. 333–339, 2019.

[15] S. S. Alam, J. Ghosh, and D. J. Das, "The coloration of cotton fabric with natural dye extracted from turmeric powder," *J. Text. Eng. Fash. Technol.*, vol. 8, no. 4, pp. 134–138, 2022, doi: 10.15406/jteft.2022.08.00311.

[16] A. Maryam, S. Iqbal Khan, A. Riaz, S. Ali, and S. Noreen, "Effect of mordants with the application of natural dye extracted from Allium cepa on natural fabric," *Int. J. Home Sci.*, vol. 5, no. 3, pp. 283–286, 2019.

[17] R. Mansour, "Natural dyes and pigments: Extraction and applications," *Handb. Renew. Mater. Color. Finish.*, vol. 10, no. 01, pp. 75–102, 2018, doi: 10.1002/9781119407850.ch5.

[18] Y. Dhanania, A. K. Samanta, D. Singhee, and P. Samanta, "Fashion Technology & Textile Engineering Review on Sources and Sustainable Methods of Natural Coloration of Textiles," *Curr. Trends Fash. Technol. Text. Eng.*, vol. 7, no. 5, p. 555721, 2022, doi: 10.19080/CTFTTE.2022.07.555721.

[19] D. Submitted *et al.*, “EXTRACTION OF NATURAL DYES AND MORDANTS FROM,” 2023.

[20] R. Chakraborty, A. K. Samanta, P. S. Vankar, and P. Samanta, “Curr Trends Fashion Technol Textile Eng Review on Extraction, Mordanting and Application of Natural Dyes on Jute,” *Curr. Trends Fash. Technol. Text. Eng.*, vol. 7, no. 4, pp. 49–010, 2022, doi: 10.19080/CTFTTE.2022.07.555719.

[21] P. A. Adeonipekun, T. A. Adeniyi, O. Q. Chidinma, and R. O. Omolayo, “Proximate, phytochemical, and antimicrobial evaluation of flowers of Mangifera indica L., stamens of Terminalia catappa L., and anther of Delonix regia (Bojer ex Hook.) Raf.,” *South African J. Bot.*, vol. 155, pp. 223–229, Apr. 2023, doi: 10.1016/j.sajb.2023.02.011.

[22] D. Ebada *et al.*, “Characterization of Delonix regia Flowers’ Pigment and Polysaccharides: Evaluating Their Antibacterial, Anticancer, and Antioxidant Activities and Their Application as a Natural Colorant and Sweetener in Beverages,” *Molecules*, vol. 28, no. 7, pp. 1–19, 2023, doi: 10.3390/molecules28073243.

[23] S. Ramaswamy Inbaraju and P. Dhanalakshmi, “The Floral Based Natural Dyes and Its Applications-A Review,” 2022. [Online]. Available: www.ijcrt.org

[24] C. Shekhar, anon anon, anon anon, and anon anon, “International Journal of Research Publication and Reviews,” *SSRN Electron. J.*, vol. 6, no. 11, pp. 5306–5311, 2025, doi: 10.2139/ssrn.5134717.

[25] O. Gupta and N. Shah, “Delonix regia (Gulmohar) – It ’ s Ethnobotanical Knowledge , Phytochemical Studies , Pharmacological Aspects And Future Prospects,” vol. 10, no. 3, pp. 641–648, 2022.

[26] D. Chhabra, R. K. Gupta, and C. K. Rajinder Gupta, “Fortification of curd using Delonix regia flower petal extract and estimation of its phytochemical, antibacterial & antioxidant activity,” *~ 299 ~ J. Pharmacogn. Phytochem. J. Pharmacogn. Phytochem.*, vol. 4, no. 3, 2015.

[27] R. Josiah TB and A. O. Oluwadare, “Fibre Characteristics of Delonix regia (Hook .) Raf .

Wood as Indices of its Suitability for Papermaking," *Am. Sci. Res. J. Eng. Technol. Sci.*, vol. 70, no. 1, pp. 34–54, 2020.

[28] S. R. Survase, N. W. A. Sheikh, and S. K. Bais, "Gulmohar (Delonix Regia) a comprehensive review on its phytoconstituents and pharmacological profile," vol. 10, no. 4, pp. 5–12, 2025.

[29] J. Raúl *et al.*, "We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %," pp. 61–78, 2018.

[30] H. Benli, *Bio - mordants : a review*, no. 0123456789. Springer Berlin Heidelberg, 2024. doi: 10.1007/s11356-024-32174-8.

[31] L. J. Rather, M. A. Khan, and F. Mohammad, "Biomordanting Potential of Acacia nilotica (Babul) in Conjunction with Kerria lacca and Rheum emodi Natural Dyes," *J. Nat. Fibers*, vol. 16, no. 2, pp. 275–286, 2019, doi: 10.1080/15440478.2017.1414657.

[32] M. Hosseinnezhad, K. Gharanjig, R. Jafari, and H. Imani, "Green Dyeing of Woolen Yarns with weld and Madder natural Dyes in the Presences of Biomordant," *Prog. Color. Color. Coatings*, vol. 14, no. 1, pp. 35–45, 2021, doi: 10.30509/pccc.2021.81678.

[33] P. Phromphen, "Optimization of Marigold Flower Dye Using Banana Peel as a Biomordant," *J. Nat. Fibers*, vol. 20, no. 1, 2023, doi: 10.1080/15440478.2022.2153193.

[34] M. M. Rahman, J. Koh, and K. H. Hong, "Sustainable Chitosan Biomordant Dyeing and Functionalization of Cotton Fabrics Using Pomegranate Rind and Onion Peel Extracts," *J. Nat. Fibers*, vol. 21, no. 1, 2023, doi: 10.1080/15440478.2023.2290856.

[35] M. O. F. Science, A. Designing, and A. Designing, "Effect of Biomordants on Dyeability of Cotton Fabric With I . C . College of Home Sciences," vol. 125004, 2022.

[36] S. Adeel *et al.*, "Microwave-assisted appraisal of neem bark based tannin natural dye and its application onto bio-mordanted cotton fabric," *Iran. J. Chem. Chem. Eng.*, vol. 39, no. 2, pp. 159–170, 2020, doi: 10.30492/IJCCE.2020.34225.

[37] P. Borah, R. R. Boruah, M. Konwar, S. Baruah, and S. Dutta, “Evaluation of colourfastness properties of cotton fabric dyed with pomegranate rind extract dye,” *~ 2127 ~ Pharma Innov. J.*, vol. 12, no. 8, pp. 2127–2131, 2023, [Online]. Available: www.thepharmajournal.com

[38] P. R. Assistant Professor, “FORMULATION AND EVALUATION OF ANTI-DANDRUFF SHAMPOO FROM THE METHANOL EXTRACT OF DELONIX REGIA (BOJER EX HOOK.) RAF. LEAVES *Corresponding Author,” *Certif. J. │ Palaniswamy al. World J. Pharm. Res. 1257 World J. Pharm. Res. SJIF Impact Factor 8.084*, vol. 12, no. 9, p. 1258, 2023, doi: 10.20959/wjpr20239-28336.

[39] A. Saeed, K. Hassan, and S. Sadaf, “A Review on Colour Fastness of Natural Dyed Textiles,” *Pakistan J. Sci. Ind. Res. Ser. A Phys. Sci.*, vol. 66, no. 2, pp. 201–212, 2023.

[40] A. A. Precious, O. A. Temitayo, and E. C. Morenike, “In vitro anti-inflammatory and antioxidant activities of Delonix regia (Bojer Ex Hook.) Raf. leaf and stem,” *J. Med. Plants Res.*, vol. 19, no. 5, pp. 70–84, 2025, doi: 10.5897/jmpr2025.7401.

[41] N. A. Ibrahim, A. R. El-Gamal, M. Gouda, and F. Mahrous, “A new approach for natural dyeing and functional finishing of cotton cellulose,” *Carbohydr. Polym.*, vol. 82, no. 4, pp. 1205–1211, 2010, doi: 10.1016/j.carbpol.2010.06.054.

[42] R. G. S. M. Ranthunga, K. V. Wanigasekara, and S. V. Udayakumara, “Dyeing of Cotton Fabric with a Natural Dye Extracted from Areca Concinna Peel,” pp. 2–3, 2021, doi: 10.31705/eru.2021.2.

Appendixes

Preparation of gulmohar flower and neem leaf as bio-mordant in the form of power



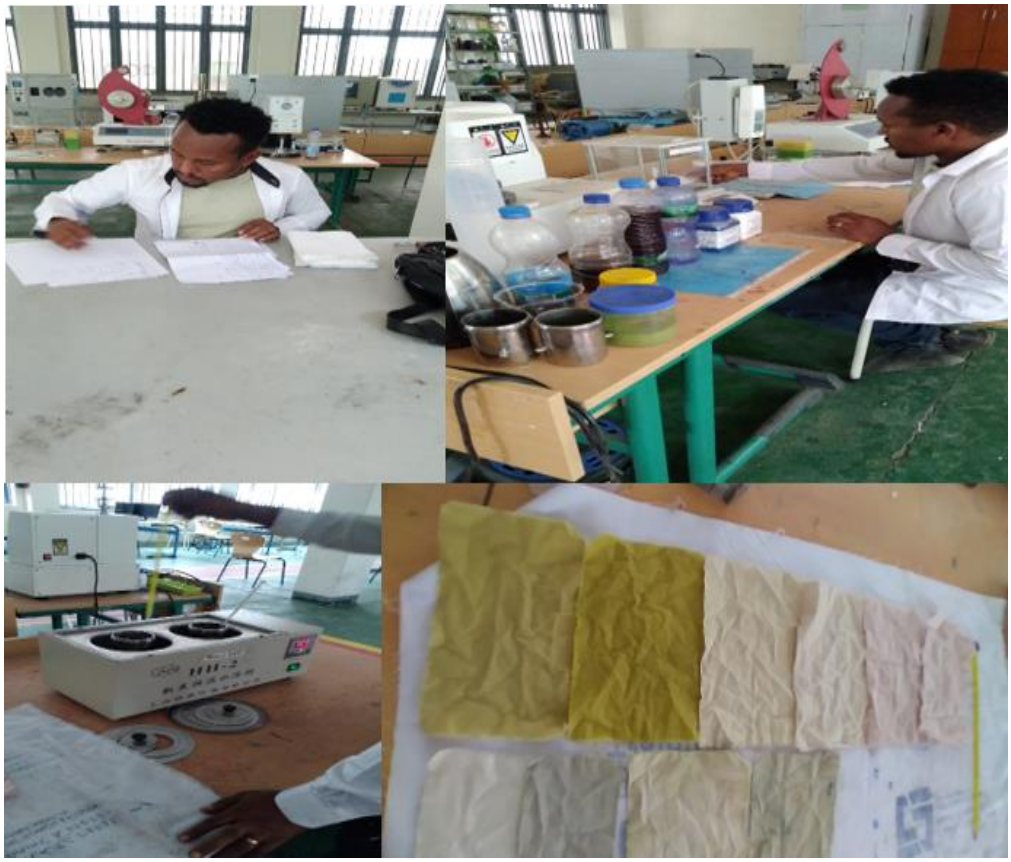
Extraction of dye and bio-mordant from gulmohar flower and neem leaf with soxhlet apparatus



Extracted gulmohar dye and neem bio-mordant in the liquid form



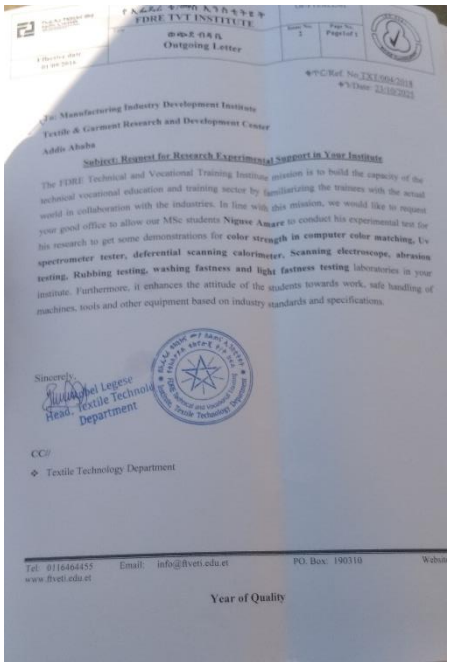
Dyeing process carried out



Testing of dyed sample



supportive letter to manufacturing industry development institute textile and garment research and development center



FDRE TVT INSTITUTE

Outgoing Letter

Ref. No: TXT/004/2018

Date: 23/10/2025

To: Manufacturing Industry Development Institute

Textile & Garment Research and Development Center

Addis Ababa

Subject: Request for Research Experimental Support in Your Institute

The FDRE Technical and Vocational Training Institute mission is to build the capacity of the technical vocational education and training sector by familiarizing the trainees with the actual world in collaboration with the industries. In line with this mission, we would like to request your good office to allow our MSc students **Niguse Amare** to conduct his experimental test for his research to get some demonstrations for **color strength in computer color matching, Uv spectrometer tester, deferential scanning calorimeter, Scanning electroscope, abrasion testing, Rubbing testing, washing fastness and light fastness testing** laboratories in your institute. Furthermore, it enhances the attitude of the students towards work, safe handling of machines, tools and other equipment based on industry standards and specifications.

Sincerely,

Head, Textile Technology Department

CC/

- Textile Technology Department

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