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Effect of Mordants on Percentage Absorption of Rubia Cardifolia Dye

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Abstract

This study examines the impact of various mordants on the absorption of Indian Madder Root dye by cotton fabric. The Indian Madder Root dye, derived from the roots of the Indian madder plant, is a natural, eco-friendly alternative to synthetic dyes. The mordants used in this investigation include ferrous sulfate, copper sulfate, zinc sulfate, magnesium sulfate, aluminum potassium sulfate, and potassium dichromate. The absorption of the dye was measured using a colorimeter at a wavelength of 680 nm. The results show that the transition metal mordants, such as copper sulfate and ferrous sulfate, exhibit the highest percentage absorption, while magnesium sulfate shows the least absorption. The study highlights the significance of mordants in enhancing the binding of dyes to fabric, resulting in improved colorfastness and retention of color. The findings of this research have implications for the textile industry, particularly in the development of sustainable and environmentally friendly dyeing processes.

Keywords: Mordants, Indian Madder Root Dye, Absorption Percentage, Transition Metal Mordants, Rubia Cardifolia, Colorfastness, dyeing.

Introduction

Coloration of fabric and the absorption of dye are critical processes in the textile industry. The rate of colour loss in fabric depends on its dye absorption percentage and the efficiency of the absorption process. Dyes are substances that alter colour by modifying certain complexes when applied to a substrate, primarily utilized in the textile industry where considerations such as cost, efficiency, and wastage are paramount. Mordants play a crucial role by aiding dye binding to fabric, resulting in colorfastness, which refers to the ability of a fabric to retain its colour without fading or running when exposed to various external factors such as water, light, or friction. It is a significant selling point for textiles. Moreover, the prevalence of synthetic dyes contributes to environmental pollution, prompting a shift towards more eco-friendly natural dyes. The local lake near my house has suffered from aquatic pollution and loss of life due to the spillage of synthetic dyes into the lakes. The excessive levels of pollution have caused many families, like mine, to stay away from the lake due to its unpleasant environment. This inspired me to investigate organic dyes such as Rubia Cardifolia made from the Indian madder root dye, and the effects of different metal mordants on their absorption efficacy on cotton fabric.

Research Question

"What is the effect of different mordants (ferrous sulfate, copper sulfate, zinc sulfate, magnesium sulfate, aluminum potassium sulfate, and potassium dichromate) on percentage absorption of the Indian Madder Root dye by cotton fabric when measured using a colorimeter measured at a wavelength of 680 nm?"

Background Information

Dyes: Substances which adhere chemically to the fabric or substrate they are applied to, while their colour arises from their capacity to absorb light within the visible spectrum, facilitated by chromophores—resonating electrons. Additionally, many dyes feature auxochromes, known as colour helpers, which modify the wavelength of light absorbed and therefore change the colour of the object.[1] Natural dyes, derived from plant, animal, or mineral sources, offering sustainable and environmentally friendly alternatives to synthetic counterparts. For this investigation, I studied natural hydrophilic dyes on cellulose substrate fabrics, such as cotton, for coloration, focusing on dyes that maintain their affinity when exposed to water. These colorants are referred to as direct dyes.

Indian Madder Root Dye: It is derived from the roots of the Indian madder plant, is valued for its vibrant red hues. It is a primary dye molecule and not affected by high temperature[2] The Indian Madder root dye is a natural dye, which has several advantages - they are sourced from renewable options, have no external side effects, biodegradable and can be cost effective.[3] Moreover, it is soluble in water (hydrophilic), maintains affinity when exposed to water, and exhibits good colorfastness.

Cotton: It is a lightweight fabric that contains cellulose fibers which are from natural plant sources. Cotton is a commonly used fabric in the textile industry and is dyed through the formation of coordination complexes which involve the cellulose chains. Rubia cordifolia interacts well with cellulose fibers. The chemical structure of the dye molecules and the cellulose fibers of cotton complement each other, facilitating strong and durable colour bonds, making cotton an appropriate choice for this study.

Colorimeter Methodology: A colorimeter measures the intensity of light passing through a sample at different wavelengths. [4]By comparing the intensity of incident light to transmitted light, it calculates the optical density of the sample. Optical density can then be used to calculate the absorption percentage by finding the percentage change of optical density of the dye sample before and after the dyeing process.

Mordants: A mordant serves as a chemical agent facilitating better binding between dyes and fabric. These agents are typically polyvalent metal ions, which form coordination complexes with specific dyes. They adhere to the dye through a process known as chelation, where the metal ion forms a coordinate covalent bond with the dye. This bond creates what is called a "lake," which refers to the coordination complex formed between the metal ion and the dye. This complex arises from a Lewis acid-base reaction, where the ligand (an electron-rich species) binds to the central metal ion (an electron-deficient species). When the metal ion becomes part of the delocalized system of the dye, it induces a colour change while simultaneously reducing the overall energy. Consequently, the absorption of light becomes

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[1] "Chemistry of Dyes." *School of Chemistry | School of Chemistry | University of Bristol*, http://www.chm.bris.ac.uk/webprojects2002/price/colour.htm#:~:text=In%201876%2C%20Witt%20proposed%20that,the%20colour%20of%20the%20dye.

[2] "Madder — Natural Dyes." *Natural Dyes*, naturaldyes.ca/madder.

[3] "Textile Information: Natural Dyes." *Textile Information*, http://textileinformation.blogspot.com/2009/06/natural-dyes.html.

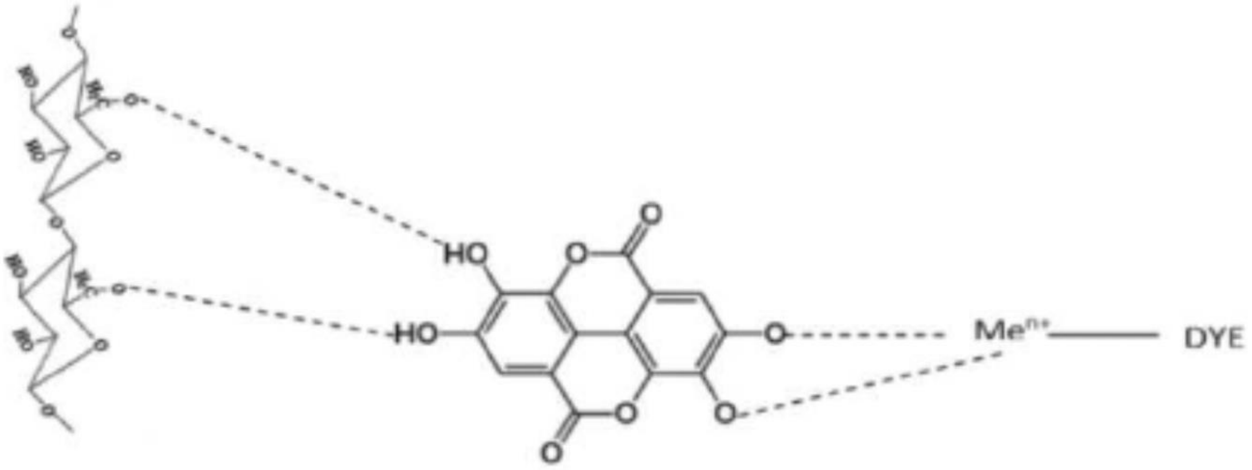
[4] Admin. "Principle of Spectrophotometer and Its Applications| Chemistry| Byjus." *BYJUS*, 18 Aug. 2022, byjus.com/chemistry/spectrophotometer-principle.

connected to this phenomenon. Additionally, dyes are noted to open up the pores of the fabric, enhancing the effectiveness of binding.

1. **Ferrous sulfate, Copper sulfate and Zinc sulfate**: Transition metal sulphates, with their unpaired 3d, 4d, or 5d orbitals, are frequently employed for coloration due to d-d transitions. When introduced to dye solutions, these transition metal ions, possessing partially filled d orbitals, offer vacant orbitals for bonding. Dye molecules, often with ligands containing lone electron pairs, bond with these vacant orbitals through coordinate covalent bonds, enhancing the adhesion of the dye to the fabric, resulting in more vibrant dyeing.
2. **Magnesium sulfate and Potassium dichromate:** Magnesium and Potassium are s block element sand and thus have a much weaker tendency to form coordination complexes. It does not have any vacant d orbitals like the transition elements do, leading to less adhesion and colour change.
3. **Aluminum Potassium Sulfate:** Aluminum ions coordinate with dye and fabric to form complexes, though with lower affinity than transition metals. Despite this, aluminum, unlike magnesium, benefits from a vacant 3d orbital, enhancing efficacy due to its higher charge and smaller size, facilitating complex formation.

Mechanism: The main process involved is adhesion, which refers to two materials to adjoin together via chemical bonds and interactions. The binding of dye and fabric via covalent bond, ionic bond, London dispersion forces, dipole interactions and hydrogen bond. When cotton interacts with dye, the hydroxyl groups on adjacent cellulose chains bond with water and dye functional groups through hydrogen bonding, creating a strong attraction between the dye and cotton fibers, aiding adhesion.

Figure 1: Adhesion of dye and Water Molecule



Hypothesis

Alternate hypothesis: Mordants with transition metal ions such as copper sulfate and ferrous sulfate would show highest percentage absorption. Magnesium sulfate would show the least percentage absorption out of the different mordants, but still have a higher percentage absorption that the control with no mordant.

Null hypothesis: Absorption percentage of fabric exposed to mordants will be statistically similar to plain fabric.

Variables

Independent Variable: type of metal mordant being used (zinc sulfate, magnesium sulfate, copper sulfate, aluminum potassium sulfate, ferrous sulfate, and potassium dichromate).

Dependent Variable: the percentage absorption of dye by cotton, measured by calculating the final and initial optical density measured using a colorimeter.

Controlled Variables:

Table 2: Controlled Variables

Variable	Significance	How it will be controlled
Mordant concentration	Varying concentrations may influence final absorption and color intensity. To isolate the independent variable (type of mordant) so that only it affects absorption consistently, concentration must be controlled for reliable results.	The concentration was 4% for the mordant solutions.
Rubia Cardifolia (dye) concentration	If the concentration of the dye solution differed for some trials, it would affect the absorption and how effectively it binds to the fabric along with the final color of the fabric. Maintaining a constant dye concentration ensures uniform saturation levels and reliable comparisons of absorption levels across trials.	1% concentration dye solution was used for all trials.
Area of fabric piece.	To ensure consistent dye-fabric interaction and absorption rates, essential for accurate and reproducible results in the trials.	The fabric was cut in 3cm-by-3cm squares.
Initial Optical Density	Since the final optical density is changing, the initial optical density of the original entire dye solution must remain consistent for reliable comparison.	The initial optical density measured was kept constant at 1.48.

Volume of solutions	Different volumes of the solution of dye and mordant for each trial can affect the exposure and how much is absorbed by each piece of cotton fabric.	The fabric is dipped into 20cm^3 of mordant solution for pre-mordanting, and 20cm^3 of dye solution for absorption.
Time for drying and heating	Varying drying and heating durations may impact color tone consistency and should be standardized for consistent results across experiments.	The fabric after pre-mordanting was dried for 24 hours. The fabric was heated for 5 minutes in dye solution.
Type of fabric	Fabric should be constant consistent results because each dye and mordant binds differently to different fabrics.	Cellulose type cotton fabric - cotton fabric was 100% bleached and washed.
Time of dipping	Extended durations can result in increased dye exposure, thereby influencing the final color and absorption readings. Keeping duration constant allows for consistent dye exposure.	Fabric pieces were heated for 5 minutes in moderant solutions for pre-mordanting.
Wavelength of colorimeter	Varying wavelengths can yield distinct optical density values, with each wavelength corresponding to a different colored solution. It must remain constant for reliable comparisons.	The optical density was read at 680 nm wavelength.

Apparatus and Chemicals

Table 2: Equipment Required

Apparatus/Equipment required	Quantity
Glass beakers (500ml)	6
Glass beakers (50ml)	35
Conical flask (100ml)	5
Volumetric flask (1000ml)	1
Measuring cylinder (± 5cm^3)	1
Glass rod	1
Tweezer	1

Bunsen Burner	1
Distilled water	1500ml
Scissors (± 0.05 cm)	1
Ruler (± 0.05 cm)	1
Weighing Balance (± 0.01 g)	1
Colorimeter (±0.01)	1
Petri dishes	30

Table 3: Chemicals Required

Chemicals required	**Quantity**
Ferrous sulfate (FeSO4)	4g
Copper sulfate (CuSO4)	4g
Potassium Aluminium Sulfate (KAl(SO4)2)	4g
Zinc sulfate (ZnSO4)	4g
Magnesium sulfate (MgSO4)	4g
Potassium dichromate (K2Cr2O7)	4g
Cotton fabric	35 squares cut 3 cm x 3 cm
Indian Madder root dye powder	6g

Methodology

PHASE I: Setup (preparation of solutions and fabric):

1. Each mordant solution (4%) was prepared by dissolving 4g of mordant (measured using a weighing balance) in 100 cm3 of distilled water (measured using a measuring cylinder) using a volumetric flask and kept in separate glass beakers.
2. The 1% Rubia Cardifolia dye solution was prepared by dissolving 6g of Indian madder root dye powder (measured using a measuring cylinder) in 600 cm3 of distilled water (measured using a measuring cylinder) in a volumetric flask. The dye solution was then transferred to a 1000ml glass beaker.
3. Cotton fabric was cut into 35 squares measuring 3 cm by 3 cm using a ruler.

PHASE II: Pre-mordanting:

4. Since 5 trials are conducted for each moderant, 30 conical flasks are required.
5. A volume of 20 cm^3 of the mordant solution was precisely measured using a measuring cylinder and dispensed into each respective conical flask. For each mordant, there were 5 conical flasks utilized.
6. A single square of cotton fabric was introduced into each conical flask, corresponding to the specific mordant being tested.
7. The solution underwent heating for 10 minutes with gentle agitation using a glass rod, while the fabric was periodically turned overusing tweezers.
8. Subsequently, the conical flasks were removed from the heating apparatus using tongs.
9. The fabric squares were extracted from the conical flasks and transferred to dry petri dishes, where they were left undisturbed overnight for a duration of 24 hours.

10. Steps 4 through 9 were repeated for all six mordants tested. All conical flasks and petri-dishes were labelled to avoid any confusion.

PHASE III: Dyeing:

11. First, the initial optical density of the dye solution was found using a colorimeter, maintaining consistency across all trials. Initially, distilled water was poured into the cuvette and value set to 0. Dye solution was then poured into the cuvette and initial optical density was measured at 680nm.
12. To initiate the dyeing process, 20 cm^3 of the dye solution was dispensed into each washed $80cm^3$ glass beaker.
13. For each specific mordant type, individual pre-mordanted fabric squares were immersed in the respective glass beakers containing the dye solution. Respective glass beakers were labelled with the mordant name to avoid confusion.
14. The solution was heated over a Bunsen burner for 10 minutes, occasionally mixed using a glass rod and periodic turning over of fabric pieces using tweezers.
15. Subsequently, the fabric from each glass beaker was extracted and transferred to dry petri dishes.
16. The final optical density of each solution across the five trials was determined using a consistent protocol similar to that described in step 11.
17. Steps 12 through 16 were systematically executed for all six mordants.

Control test:

18. Steps 12 to 16 were conducted on plain cotton fabric pieces as control for the experiment.

Safety Precautions

- Wear lab coat, gloves and goggles (Personal protective equipment) during the experiment.
- Glassware and equipment to be handled with care to avoid damage.
- Bunsen burner to be handled with care and was switched off when not in use.
- Disposal of chemicals such as dye solution and mordant solution to be done in the fume cupboard, and disposal of dyed cotton fabric pieces in a plastic bag.

Data Analysis

The initial optical density of the dye solution was determined and kept constants for all trials.

The Initial Optical Density of dye solution (± 0.01)	**1.48**

Raw Data

Table 4: Raw Data

Type of Mordant	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
	Final OD (± 0.01)	Final OD (± 0.01)	Final OD (± 0.01)	Final OD (± 0.01)	Final OD (± 0.01)
Magnesium sulfate ($MgSO4$)	1.06	1.09	1.12	1.05	1.08
Zinc sulfate ($ZnSO4$)	0.72	0.68	0.69	0.62	0.73
Copper sulfate ($CuSO4$)	0.68	0.72	0.64	0.69	0.62
Potassium Aluminum Sulfate ($KAl(SO_4)_2$)	0.97	0.92	0.89	0.95	0.92

Ferrous sulfate ($FeSO_4$)	0.81	0.84	0.79	0.83	0.82
Potassium dichromate ($K_2Cr_2O_7$)	0.99	1.01	0.95	1.04	0.98
No Mordant (Control)	1.19	1.21	1.15	1.24	1.14

Processed Data

The percentage absorption was calculated using the formula below, as used by Syed Maqbool.

$$\text{Percentage absorption} = \frac{O.D\ before\ dying\ (initial\ O.D\ ) - O.D\ after\ dying\ (final\ O.D)}{O.D\ before\ dying}$$

For example, for Magnesium Sulfate in trial 1 = $\frac{1.48-1.06}{1.48}\ x\ 100 = 28.37837\% \approx 28\%$

Table 5: Processed Data with Percentage Absorption

Type of Mordant	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
	Percentage absorption (%)	Percentage absorption (%)	Percentage absorption (%)	Percentage absorption (%)	Percentage absorption (%)
Magnesium sulfate (MgSO4)	28	26	24	29	27
Zinc sulfate (ZnSO4)	51	54	53	58	51
Copper sulfate (CuSO4)	54	51	57	53	58
Potassium Aluminum Sulfate ($KAl(SO_4)_2$)	34	38	40	36	38
Ferrous sulfate ($FeSO_4$)	45	43	47	44	45
Potassium dichromate ($K_2Cr_2O_7$)	33	32	36	30	34
No Mordant (Control)	20	18	22	16	23

The mean percentage absorption was calculated using the following formula:

$$Mean = \frac{\text{sum of all trials (trial1+trial2…)}}{\text{number of trials (5)}}$$

For example, for Magnesium sulfate: $\frac{28+26+24+29+27}{5} = 27.02703 \approx 27.0\%$

Table 6: Processed Data with Mean Percentage Absorption and Std. Deviation

Type of Mordant	Average Percentage Absorption (%)	Standard Deviation
Magnesium sulfate (MgSO4)	27.0	1.9
Zinc sulfate (ZnSO4)	53.5	2.9
Copper sulfate (CuSO4)	54.7	2.7
Potassium Aluminum Sulfate ($KAl(SO_4)_2$)	37.2	2.1
Ferrous sulfate ($FeSO_4$)	44.7	1.3
Potassium dichromate ($K_2Cr_2O_7$)	32.8	2.3
No Mordant(Control)	19.9	2.8

Propagation of Uncertainties

For each trial, the percentage uncertainty was found using formula $= \frac{uncertainty\ value\ of\ apparatus}{measured\ or\ calculated\ value}\ x\ 100$

Sample calculation showing how average percentage uncertainty was calculated for $\frac{initial\ O{\cdot}D - final\ O{\cdot}D}{initial\ O{\cdot}D}$

For Zinc sulfate, $\frac{(\frac{0.01}{0.51} \cdot 100\%) + (\frac{0.01}{0.54} \cdot 100\%) + (\frac{0.01}{0.53} \cdot 100\%) + (\frac{0.01}{0.58} \cdot 100\%) + (\frac{0.01}{0.51} \cdot 100\%)}{5} = 1.87\%$

Sample calculation showing how percentage uncertainty for mass of solute added $\frac{0.01}{4}\ x\ 100 = 0.25$

Sample calculation showing how total uncertainty was calculated:

For zinc sulfate, $1.87 + 0.25 + 0.166 + 0.1 + 3.33 = 5.72$

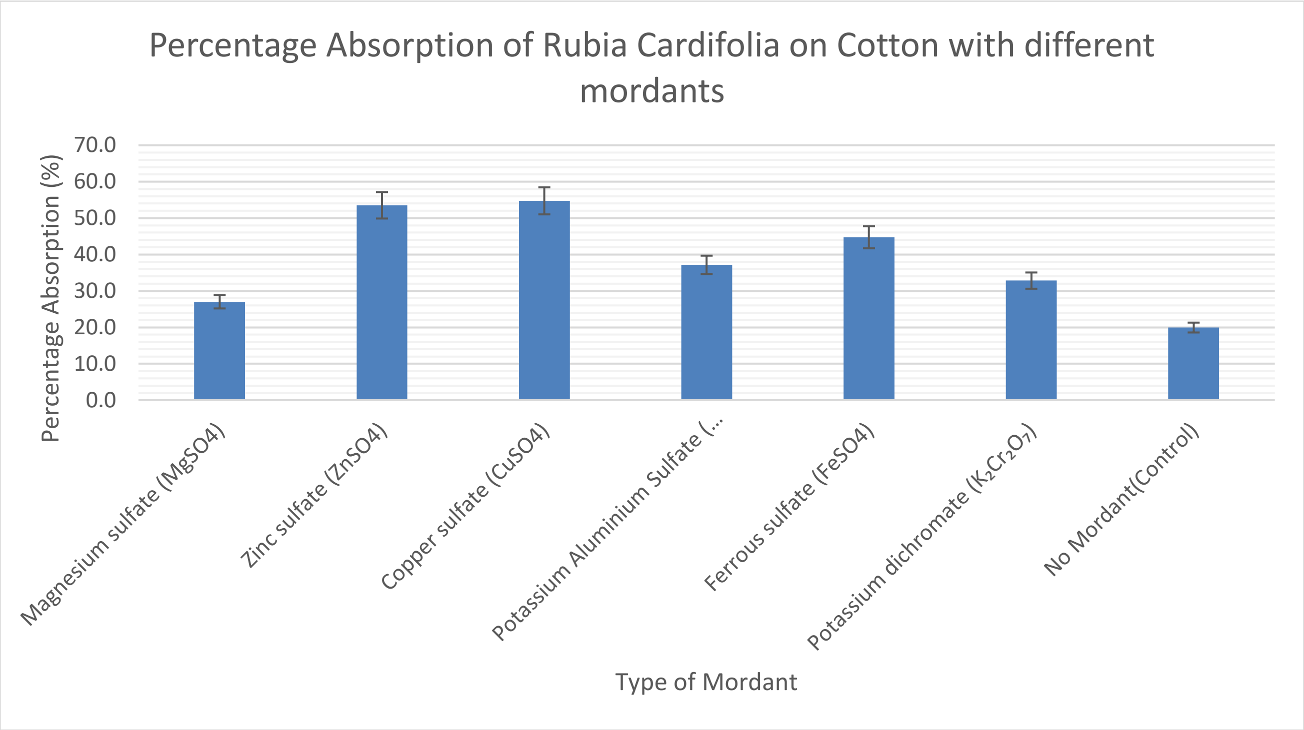
Sample calculation showing how random error was calculated: $\frac{7.56 + 5.72 + 5.68 + 6.54 + 6.08 + 6.90 + 8.94}{6} = 6.78\%$

Table 7: Processed data with error propagation

Type of Mordant	Mean Percentage Uncertainty (Initial OD – Final OD)/Initial OD	Percentage uncertainty: mass of mordant (%)	Percentage uncertainty: mass of dye (%)	Percentage uncertainty: volume of distilled water in solution (%)	Percentage uncertainty: measuring fabric length (%)	Total uncertainty (%)	Random error (%)
Magnesium sulfate	3.71	0.25	0.166	0.1	3.33	7.56	6.78
Zinc sulfate	1.87	0.25	0.166	0.1	3.33	5.72	
Copper sulfate	1.83	0.25	0.166	0.1	3.33	5.68	
Potassium Aluminum Sulfate	2.70	0.25	0.166	0.1	3.33	6.54	
Ferrous sulfate	2.24	0.25	0.166	0.1	3.33	6.08	
Potassium di-	3.06	0.25	0.166	0.1	3.33	6.90	

chromate							
No Mordant (Control)	5.10	0.25	0.166	0.1	3.33	8.94	

Figure 2: Plotted Graph with Results



Data Interpretation

Qualitative Data: The Indian Madder root dye caused different red hues in each fabric, reflecting the different absorption percentages. As ferrous sulfate is a saddening agent, we can see that the colour changes to a much darker colour. The colour change most different from the fabric with no mordant is seen in copper, ferrous and zinc sulfate.

Quantitative Data: The bar graph illustrates the relationship between specific mordants and percentage absorption, as opposed to showing a linear trendline. It's evident from the graph that fabric treated with copper sulfate, owing to its transition metal properties, exhibits the highest percentage absorption, while magnesium sulfate shows the lowest. Fabrics without any mordant display the lowest absorption rates, even lower than those treated with magnesium sulfate, due to the absence of mordants for binding affinity. Transition metal mordants, particularly copper sulfate, demonstrate the highest absorption values. However, the data's reliability is somewhat diminished by slightly large error bars, indicating higher standard deviation. This could be mitigated by increasing the sample size. Comparing the bars without mordant to others, none have overlapping error bars with no error bars, suggesting a statistically significant difference.

Conclusion

The study aimed to answer the research question **“What is the effect of different mordants (ferrous sulfate, copper sulfate, zinc sulfate, magnesium sulfate, aluminum potassium sulfate, and**

potassium dichromate) on percentage absorption of the Indian Madder Root dye by cotton fabric when measured using a colorimeter measured at a wavelength of 680 nm?"

The research question was answered as the alternate hypothesis was confirmed as the transition metal mordants were shown to have the higher percentage absorption of dye, as the metal ion with vacant d orbitals was able to form a much more effective coordination complexes, change colour and increase percentage absorption. The fabric with no mordant was shown with least percentage absorption as there was no mordant to enable the binding between the dye and the fabric.

The data interpreted from Graph 1 is justified using scientific context. Transition metal mordants, including ferrous sulfate, copper sulfate, and zinc sulfate, were investigated for their effectiveness in dyeing textiles. Background research indicated that these particular metals were good choices due to their vacant d orbitals. These vacant orbitals allow the metals to form coordination complexes with the dye molecules and the fabric itself. The formation of these complexes is believed to be responsible for a more intense colour change in the dyed fabric, thus making these transition metal mordants more effective as seen in Graph 1. This is consistent with findings from Manians and Avinash P's study on Metal mordanting in dyeing with natural colorants. Magnesium and potassium have no vacant d orbitals, hence have lower tendency to form complex coordinate bonds, leading to lower absorption percentage. Moreover, Potassium Aluminum sulfate have aluminum have vacant 3d orbitals, higher charge and smaller size, hence displaying a larger percentage absorption compared to magnesium sulfate, as seen in Graph 1. This is further supported in Hooman Imani's study of eco-friendly dyeing of wool using madder extracts, which explains the difference in behaviors of zinc sulfate and magnesium sulfate as mordants and the different processes such as pre-mordanting (done in this study) and meta-mordanting. Without the mordant, the percentage absorption was observed to be the least as no coordination complex or lake was formed without the mordant. This is further supported in Graph 1, with the control showing the least absorption. This is further corroborated by Arsheen Moiz.[5]

Evaluation

Table 8: Strengths of the Experiment

Strengths	Significance
Random error and uncertainty	The random error was seen as (6.78) was relatively low and increases thecertainty or validity of results.
Choice of dye and fabric	Both being natural dyes and fabric was an important environmental consideration in methodology.
Qualitative data and control test.	The qualitative data showed the dye color changes on the fabric and added more evidence to the working of the mordant via color hues, their lightness and depth. Comparisons were made easier due to the inclusion of a control test, helping to verify the efficacy of different mordants.
Precision of Equipment	Equipment used had low reading uncertainties, leading to more precise measurements. For example, the colorimeter and weighing balance had an uncertainty of 0.01, which is insignificant and allows for precise measurements.

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[5] Moiz, Arsheen, et al. "Study the Effect of Metal Ion on Wool Fabric Dyeing with Tea as Natural Dye." *Journal of Saudi Chemical Society*, no. 1, Elsevier BV, Jan. 2010, pp. 69–76. *Crossref*, doi:10.1016/j.jscs.2009.12.011.

Table 9: Weaknesses

Weakness	Significance	Improvement
Initial optical density assumedto be equal	For more accurate data, initial optical density should have been taken for all trials. Assuming it was the same can reduce the reliability of the actual result.	Measure the initial optical density for all trials taking an average
Error bars	The error bars were slightly higher with some overlap in which reduced the validity.	Conduct more trials to improve precision of data collected.
Parallax error	Parallax error could have occurred when measuring lower meniscus of water or dye, accounted as a random error. This causes differences in the measurements in controlled variables leading to inaccuracies.	Eye level should be perpendicular to the measurement readings.
High standard deviation	Higher standard deviation usually shows that the data is more spread out reducing its reliability	Increasing the sample trial size from 5 trials to more would help to reduce the deviation and increase precision of data.
Staining of cuvette during trails	As the same cuvette was used during trials, the madder root dye could have caused slightly staining on the walls, thus affecting the next reading.	Cuvette should be thoroughly washed and dried between trials and readings taken.

Limitations

1. Confounding variables such as temperature and humidity: Environmental factors like temperature and humidity are difficult to control, potentially causing inaccuracies in colorimeter readings. To mitigate this, experiments could be conducted in controlled artificial settings or consistently at similar times of day to minimize variations in conditions.
2. Resource Limitations:_A UV spectrophotometer could be used for more precise and accurate measurements of Optical Density. However, this was not available in our lab and unfeasible to obtain. The dye and fabric may contain impurities which affect the binding of dye, and hence the percentage absorption, limiting the results of this investigation.

Extension

Future studies could explore wash fastness, colour strength, and colour coordinates. For the next phase, wool fabric could be used because it has a stronger tendency to coordinate due to its balanced levels of amino and carboxyl groups. Other processes such as meta mordanting[6] could be investigated and compared.

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