

**“STUDIES ON COMPUTER AIDED COLOUR MEASUREMENT,
MATCHING AND COMPATIBILITY OF DYES FOR COMPOUND
SHADES PRODUCTION ON TEXTILES USING NATURAL DYES”**

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Chapter 1

Introduction

Textile materials (natural and synthetic) used to be coloured for value addition, look, and the desire of the customers. Anciently, this purpose of colouring textiles was initiated using colours from natural sources until synthetic colours and dyes were invented and commercialized. Due to the ready availability of pure synthetic dyes of different types and classes and their cost advantages, most textile dyers and manufacturers shifted towards the use of synthetic colourants. Almost all the synthetic colourants being synthesized from petrochemical sources through hazardous chemical processes pose a threat to their eco-friendliness. Hence, worldwide, growing consciousness about the organic value of eco-friendly products has generated renewed interest among consumers in the use of textiles (preferably natural fibre products) dyed with eco-friendly natural dyes. Natural dyes have been known for their use in the colouring of food substrates, leather, and natural fibres like wool, silk, and cotton as major areas of application since pre-historic times. Although this ancient art of dyeing textiles with natural dyes withstood the ravages of time, due to the wide availability of synthetic dyes at an economical price, a rapid decline in natural dyeing continued.

The consumption of synthetic dyes is more than one million metric tonnes per year, and more than 1000 metric tonnes of natural dyes are required, which is almost 1% of the world's synthetic dye consumption. However, even after a century, the use of natural dyes has never eroded completely, and they are still used in different parts of the world. Thus, natural dyeing of different textiles and leathers has been continued mainly in the decentralized sector for specialty products, besides the use of synthetic dyes in the large-scale sector for general textiles and apparel. (Gulrajani, 2001).

All the local craftsmen/artisans are extracting the dyes themselves and dyeing as per their skills. Besides that, many organizations are producing the dyes. Some Indian companies are: Satal Katha, Sam & Ram, Amma Herbal, D. Manohar Lal, etc. (Gulrajani, 2001).

Natural dyes have a complex chemical constitution. Unlike synthetic dyes, they are usually not a single entity but a mixture of closely related chemical compounds. Natural dyes have been grouped together as a class in the color index. In Volume 3 of the color index, 32 natural reds, 6 natural oranges, 3 natural blues, 5 natural greens, 29 natural yellows, 12 natural browns, 6 natural blacks, and 1 natural white have been listed (Saxena & Raja, 2014). Natural dyes available in primary colours: In the colour index, the natural dyes are classified according to hue, and there are 28 yellow dyes, 3 blue dyes, and 32 red dyes. Red colour dyes: Most red dyes are hidden in the roots or barks of plants or camouflaged in the bodies of dull grey insects. They are almost invariably based on anthraquinone and its derivatives. These dyes are stable to light and wash. Yellow colour dyes: Yellow is the liveliest and perhaps the most abundant of all hues in nature. About 90% of the yellow dyes are flavonoids. Generally, they produce a pale shade with quicker fading, except turmeric, which produces a dull, deep shade but is considered susceptible to light as it emits fluorescence. The

wash fastness rating of natural yellow dyes ranges from fair to excellent, e.g., tesu, turmeric, and kapila. Blue dyes, such as indigo and wool, give excellent fastness to light and washing. An attempt will thus be made to find the gamut of suitable natural dyes that are compatible, thus producing spectral data to formulate the recipe by spectrophotometer.

1.1 Statement of the problem

As the scope of organic and natural products is increasing day by day, the use of natural dyes in textiles is also picking up pace. In this scenario, lots of scientific research is going on to increase the use of natural dyes. Many researchers are trying to simplify the process of natural dyeing in many possible ways. Many studies are available in the literature regarding the extraction, application, dyeing behavior, antibacterial activities, and others of many individual natural dyes. However, the reports on applying natural dyes in combination are very scanty. There is a well-established method for computerized color matching for synthetic dyes, but for natural dyes, such studies are not found in the literature. Readily available reports on compatible dyes will make it easier for natural dye users to produce a variety of mixed shades. Computerized prediction of recipes would further smooth the task of natural dyers. Against this background, it is thought to provide a wide range of information on natural dye compatibility for selected dyes to the people working in large or small sectors and the researchers working in this field so that it may be easier for them to make mixed shades using natural dyes. Combinations of natural dyes in compound shades will provide a variety of newer or less common shades. In this study, therefore, an attempt will be made to find the gamut of compatible natural dyes, thus producing spectral data to formulate the recipe by spectrophotometer.

1.2 Objective of the research

- To optimize the extraction process of selected natural dyes
- To find the optimal dyeing parameters of selected natural dyes on cotton fabric
- To dye the cotton fabric with binary and tertiary mixture of natural dyes
- Assessment of compatibility for a mixture of dyes using qualitative and quantitative methods
- Spectral database creation for the selected dyes using a computer-aided spectrophotometer.
- To predict the recipe for certain standard shades using a spectral database in a spectrophotometer
- To analyze the fastness properties of selected dyed samples

1.3 Delimitation of the study

- The study was limited to only 8 natural dyes, namely Marigold, Pomegranate, Madder, Sappanwood, Rhubarb, Annatto, Katha (Catechu), and Babool (Acacia

Nilotica)

- The study was limited to cotton and the use of alum mordant using the pre-mordanting method
- The study was limited to exhaust method of application

1.4 Scope of the Study

- The study attempts to find the optimized extraction conditions for selected dyes and optimized dyeing conditions for them on cotton fabric.
- The study will attempt to find out the compatible/ non-compatible set of dyes from a set of dyes using different methods. This will give rise to the possibility of producing new shades using compatible dyes.
- This study will attempt to predict the recipe using a spectrophotometer. The dyer can predict the recipe for a particular standard, as done in the case of synthetic dyes.

Chapter 2

Literature Review

2.1 Research Review related to Compatibility Assessment Methods

Most of the dye producers are providing the different tones and hues of the three basic colours. They try to provide as many tones as possible by changing the structure of the dye. To dye a piece of fabric for any given colour standard, three colours are generally required. If the dyer is lucky enough, the same tone may be obtained by single dyeing or combining two dyes, but this is a rare phenomenon. Mostly, the dyer would require three primary colours. The dyer's task of mixing the dyes and getting a shade out of them is not an easy one. The dyer has to check the compatibility of the dyes being mixed. The optimum dyeing conditions may be different for different dyes. The fastness properties of the different dyes may be different, or the mixture may change the tone during the dyeing cycle. Reproducibility of the shade is a very crucial matter of concern for the dyer. There is scope for improvement using better compatible dyes (Sivaramakrishnan, 2014). All the dyes in the mixture should have the same rate of dyeing. They should have similar rates of exhaustion when used in mixtures under the given dyeing conditions. During dyeing, the colour of the goods will then gradually become deeper, but, since the dyes are absorbed in the same proportions throughout the process, the hue does not change, and the goods will always be in shade (Broadbent, 2001).

In the AATCC technical manual (1989) compatibility is defined as **"the propensity of individual dye components in a combination shade to exhaust at similar rates resulting in a buildup of shade that is constant or nearly constant in hue throughout the dyeing process"**.

In this way, several dyeing parameters are mentioned in the literature, which define the compatibility of dyes. Many researchers have attempted to define the qualitative and quantitative methods for compatibility.

Methods to find the compatibility of a combination of dyes need to check different aspects of color parameters. Various methods have been developed to check the compatibility by different authors. These include methods such as dip test, plotting ΔL versus K/S or ΔC versus K/S , using diffusion coefficient values, and finding relative compatibility rating (RCR), a newer method for compatibility check. Most of the methods used do far used for the synthetic dyes (Garg & Chattopadhyay, 2019).

Sultana & Uddin (2007) checked the compatibility of dyes using a dip test. In this test, small pieces of cotton of equal weight are dyed in the same bath with a mixture of dyes. At various intervals, a small dyed sample is removed from the bath and replaced by an identical piece of undyed fabric. A series of dyed samples arranged in order of increasing dyeing time will have gradually decreasing color depth, but the invariant hue when the dyes used are compatible.

Mclaren (1976) devised an objective method with a view to answering the doubts and disputes caused by the earlier methods of assessing compatibility because of its subjective nature. With the introduction of color measurement systems, a series of compatibility tests can be assessed by measuring, e.g., the hue angle. Compatible mixtures will have approximately the same hue angle throughout the dyeing process.

Datye & Mishra (1983, 1984) introduced a technique that involves plotting the lightness (L) versus the chroma (C) for dyeing nylon, polyester, and acrylic fibers. This technique utilizes different combinations of dispersion dyes. The qualitative demonstration of the compatibility level of a specific mixture can be achieved by observing the proximity or complete alignment of plots for dyes that share a close resemblance in color.

Samanta et al. (2015) assessed the compatibility by plotting ΔL versus K/S or ΔC versus K/S. It is generally used for compatibility assessment of two dyes for two sets of the progressive depth of shade developed for a binary mixture of dyes. It is done by varying the temperature and time of dyeing for one set and varying the total dye concentrations of the binary mixtures of dyes in another set to judge whether the two sets of curves for shade buildup run alike or not. A plot of ΔL versus ΔC and ΔL versus K/S gives better results than other methods because it assumes that there is no interaction between dyes and no change in the rate of dyeing in the presence of another dyestuff, which is not true. A plot of ΔL versus ΔC and ΔL versus K/S would require a precise temperature-controlled machine for progressive shade buildup. This method is time-consuming and subjective.

Teli, Sheikh, Mahalle & Labade (2012) reported a study of self and mixed shades of catechu and heena on cotton and silk using harda as a natural mordant. The analysis was encouraging as the results showed a wide range of shade gamut. The effect of pH on the color depths of different dyes in compound shades was also examined. Other shades were possible to obtain at different pH. The fastness properties remained unchanged even with the combination of dyes.

Teli, Valia & Agrawal (2014) reported a study of mixed shades of Indian madder and sappanwood on cotton and silk fabrics using alum and ferrous sulphate as mordants. Mixed shades were developed by increasing the proportion of sappanwood at the cost of madder, the samples treated with alum mordant showed darker and brighter shades, and samples treated with ferrous sulphate showed deeper but duller shades of red on both cotton and silk, with good wash and light fastness ratings.

2.2 Research Review related to Compatibility of Dyes in Combination

Many researchers have assessed the compatibility of dyes using the methods mentioned above. The assessment was done majorly in the area of synthetic dyes for different classes of dyes like direct dyes, reactive dyes, disperse dyes, etc. The outcomes of some of those studies are mentioned in this section. Later, few researchers attempted to assess the compatibility of

natural dyes. Some of those studies are also mentioned.

Shukla & Dhuri (1993c) utilized three distinct binary combinations created by combining disperse dyes of similar hues onto polyester fabric at a total depth of shade of 4.0%. The binary mixtures were evaluated qualitatively by analyzing the variations in CIELAB color coordinates, specifically in relation to the undyed substrate. Various plots were built to visualize these differences. The hue angle and K/S values were measured as well. The compatibility behavior of three binary combinations, both with and without a leveling agent, has been elucidated based on the molecular mass and color strength of the constituent dyes.

Collishaw, Glover, & Bradbury (1992) found that using dyes with comparable profiles in combination assures that they are fully employed, spread evenly, and fixed as a single dye, resulting in a consistent color angle throughout the process. Hence, while selecting dyes for binary and ternary shades, it is crucial to examine the compatibility of the individual profiles and any potential impact of dye-dye interaction. The researchers analyzed the behavior of individual colors in mixture using cell transmission measurements. The suggestion is to choose dyes that have been molecularly engineered to have compatible profiles. This will minimize sensitivity to both assignable and random variables in the production environment, resulting in better dyeing performance in exhaust application.

In their study, Kamel, Shakra, & Zayat (2001) conducted dyeing experiments on cotton using combinations of 3 direct dyes. The objective was to determine the parameters that influence the color properties exhibited by a single dye when combined with other dyes. They noticed that some colors overpower others in mixtures while others enhance the transmission of their own color qualities and diminish the impact of other dyes.

It was observed by Kumar Samanta & Agarwal (2009) that the use of a mixture of turmeric and madder on cotton in case of simultaneous mordanting shows a synergistic effect in color development than that for single dye application; a 50:50 ratio of turmeric and madder gives the best results. For the combined dye application, it is observed that in the case of the simultaneous mordanting method, turmeric, when combined with either madder or red sandalwood gives better color strength, while myrobolan shows the reverse trend.

In a study by Samanta, Agarwal, & Datta (2008), bleached jute fabric that had been pre-mordanted with 20% myrobolan and 20% aluminium sulphate was dyed by altering the proportions of binary mixtures comprising aqueous extracts of jackfruit wood (JFW) and other natural dyes such as marigold (MG), sappanwood (SW), manjistha (MJ), and babool (BL). The compatibility was determined using both the traditional and modern approaches (by finding RCR). The order of relative degree of compatibility of these binary pairs of natural dyes applied on pre-mordanted jute was found to be $JFW:RSW \geq JFW:BL \geq JFW: MJ \gg \gg JFW: MG \gg \gg JFW: SW$.

Chapter 3

Materials and Methods

3.1 Materials

3.1.1 Cotton Fabric

Ready for dyeing (R.F.D.) bleached 100% cotton cambric fabric was selected for this study. The fabric was procured from R.M.P. Fab Sourcing Pvt. Ltd., Faridabad, Haryana, India.

3.1.2. Chemicals, Dyes and Auxiliaries

Citric Acid $C_6H_8O_7$ (anhydrous), Sodium Carbonate Na_2CO_3 , Alum (Aluminium Potassium Sulphate) $KAl(SO_4)_2 \cdot 12H_2O$, and non-ionic detergent were used in this present work. All these were laboratory-grade chemicals from Fisher Scientific and Loba Chemie Pvt. Ltd. The details of dye materials used were as per Table 1 and were procured from Jaipur.

Table 1 : List of dyes used

S. No.	Common name	Hindi Name	Botanical name	Color used	Code Given
1	Madder	Manjistha	Rubia Tinctorum	Red	D
2	Sappanwood	Pathangi	Caesalpinia Sappan	Pink	S
3	Annatto	Sinduri	Bixa Orellana	Orange	A
4	Marigold	Genda	Tagetes Erecta	Yellow	M
5	Pomegranate	Anar	Punica Granatum L.	Yellow	P
6	Catechu (called as Katha in this study)	Katha	Acacia Catechu	Brown	K
7	Bark of Acacia (called as Babool in this study)	Babool	Acacia Nitotica	Brown	B
8	Himalayan Rhubarb	Dolu	Rheum Emodi	Brown	R

3.1.3. Instruments and Apparatus

Electronic pH meter, Electronic Weighing Scale, HTHP Beaker Dyeing Machine; Make- R. B. Electronic & Engineering Pvt Ltd., Laundrometer and Crock meter; Make-Ramp Impex Pvt Ltd., Light fastness tester; Make - Innolab, Shimadzu Spectrophotometer for optical density, Konica-Minolta Spectrophotometer, model-3600d for dyed samples were used in thiswork.

3.2 Methods

This part includes a pilot run and an experimental study. The pilot run acted as the basis of experimental work, including optimizing the extraction and dyeing process. The experimental work includes the dyeing in mixture and recipe prediction work.

3.2.1 Pilot study

Optimization of extraction parameters for all the selected dyes

Dye material for Marigold, Pomegranate, Madder, Annatto, Acacia Nilotica, Sappanwood, Rhubarb and Catechu dye material were taken for extraction optimization. This was done using a range of temperature, time and MLR. The extracted dyed solution was measured using a spectrophotometer to obtain the absorbance value / optical density to find the maximum color extract for each dye.

Optimization of Dyeing Parameters

Box Behnken's design of experiment was used for the experimental setup as indicated in Table 2. 17 samples were dyed for each dye, with a total of 136 samples for all 8 dyes to find the optimum dyeing condition for each dye. The detailed recipe and dyeing procedure followed are mentioned below:

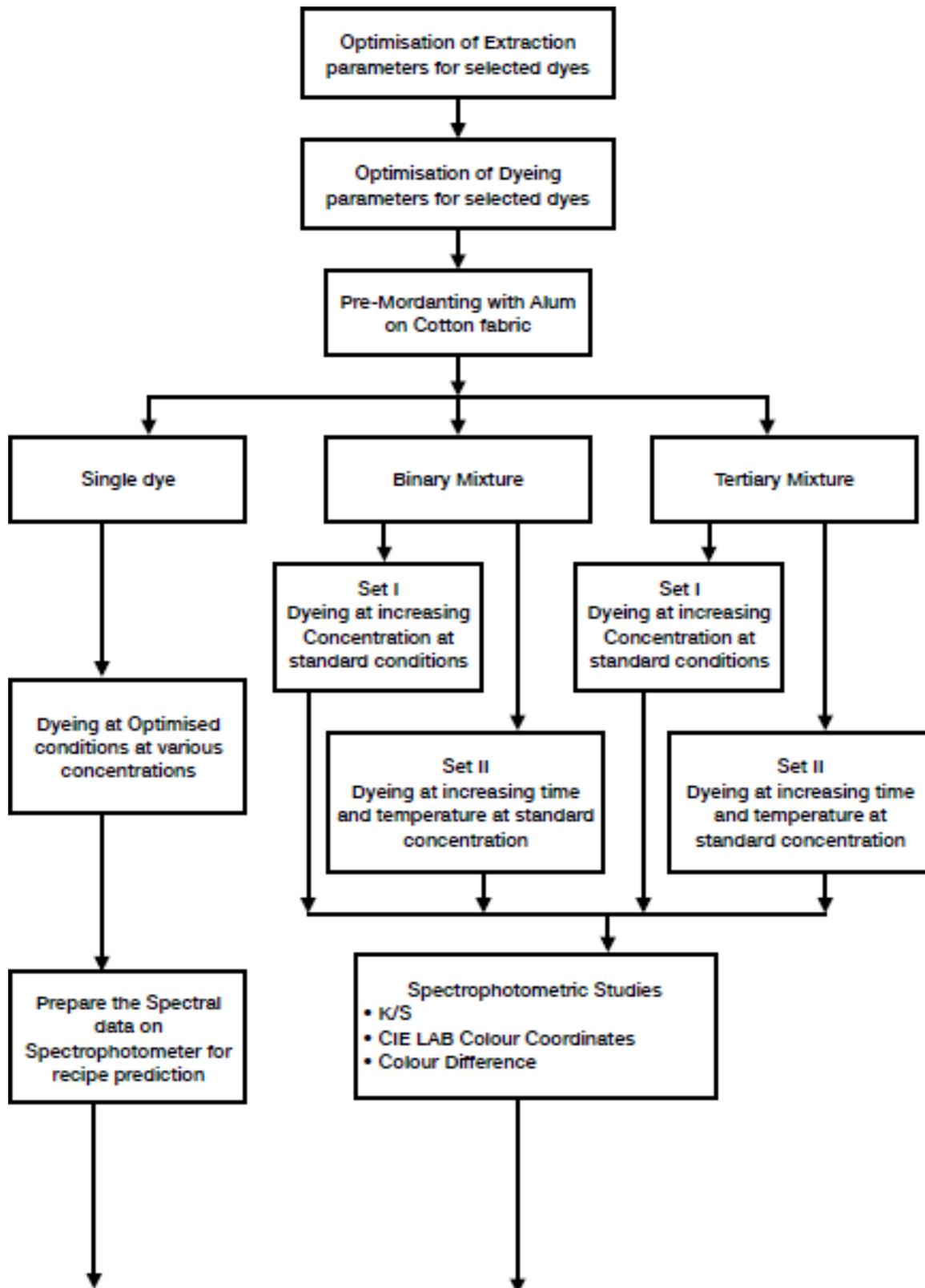
Dye extraction was done as per requirement at optimum extraction conditions. Ready for dyeing (R.F.D.), bleached cotton cambric fabric samples were mordanted using alum (5% owf) with M.L.R. – 1:60, temperature – 90°C for 60 mins. After the complete process, the samples were rinsed twice to remove the excess alum particles on the surface to prepare them for dyeing. The dyeing of pre-mordanted samples was done at M.L.R. 1:90 with 30% owf extracted dye material at a range of pH, time, and temperature.

Table 2: Experimental Setup for Optimization of Dyeing Parameters

Control Factors	
Parameter	Values
pH	3,5,7
Temperature (°C)	65, 80, 95
Time (min)	30, 60, 90
Response Variable: Surface Color Strength (K/S)	

The optimized parameters were then found based on the maximum K/S obtained for each dye. Using the obtained value of K/S, the best 6 dyes were obtained to complete a set of two yellow, two red/orange, and two brown dyes. The common dyeing conditions for all the dyes had to be found to dye the binary and tertiary mixtures. The common dyeing conditions were found using the design expert software to maximize K/S for each.

Schematic Diagram of Work Plan



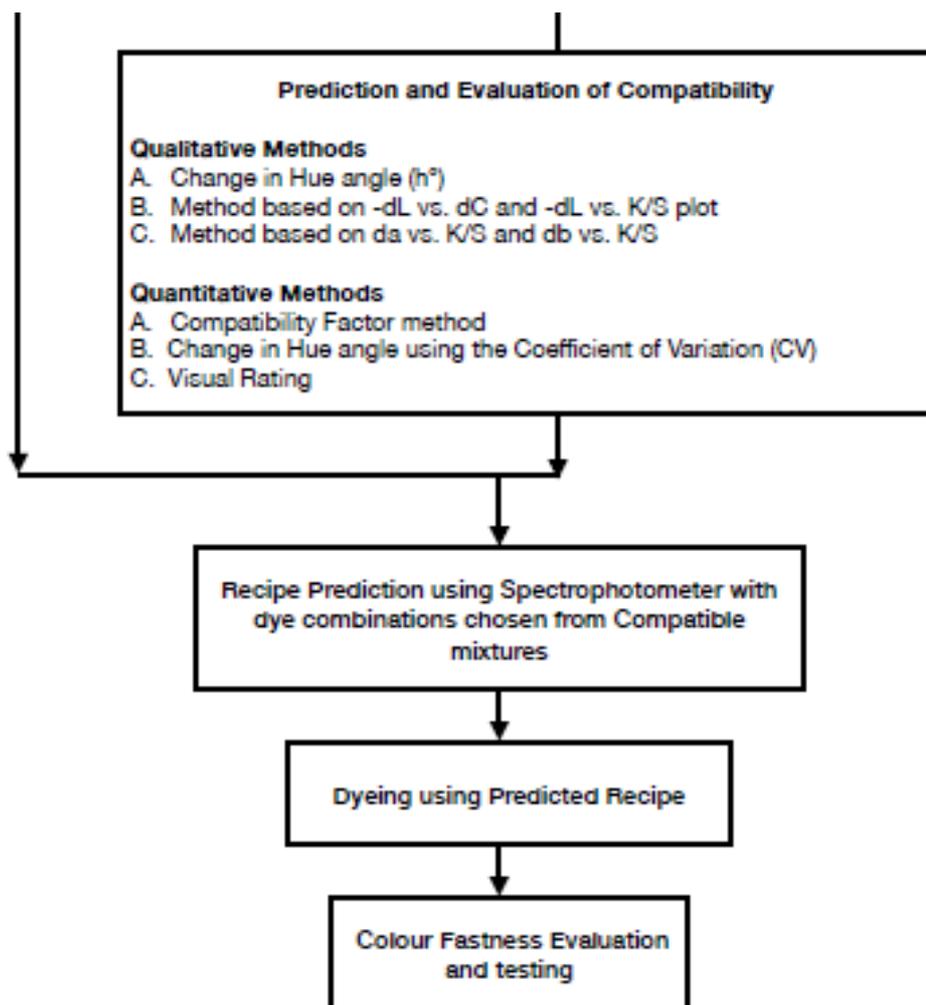


Figure 1: Schematic Diagram of Work Plan

3.2.2 Experimental Study

The common dyeing condition for all the dyes obtained from the pilot study was used for the experimentation. As per the objectives of the study, the following work was done in this part of the study:

- Dyeing using binary and tertiary dye mixtures
- Dyeing of primary dyes at various percentages for spectral data
- Prediction of recipe and dyeing of samples as per standard

Dyeing using Binary and Tertiary dye mixtures

In the case of binary mixtures for 6 dyes, a total of 12 mixtures were possible, and in the case of tertiary mixtures, a total of 8 mixtures were possible. For each mixture, two sets of samples were prepared, *viz.* set I and set II. For each set I, six samples were dyed at an equal increment of color percentage up to the total depth of shade of dye mixture with an equal concentration of the component dyes. The dyeing of all the samples in the set I was done at the common dyeing condition found in pilot study. For set II, six samples were dyed with

specific time period intervals with a corresponding increase in temperature, keeping the constant concentration (with an equal concentration of component dyes).

A total of 144 samples were dyed for 12 binary mixtures, and 96 samples were dyed for 8 tertiary mixtures.

Dyeing of Primary Dyes at various percentages for spectral data

Dyeing of each of the 6 selected dyes was done at varied percentages to prepare the spectral data using a spectrophotometer for recipe prediction. 10 samples were dyed for each dye starting from the minimum to maximum possible concentrations.

The following recipe and dyeing process used for the dyeing of these samples:

Extracted dye material (% owf) – 1%, 2%, 4%, 8%, 12%, 20%, 24%, 32%, 40%, and 44%.

MLR – 1: 90, Temperature - 85°C, pH – 7, Time – 90 mins

10 samples were dyed for each dye. A total of 60 samples were dyed for 6 dyes. These samples were scanned using a spectrophotometer and served as spectral data to predict the recipe.

Prediction of Recipe and Dyeing of samples as per standard

As per the study's objective, the recipe was predicted for several chosen standards using computer color-matching (CCM) equipment. The predicted recipe for each standard was used to dye the samples. The suitable standards from the PANTONE – Cotton planner were selected.

3.3 Testing and Evaluation

3.3.1 Optical Density measurement

3.3.2 Computer Color Measurement using Spectrophotometer

The color parameters were measured using Konica-Minolta Spectrophotometer, model-3600d. The measurement was done in a commonly used Daylight (D-65) illuminant with a 10° standard observer over the 400-700 nm range. The R.F.D. fabric was used as standard, and the color difference values dL^* , da^* , db^* and dC^*_{ab} were also determined. The CIE color coordinate values were used to find the optimization of dyeing parameters, compatibility in the dye mixture and shade matching.

3.3.3 Compatibility Evaluation

Set I & II dyed samples were obtained by binary and tertiary dyes mixture. Both sets have 6 samples each for the respective mixture. The compatibility was evaluated using the methods as below:

3.3.3.1 Qualitative Methods

- A. Change in hue angle (h°)
- B. Method based on $-dL$ vs. dC and $-dL$ vs. K/S plot
- C. Method based on da vs. K/S and db vs. K/S plot

A. Change in Hue Angle (h°)

The hue angle (h°) values indicate the hue and depend on the a^* and b^* in CIELAB

coordinates. The plot of hue (h°) values against the samples in set I and set II shows the change in hue with time, temperature, and concentration. The compatibility of the dyes in the mixture was determined by observing whether there was any alteration in color between the samples dyed at different time, temperature, and concentrations.

B. Method based on -dL vs. dC and -dL vs. K/S Plot

For a binary or tertiary mixture, plots of -dL vs. dC were made for both set I and set II. The compatibility analysis was done based on the closeness of curves for set I and set II. In the same way, the plots of -dL vs K/S were made for both set I and set II. The compatibility analysis was done based on the closeness of curves for set I and set II (Samanta et al., 2015)

C. Method based on da vs. K/S and db vs. K/S Plot

Shukla & Dhuri, (1993) used the plots of da vs. K/S and db vs. K/S to check the compatibility of dyes. It was desired that the redness or yellowness buildup should be in accordance with K/S for both sets. In the case of compatible mixtures, the curves for set I and II in plots of da vs. K/S and db vs. K/S should coincide. The compatibility is assessed by observing the curves for both sets.

3.3.3.2 Quantitative Methods

- A. Compatibility factor method
- B. Change in hue angle using the coefficient of variation (CV)
- C. Visual rating

A. Compatibility Factor method

The ratio between the estimated and observed K/S values for the mixture at the respective λ_{max} of component dyes should be as close as possible for compatibility. The reported K/S ratio of the estimated mixture to the observed mixture is denoted as the compatibility factor (C.F.). The compatibility factor (CF) should ideally be '1'.

$$C.F. = \frac{(K/S) \text{ mix calculated}}{(K/S) \text{ mix observed}}$$

B. Change in Hue Angle using the Coefficient of Variation (CV)

The coefficient of variation was calculated to check the hue angle (h°) variation in both the mixture sets. The coefficient of variation was also used to give the compatibility rating for variation in hue angle (h°) values among all the 12 binary mixtures. The same rating method was used for 8 tertiary mixtures.

C. Visual Rating

Two observers were asked to rate the 12 binary and 8 tertiary mixture samples for compatibility. They were asked to rate the samples out of 30 points for binary and out of 20 points in case of tertiary mixtures. The average rating of both observers was used to give a

rating for the samples. The rating was converted into ranks to calculate Spearman's rank correlation coefficient. The value of the coefficient indicated the correlation between the two observers.

3.3.4 Colour Fastness Evaluation

Colourfastness to washing, light and rubbing tests were conducted on samples from pure dyes, binary and tertiary combinations.

- Color fastness to washing was done using test method AATCC 61-2009 (1B).
- Color fastness to light was done using test method ISO-105-B02
- Color fastness to rubbing was done using ISO 105/X-1984 method.

3.3.5 Anti-Microbial Testing

Anti-microbial testing was carried out by using AATCC 100:- 2019 (Using Nutrient Agar) test method.

Chapter 4

Results and Discussion

4.1 Pilot Study

Optimization of Extraction parameters for all the selected dyes

Optimized extraction parameters for all the dyes are mentioned in Table 3. It shows that the optimized MLR in all the cases was 1:10. The optimized temperature for all the dyes was 100°C except for Babool dye at 80°C. The optimized extraction time for many dyes was 90 minutes, and it was 60 minutes for Annatto, Babool, and Pomegranate dyes. All the dyes were extracted using these conditions for all the dyeing purposes.

Table 3: Optimized extraction conditions for dyes

Dye	MLR	Temperature (°C)	Time (min)
Annatto	1:10	100	60
Madder	1:10	100	90
Sappanwood	1:10	100	90
Babool	1:10	80	60
Katha	1:10	100	90
Rhubarb	1:10	100	90
Marigold	1:10	100	90
Pomegranate	1:10	100	60

Optimization of dyeing parameters and finding the Common dyeing conditions

Table 4 shows the data predicted by design expert software using the Box-Behnken method. It was found that optimized conditions for all the dyes were at the near neutral pH, temperature - 65°C to 95°C and time – 60 mins to 90 mins.

It shows each dye's predicted optimum dyeing conditions with K/S (Individual maximum). The common dyeing conditions for all the dyes were also obtained using the software, keeping the condition for maximum K/S for all the dyes. The common dyeing conditions were used for binary and tertiary mixtures. The common conditions obtained were pH – 7, temperature- 82.8°C, and time – 88 mins. The nearest dyeing conditions were used for ease in practical dyeing: pH – 7, temperature- 85°C, and time – 90 mins.

Table 4: Optimum and common dyeing conditions for all dyes

Dye Name	pH	Temperature (°C)	Time (min)	K/S (Individual Maximum)	K/S (at common dyeing condition)
Katha	7.00	95.00	81.84	2.538	2.327
Marigold	7.00	65.00	90.00	0.861	0.756
Rhubarb	7.00	94.00	85.00	1.185	1.152
Pomegranate	6.94	65.09	89.38	3.774	3.303
Madder	7.00	95.00	60.00	4.447	3.786
Annatto	6.99	84.34	81.39	0.976	0.961
Babool	7.00	95.00	90.00	2.395	2.253
Sappanwood	7.00	95.00	67.75	0.821	0.671
Common conditions by Design expert software	7.00	82.86	88.07		
Dyeing conditions used	7.00	85.00	90.00		

K/S (at common dyeing conditions) was also predicted for all the dyes. It showed the predicted K/S when common dyeing conditions were taken, and it was found that there was a slight decrease in K/S due to a change in optimum dyeing conditions.

4.2 Experimental Study

4.2.1 Dyeing Results and Compatibility Assessment for dye mixtures

4.2.1.1 Qualitative Methods

(A) Change in Hue Angle (h°)

- In the case of change in hue angle method (qualitative) for binary mixtures, it was observed that the samples in set I show less variation than set II samples. It means that the hue angle varied more by varying the time and temperature than by concentration change. It was also observed that in some cases, initial samples (no. 7 and 8) of set II samples are yellower than others. It showed that Pomegranate and Marigold had higher affinity than few other dyes.

- **Binary mixtures:** Mixtures of Pomegranate/Madder (PD), Pomegranate/Babool (PB), Babool/ Madder (BD), Katha/Annatto (KA), and Marigold/Madder (MD) showed low variation in hue angle. They were considered to be satisfactory compatible mixtures using this method. Mixtures of Marigold/Katha (MK), Katha/Madder (KD), Babool/Annatto (BA), and Marigold/Babool (MB) showed average variation in hue angle. These mixtures were considered partial compatible using this method. High variation was shown by Pomegranate/Katha (PK), Marigold/Annatto (MA), and Pomegranate/Annatto (PA) mixtures, which were considered incompatible mixtures in this analysis.
- **Tertiary mixtures:** It was observed that the mixtures of Pomegranate/Katha/Madder (PKD) and Marigold/Babool/Madder (MBD) showed low variation in hue angle. They were considered to be satisfactory compatible mixtures using this method. Mixtures of Marigold/Katha/Annatto (MKA), Marigold/Katha/Madder (MKD), Pomegranate/Babool/Annatto (PBA), Pomegranate/Babool/Madder (PBD) and Pomegranate/Katha/Annatto (PKA) showed average variation in hue angle. These mixtures were considered partially compatible using this method. This analysis showed high variation in the Marigold/Babool/Annatto (MBA) mixture, which was considered incompatible.

(B) Method based on -dL vs. dC and -dL vs. K/S Plot

- In the case of plots for -dL vs. dC, -dL vs. K/S, da vs. K/S, and db vs. K/S method, it was visible from the plots that both the curves of set I and set II were not represented by a single curve. Generally, both curves were distinct, and the set II curve joined the set I curve. Both curves took the common path toward the end of the curves. This was true for binary and tertiary mixtures.

Binary Mixtures:

- It was visible from the plots that both the curves of set I and set II were not represented by a single curve. Generally, both curves were distinct, and the set II curve joined the set I curve. Both curves took the common path toward the end of the curves.
- In -dL vs. dC plots for all mixtures, it was observed that the mixture of Marigold/Madder (MD) showed a good overlap of set I and set II curves. This mixture was considered as highly compatible mixture. Some mixtures showed small deviation in overlapping but can be regarded as compatible mixtures as per observation using this method, which includes Katha/Madder (KD), Babool/Annatto (BA), Katha/Annatto (KA), and Pomegranate/Annatto (PA). Certain mixtures had significant variations between both curves, which include Pomegranate/Madder (PD), Marigold/Katha (MK), Pomegranate/Babool (PB), Pomegranate/Katha (PK), Babool/Madder (BD), Marigold/Annatto (MA) and Marigold/Babool (MB). These mixtures were considered incompatible mixtures as per the study using this method.

- It was also observed that most incompatible mixtures contain either Pomegranate or Marigold, where the sample no. 7 and 8 of set II (low time/temperature was given) were yellower than other samples in set II. This was considered as the reason for the deviated chroma in these cases.
- The sets showed better overlap in -dL vs. K/S plots for all mixtures than -dL vs. dC plots, and showed more compatibility amongst mixtures. It was observed that the mixture of Pomegranate/Madder (PD), Marigold/Katha (MK), Pomegranate/ Babool (PB), Marigold/Babool (MB), and Marigold/Madder (MD) showed good overlap of set I and set II curves. These mixtures were considered as highly compatible mixtures. Some mixtures showed some deviation in overlapping but can be regarded as compatible mixtures as per observation using this method, which includes Katha/Madder (KD), Pomegranate/Katha (PK), Babool/Madder (BD), Marigold/ Annatto (MA), and Katha/Annatto (KA) mixtures. Mixtures Babool/Annatto (BA) and Pomegranate/Annatto (PA) showed significant deviations in curves and were considered incompatible mixtures.

Tertiary Mixtures:

- In -dL vs. dC plots for all tertiary mixtures, it was observed that the mixture of Marigold/Babool/Madder (MBD), Marigold/Katha/Annatto(MKA), Pomegranate/ Babool/Annatto (PBA), Pomegranate/Katha/Annatto (PKA) and, Pomegranate/ Katha/Madder (PKD) showed the good overlap of set I and set II curves. These mixtures were considered compatible mixtures. The mixture Marigold/Katha/ Madder(MKD) showed some deviation in overlapping but can be viewed as a partially compatible mixture as per observation using this method. Certain mixtures had significant variations between both curves, which include Marigold/ Babool/Annatto (MBA) and Pomegranate/Babool/Madder (PBD). These mixtures were considered incompatible mixtures as per the study using this method.
- For -dL vs. K/S plots, it was observed that the mixture of Marigold/ Babool/Madder (MBD), Pomegranate/Babool/Madder (PBD), and Pomegranate/Katha/Madder (PKD) showed very good overlap and found to be highly compatible mixtures. Marigold/Katha/Annatto(MKA), Pomegranate/ Babool/ Annatto (PBA), and Pomegranate/Katha/ Annatto (PKA), showed good overlap of set I and set II curves. These mixtures were considered compatible mixtures. The mixture Marigold/Katha/Madder (MKD) showed some deviation in overlapping but can be considered a partially compatible mixture as per observation using this method. The mixture Marigold/Babool/Annatto (MBA) showed significant deviation and was considered an incompatible mixture.

(C) Method based on da vs. K/S and db vs. K/S Plot

- It was visible from the plots that both the curves of set I and set II are not represented by a single curve. Generally, both curves were distinct, and the set II curve joined the set I curve. Both curves took the common path toward the end of the curves.

Binary Mixtures:

- In da vs. K/S plot for all mixtures, it was observed that the mixture of Pomegranate/Babool (PB), Marigold/Babool (MB), and Marigold/Madder (MD) showed good overlap of set I and set II curves. This mixture was considered a compatible mixture. Some mixtures showed slight deviation in overlapping but can be regarded as compatible mixtures as per observation using this method, which includes Pomegranate/Madder (PD), Marigold/Katha (MK), Katha/Madder (KD), Katha/Annatto (KA), and Pomegranate/Katha (PK). As per the plot for Babool/Madder (BD) and Marigold/Annatto (MA), they were considered partially compatible mixtures. Certain mixtures had significant variations between both curves, which included Babool/Annatto (BA) and Pomegranate/Annatto (PA). These mixtures were considered incompatible mixtures as per the study using this method.
- In the db vs. K/S plot for all mixtures, as mentioned earlier, it was observed that in some cases, initial samples (no. 7 and 8) of set II samples were yellower than others. It seems that Pomegranate and Marigold have higher affinity than few other dyes.
- It was also observed in the db value of set II for the binary mixture of Marigold. In the case of the Marigold/Annatto (MA) mixture, the db value of sample 7 was 28.84 and then decreased to 27.48 for sample 12 after some intermediate increase. It showed that the Marigold absorption was very fast at the beginning of the process and then reduced towards the end. Similar behavior was exhibited by Marigold/Babool (MB), Marigold/Madder (MD), and Marigold/Katha (MK) mixtures. In the case of the binary mixture of Pomegranate, Pomegranate/Madder (PD) and Pomegranate/Katha (PK) showed similar behavior.
- As per plots of db vs. K/S, it was observed that the mixture of Pomegranate/Babool (PB) and Pomegranate/Annatto (PA) showed good overlap of set I and set II curves. This mixture was considered a compatible mixture. Some mixtures showed slight deviation in overlapping but could be regarded as compatible mixtures as per observation using this method, which included Pomegranate/Madder (PD), Katha/Madder (KD), Babool/Annatto (BA), Babool/Madder (BD), Katha/Annatto (KA), Marigold/Babool (MB), and Marigold/Madder (MD). As per the plot for Marigold/Katha (MK), Pomegranate/Katha (PK), and Marigold/Annatto (MA), they were considered partially compatible mixtures.

Tertiary Mixtures:

- In da vs. K/S plot for all mixtures, it was observed that the mixture of Marigold/Babool/Madder (MBD), Pomegranate/Babool/Madder (PBD), Pomegranate/Katha/Annatto (PKA), and Pomegranate/Katha/Madder (PKD) showed good overlap

of set I and set II curves. This mixture was considered a compatible mixture. Some mixtures showed some deviation in overlapping but can be considered partial compatible mixtures as per observation using this method, which includes Marigold/Katha/ Annatto (MKA) and Marigold/Katha/Madder (MKD) mixtures. Mixtures Marigold/ Babool/Annatto (MBA) and Pomegranate/Babool/Annatto (PBA) showed significant deviations and were considered incompatible mixtures.

- As per plots of db vs. K/S, it was observed that the mixtures Marigold/Babool/Madder (MBD), and Pomegranate/Katha/Madder (PKD) showed very good overlap and were considered as highly compatible mixtures. All the other mixtures showed good overlap of set I and set II curves and were considered compatible mixtures.

4.2.1.2 Quantitative Methods

(A) Compatibility Factor method

- In case of binary mixtures, it was observed that the Pomegranate/Babool (PB) and Pomegranate/Katha (PK) had the same C.F. at respective wavelengths of component dyes, indicating compatibility. Some mixtures showed less than 10% difference in the C.F. at the respective wavelength of component dyes and were considered compatible using this method. These mixtures were Marigold/Katha (MK), Katha/Annatto (KA), Marigold/Madder (MD) and Marigold/Babool (MB). Mixtures Babool/Madder (BD), Katha/Madder (KD), and Marigold/Annatto (MA) had 11-20% difference in the C.F. at a respective wavelength of component dyes and were considered partially compatible using this method. Babool/Annatto (BA), Pomegranate/Madder (PD), and Pomegranate/Annatto (PA) showed approximately 23%, 25%, and 70% differences in the C.F. at a respective wavelength of component dyes and were considered an incompatible mixture.
- In case of tertiary mixtures, it was observed that the Marigold/Babool/Madder (MBD), Marigold/Katha/ Annatto (MKA) Marigold/Katha/Madder (MKD), Pomegranate/Babool/Madder (PBD), and Pomegranate/Katha/Madder (PKD) showed less than 10% C.V. in compatibility factor values at the respective wavelength of component dyes and may be considered as compatible mixtures. In the case of Marigold/Babool/Annatto (MBA) and Pomegranate/Katha/Annatto (PKA) mixtures, the C.V. was found in the range of 10-16% and considered as partially compatible using this method. The C.V. for Pomegranate/Babool/Annatto (PBA) was 29.74% and was considered an incompatible mixture.

(B) Change in Hue Angle using Coefficient of Variation (C.V.)

The compatibility was defined by using the sum of the coefficient of variation for set I and set II.

- In case of binary mixtures, it was concluded that the Pomegranate/Babool (PB), Babool/Annatto (BA), Katha/Annatto (KA), and Marigold/Babool (MB) showed low C.V. and can be considered as compatible mixtures. The mixtures *viz.* Marigold/Katha (MK), Katha/Madder (KD), Babool/Madder (BD), and Marigold/Madder (MD) had mid-range C.V. and can be considered as partial compatible. The C.V. for Pomegranate/Madder (PD), Pomegranate/Katha (PK), Marigold/Annatto (MA), and Pomegranate/Annatto (PA) was high and were considered incompatible mixtures.
- In case of tertiary mixtures, it was observed that the C.V. for sets I and II were different and generally higher for sets I with exceptions. It was concluded that the Marigold/Babool/Annatto (MBA), Marigold/Katha/Madder (MKD), and Pomegranate/Babool/Annatto (PBA) showed low C.V. and can be considered as compatible mixtures. The mixtures *viz.* Marigold/Babool/Madder (MBD), Marigold/Katha/Annatto (MKA), and Pomegranate/Katha/Annatto (PKA) were having mid-range C.V. and can be considered as partially compatible. The C.V. for Pomegranate/Babool/Madder (PBD) and Pomegranate/Katha/Madder (PKD) was high and were considered incompatible mixtures.

(C) Visual Rating

The visual score was used to assess the compatibility of the mixtures.

- In case of binary mixtures, it was observed that mixture Katha/Annatto, Marigold/Madder, Pomegranate/Katha, and Marigold/Katha mixtures had a score of above 21 and were considered compatible mixtures. Babool/Annatto, Pomegranate/Babool, Marigold/Babool and Pomegranate/Annatto had average scores and were considered as partially compatible mixtures. Other mixtures namely, Marigold/Annatto, Pomegranate/Madder, Katha/Madder and Babool/Madder had low score and considered as not compatible mixtures.
- In case of tertiary mixtures, it was observed that the mixtures Pomegranate/Katha/Annatto (PKA), Marigold/Katha/ Madder (MKD), Pomegranate/Katha/Madder (PKD), and Marigold/Katha/ Annatto(MKA) had a score of above 14 and were considered compatible mixtures. Marigold/Babool/Madder (MBD), Pomegranate/Babool/Madder (PBD), Marigold/ Babool/Annatto (MBA), and Pomegranate/Babool/Annatto (PBA) had average scores and were considered as partially compatible mixtures.

Summary of Different Method's results and overall rating

As per sections qualitative and quantitative methods, different methods were used to assess the compatibility. Some of these methods showed different compatibility aspects for the particular mixture and others provide comprehensive compatibility assessment. Compatibility factor and visual rating provide the comprehensive assessment and other methods provide different aspects.

- It is visible that compatibility assessment varies for different methods for a particular mixture. This may be due to the different compatibility aspects covered in methods. The mixtures were given ratings based on the compatibility behavior shown for a particular method. These were highly compatible, compatible, partially compatible, and non-compatible mixtures. Thus, an overall rating was also given for each mixture based on the ratings obtained in all methods.
- Marigold/Katha, Pomegranate/Babool, Katha/Annatto, Marigold/Babool and Marigold/ Madder mixtures were found as compatible mixtures. Pomegranate/ Madder, Katha/Madder, and Pomegranate/Katha were found as partially compatible mixtures. Other mixtures Babool/Annatto, Babool/Madder, Marigold/Annatto and Pomegranate/Annatto were found as non-compatible mixtures.
- Marigold/Babool/Madder(MBD), Marigold/Katha/Annatto(MKA), Marigold/ Katha/Madder (MKD), and Pomegranate/Katha/Madder (PKD) mixtures were found to be compatible mixtures. Pomegranate/Babool/Madder (PBD) and Pomegranate/ Katha/Annatto (PKA) were seen as partially compatible mixtures. Other mixtures of Marigold/Babool/Annatto (MBA) and Pomegranate/Babool/Annatto (PBA) were found to be non-compatible.

The compatible mixtures found in tertiary mixture assessment were analyzed with binary combinations and the following was found.

- The first tertiary mixture Marigold/Katha/Madder (MKD) was found compatible. The compatibility was checked for its possible binary combinations Marigold/Katha (MK), Katha/Madder (KD) and Marigold/Madder (MD) from previous results. Marigold/Katha (MK), and Marigold/Madder (MD) were compatible mixtures while Katha/Madder (KD) was found to be partially compatible mixture. It may be concluded from this that the three dyes Marigold, Katha, and Madder are compatible amongst themselves in all types of combinations.
- The second tertiary mixture Marigold/Babool/Madder (MBD) was found compatible. The compatibility was checked for its possible binary combinations Marigold/Babool (MB), Babool/Madder (BD) and Marigold/Madder (MD) from previous results. Marigold/Babool (MB), and Marigold/Madder (MD) were compatible mixtures while Babool/Madder (BD) was found to be non-compatible mixture. It may be concluded from this that the three dyes Marigold, Babool, and Madder are compatible amongst themselves in all types of combinations except binary combination of Babool/Madder (BD).
- The third tertiary Marigold/Katha/Annatto (MKA) was found compatible. The compatibility was checked for its possible binary combinations Marigold/Katha (MK), Katha/Annatto (KA) and Marigold/Annatto (MA) from previous results.

Marigold/Katha (MK), and Katha/Annatto (KA) were compatible mixtures while Marigold/Annatto (MA) was found to be non-compatible mixture. It may be concluded from this that the three dyes Marigold, Katha, and Annatto are compatible amongst themselves in all types of combinations except binary combination of Marigold/Annatto (MA).

- Another tertiary Pomegranate/Katha/Madder (PKD) was found compatible. The compatibility was checked for its possible binary combinations Pomegranate/Katha (PK), Katha/Madder (KD), and Pomegranate/Madder (PD) from previous results. All the binary combinations were found to be partially compatible mixtures. It may be concluded from this that the three dyes Pomegranate, Katha, and Madder are compatible amongst themselves in all types of combinations keeping in mind about the partial compatibility in binary mixtures.

This will help in accomplishing the objective of the study to check the compatibility and obtain newer shades.

4.2.2 Data Preparation for Recipe Prediction

Dyeing of each of the six selected dyes was done at varied percentages to prepare the spectral data on the spectrophotometer for recipe prediction. The data of primary dyes was stored successfully in a spectrophotometer for recipe prediction.

4.2.3 Prediction of Recipe and Dyeing of Samples as per standard

As per the study's objective, the recipe was predicted for several chosen standards using computer color-matching equipment. The predicted recipe for each standard was used to dye the samples. The suitable standards from the PANTONE – Cotton planner were selected as per table 5.

Table 5: List of Pantone standards for recipe prediction

S. No.	PANTONE-TCX number
1	TCX 15-1327
2	TCX 16-1317
3	TCX 15-1317
4	TCX 14-1122
5	TCX 16-1220
6	TCX 15-1213
7	TCX 15-1415
8	TCX 14-1316

The recipe was predicted using a spectrophotometer, and some recipe options were obtained. A compatible, suitable recipe option was selected from the obtained options. It has been observed in practical work with CCM that the sample dyed using the predicted recipe does not match entirely with the standard, and hence, the recipe was optimized to match visually. Colorimetric and color difference parameters were recorded for the standard and dyed samples using two CIE standard illuminants, D65 and A. The L^* , a^* , b^* , C^* , and h values were obtained for standard and sample in both light sources. The color difference parameters dE , dL^* , dC^* , dh , and metamerism index were also calculated.

As per the color match and its analysis, it was established that the color matching could be done successfully. However, in some cases, the selected recipe may not be suitable and have to be revised. This will help the dryer to select the appropriate combination and recipe. This also accomplishes the objective of the study to obtain newer shades. However, the dyes chosen in this study are limited, and hence, the color matching can be done for that gamut only.

4.2.4 Color Fastness Evaluation

Color fastness properties were evaluated for selected samples. In color fastness tests, color fastness to washing, color fastness to light, and color fastness to rubbing were done. The samples were chosen from primary dyes, binary, and tertiary combinations. A sample of dye concentration of 24% owf was tested for every primary dye. Sample number 5 from set I was chosen for each combination for binary and tertiary combinations.

A color fastness to washing test was done using the AATCC test method 61-2009 (1B). A fade-o-meter was used for light fastness testing using the test method ISO-105-B02. The rubbing fastness of the dyed samples, in both dry and wet conditions, was assessed using the Crock-o-meter following the test method IS 766: 1988, which is based on ISO 105/X-1984.

Color Fastness Tests

The current study examined the fastness of samples dyed individually and in binary combinations, with respect to their compatibility and incompatibility. The findings are presented in Table 6 to Table 9. It is visible that the all the color fastness properties of pure dyes shown average to very good rating. It was also observed that in case of color fastness to washing, the Madder stained nylon fibers and almost no staining on any other fiber by any other dye. It may be attributed to the high affinity of Madder dye towards nylon material as mentioned by Sadeghi-Kiakhani, (2015). In case of color fastness to rubbing, same dye Madder showed some staining in wet conditions and got an average rating.

The data also shows the color fastness of mixtures with respect to the component dyes in the mixtures. It was observed in most cases that all the color fastness properties for mixtures were in accordance with the fastness of component dyes.

However, in some instances, the mixture's fastness was found to be lower or higher than the component dyes. **By examining the results, it was visible that there was no relation between compatibility/non-compatibility and color fastness.**

Table 6: Colorfastness to washing of binary mixtures with respect to component dyes

Sample Code (AB)	Mixture		Individual Dyes			
			Component A		Component B	
	Color Change	Color Staining (Nylon)	Color Change	Color Staining (Nylon)	Color Change	Color Staining (Nylon)
PA	3-4	4-5	4	4-5	3	4-5
PB	4-5	4-5	4	4-5	4	4-5
PK	3	4-5	4	4-5	3-4	4-5
PD	3-4	3-4	4	4-5	3-4	4

Table 7: Color fastness to light for binary combination with respect to component dyes

Sample Code (AB)	Mixture	Component A	Component B
PA	3	3-4	2-3
PB	3-4	3-4	4
PK	3-4	3-4	3
PD	4	3-4	4

Table 8: Color fastness to rubbing for pure dyes

Test Sample	Color change		Staining	
	Dry	Wet	Dry	Wet
Katha	5	4-5	5	4-5
Babool	5	4-5	5	4-5
Pomegranate	5	4-5	5	4-5
Annatto	5	5	5	5
Madder	4-5	4	4-5	3-4

Table 9: Color fastness to rubbing for binary mixtures

Sample Code	Color change		Staining	
	Dry	Wet	Dry	Wet
PA	5	4-5	5	4-5
PB	5	4-5	5	4-5
PK	5	4-5	5	4-5
PD	5	4	5	4

Compatibility assessment of binary mixtures of pomegranate with babool, katha, madder and annatto dyes

4.2.5 Anti-Microbial testing

Anti- microbial test was done for each sample of primary dyed samples using AATCC 100:- 2019 test method. The test results were assessed as the percentage of bacterial reduction for both bacteria used in the method.

The anti-bacterial results for six primary dyes shows that all the dyes show approx. 90% or above bacterial reduction.

Summary and Conclusion

The study's objectives include optimizing the extraction and dyeing parameters of the selected natural dyes. Another objective is assessing compatibility for binary and tertiary mixtures of dyes using qualitative and quantitative methods. The other objective of the study is to create a spectral database for recipe prediction and shade matching using a spectrophotometer.

Marigold, Pomegranate, Madder, Annatto, Babool (*Acacia nilotica*), Sappanwood, Rhubarb, and Katha (*Catechu*) dyes were taken for the study. A total of 12 and 8 mixtures are studied for binary and tertiary mixtures, respectively. Two sets of samples were prepared for each mixture, *viz.* sets I and II. For set I, six samples were dyed at an equal increment of dye concentration and set II samples were dyed at increasing time and temperature conditions. The CIELAB coordinates L^* , a^* , b^* , C^* , h^* , and K/S values were measured for these mixtures, and compatibility was checked based on quantitative and qualitative methods. These methods include a change in hue angle, change in lightness/darkness with respect to chroma and K/S, change in a^* and b^* coordinates with respect to K/S, compatibility factor, and visual assessment. The color fastness tests were also done for primary and mixtures of dyes.

The study results showed that the compatibility assessment varies for different methods for a particular mixture. This may be due to the various compatibility aspects covered in these methods. The mixtures are given ratings based on their compatibility behavior. These are highly compatible, compatible, partially compatible, and non-compatible mixtures. Thus, an overall rating is also given for each mixture based on the ratings obtained in all the methods.

In the case of binary and tertiary mixtures, some of the mixtures found are compatible, and others are partial or non-compatible. In the case of binary mixtures, Marigold/Katha, Pomegranate/Babool, Katha/Annatto, Marigold/Babool, and Marigold/Madder were found to be compatible mixtures. Pomegranate/Madder, Katha/Madder, and Pomegranate/Katha were found to be partially compatible mixtures. Other mixtures, Babool/Annatto, Babool/Madder, Marigold/Annatto, and Pomegranate/Annatto were found to be non-compatible mixtures. Similar results were obtained in tertiary mixtures. It was also found that the compatible tertiary mixture can contain compatible/partial-compatible/non-compatible binary mixtures.

The data of primary dyes was stored successfully in a spectrophotometer for recipe prediction. From the shade match and its analysis, it was established that the colour matching could also be done successfully. However, in some cases, the selected recipe may not be suitable and needs to be revised. The understanding of compatibility, recipe prediction and shade matching accomplishes the objective of the study to obtain newer shades.

Color fastness to washing, light, and rubbing were done, and it was found that dyes had average to very good fastness properties. It was observed that the color fastness properties

(wash, light, and rubbing) for mixtures were in accordance with the fastness of component dyes in most cases.

Recommendations and Suggestions

The study was limited to only 8 natural dyes, namely Marigold, Pomegranate, Madder, Sappanwood, Rhubarb, Annatto, Katha (Catechu), and Babool (Acacia Nilotica). It is recommended that similar studies can be done for other dyes as well. The study was limited to cotton and the use of alum mordant using the pre-mordanting method and it is recommended that the studies can be done on other textile materials using different mordants/methods.

It is recommended that compatibility be checked for different materials with different processes. It is also recommended that the spectral data should be prepared for maximum possible number of dyes so that color matching can be done for wider range of shades.

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