ECO-FRIENDLY DYEING OF KHADI SILK: OPTIMIZING PARAMETERS FOR *DELONIX REGIA* FLOWER EXTRACTS

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Abstract

The Delonix regia flowers are available in plenty and very limited study has been done on the extraction for natural dyes from these abundantly available flowers, so it was taken for study. Fallen flowers were collected and natural dye was extracted from it. Extracted dye was applied on khadi silk fabric with different mordants using different parameters. Colour measurement was done using spectrophotometer and optimum parameters was decided on the basis of colour measurement. It was found that various shades of reddish brown can be produced from Delonix regia flower dye on khadi silk fabric. The common mordants such as Alum, Ferrous Sulphate and amla were used for mordanting of silk. The concentration of mordants, dyeing time, mordanting techniques were optimized. Mordanting time, mordanting temperature and M:L ratio was kept constant. The samples were then evaluated for colour measurement value. The K/S Values, L a* b* values proved that the samples dyed with optimized parameters produced varied range of shades. The colour fastness tests of the samples dyed with optimized parameters showed good to excellent colour fastness to various agents.*

Key words: *Delonix regia* flowers, mordants, natural dye.

Introduction

Natural dyes, sourced from plants, animals, and minerals, offer a vibrant spectrum of colors, including red, yellow, brown, blue, black, green, and orange. They are eco-friendly and renewable, aligning with the "Go Green" movement advocating for environmental protection. Increasing global awareness of their therapeutic properties has driven demand for natural dyes. Environmental consciousness emphasizes choices that sustain the planet, recognizing the need for its preservation. Sustainability has become a global imperative, spurred by awareness of the harmful effects of synthetic dyes. The resurgence of natural dyes reflects a health-conscious and culturally aware global community. Mordants, naturally occurring water-soluble metallic salts, play a vital role in creating colorfast dyes by bonding them to fibers, ensuring lasting color.

Aims and Objectives:

- Extraction of natural dyes from selected *Delonix regia* flowers.
- Mordanting of khadi silk fabric with selected mordants.
- Dyeing of khadi silk fabric with extracted natural dye.
- Colour measurement of the dyed samples using spectrophotometer

- Optimization of parameters for mordanting and dyeing.
- Dyeing of silk fabrics with optimized parameters.
- Evaluation of colour fastness of fabrics dyed with optimized parameters.

Methodology

1. Selection of Raw Material for Extraction of Dye:

Gul mohar (Delonix regia) flowers were selected for dye extraction due to limited research on their dyeing properties. Fresh flowers were collected, shade-dried, and pretested on various fabrics. Their selection was driven by abundance, availability as waste material, and the appealing colors observed during pretesting.

2. Selection of Mordant:

Three different mordants were selected. Two were safe metallic mordant which are not red listed i.e., aluminium potassium sulphate (5%,10%,15%), ferrous sulphate (1%,3%,5%) and one natural mordant i.e., amla (10%,20%,30%) because it contains high amount of tannin. All these mordants were selected to get different shades of colour.

3. Selection and Preparation of Fabric for Dyeing:

100% pure khadi silk was obtained from Khadi Ashram to ensure uniformity for the study. Khadi silk was chosen due to its common use, easy availability, and positive results in pre-testing with the selected dye. Prior to dyeing, the material underwent cleaning, or scouring, to remove impurities. Scouring involved soaking the fabric in a mild detergent solution, followed by rinsing, gentle squeezing, and drying in shade.

2. Extraction of Dye from *Delonix regia* flowers:

To extract the dye from *Delonix regia* flowers, a substantial quantity of flowers was collected and dried in shade for 8-10 days. Once dried, the flowers were ground into a fine powder. Subsequently, 200 grams of the dye powder was boiled in one litre of water for an hour at 100°C. After boiling, the dye solution was left to cool down and then filtered through muslin to remove any solid particles. Following proper filtration, the dye solution was ready for dyeing.

3. Mordanting and Dyeing of Samples:

Mordanting and dyeing of fabric was carried out as per the following parameters (table-1)

Table:1 Parameters used for Mordanting and Dyeing of khadi Silk Fabric

Mordants	Mordanting Techniques	Mordanting Concentrations (In % o.w.f)	Mordanting Time (In Minutes)	Mordanting Temperature (in ^{o} C)	Dyeing Time (In Minutes)
Aluminium Potassium Sulphate	PRM	5%,10%,15%	30	100	30, 45, 60
	POM				
	SIM				
Ferrous Sulphate	PRM	1%,3%,5%	30	60	30,45,60
	POM				
	SIM				
Amla	PRM	10%,20%,30%	30	100	30,45,60
	POM				
	SIM				

PRM: pre-mordanting, **POM:** post- mordanting, **SIM**: simultaneously mordanting

Mordanting was performed in three phases: pre-mordanting, post-mordanting, and simultaneous mordanting, using different mordant concentrations—ferrous sulphate (1%, 3%, 5%), aluminium potassium sulphate (5%, 10%, 15%), and amla (10%, 20%, 30%). The material-to-liquor (M:L) ratio was 1:50, with treatment at 60°C for ferrous sulphate and 100°C for aluminium potassium sulphate and amla, each for 30 minutes. Samples were pre-soaked in water for uniform mordant absorption.

Dyeing was also conducted in three stages—before, after, and during mordanting—using 20 ml of extracted dye while maintaining an M:L ratio of 1:50. The process was carried out at 100°C for 30, 45, and 60 minutes.

Colour Measurement of Dyed Samples using Spectrophotometer:

Dyed samples were analyzed using a spectrophotometer to measure K/S, L*, a*, b*, c*, and h* values for color evaluation. K/S indicates color depth, while L* represents lightness (0 = black, 100 = white), with the lowest L* values selected for maximum shade depth. The a* value denotes red (+) or green (-), and b* indicates yellow (+) or blue (-). Chroma (c*) measures color intensity, and the hue angle (h*) determines color direction, starting at +a* (red) and moving in degrees (90° = yellow).

4. **Selection of Optimized Parameters for Dyeing and Mordanting:**

On the basis of colour measurement on the basis of spectrophotometer, optimized parameter for dyeing and mordanting were selected (table no: 11). It was selected on the basis of K/S Value, higher the K/S value darker is the shade.

5. **Determination of Colour-Fastness Properties (Sunlight, Washing, Ironing, Rubbing, Perspiration) of the Dyed Fabric:**

Based on spectrophotometric color measurement, the optimized dyeing and mordanting parameters were selected (Table No. 11). Selection was based on the K/S value, where a higher K/S value indicates a darker shade.

6. **Determination of Colour-Fastness Properties (Sunlight, Washing, Ironing, Rubbing, Perspiration) of the Dyed Fabric:**

Color fastness refers to a material's resistance to changes in hue, value, or intensity when exposed to conditions like light or washing. According to AATCC (1995), it is the resistance to color change or transfer due to processing, testing, storage, or use. Various color fastness tests were conducted to evaluate the dyed samples.

Colour Fastness to Sunlight

A 2" × 8" specimen was cut from each dyed sample and divided into eight equal parts. A black paper of the same size was attached at the top. Each day, one section was exposed to sunlight for 7-8 hours, with the first section receiving seven days of exposure. After completion, color change was assessed using a gray scale against the unexposed sample.

Colourfastness to washing

A 2" × 4" specimen was cut from each dyed sample and attached to bleached cotton fabric of the same size. A soap solution was prepared as per ISO-3 standards and placed in separate beakers. Each composite specimen was immersed, shaken for 30 minutes at 60°C, then rinsed, squeezed, and dried. Color change and staining were assessed using a gray scale.

Colour fastness to Crocking (wet and dry)

Crocking, as defined by AATCC (1995), is the transfer of color from dyed fabric to another surface through rubbing. The Sasmira Crockmeter was used to test color fastness to crocking. A 10" × 8" specimen was mounted on a flat base, and a white material was attached to the rubbing finger. Each sample underwent 20 rubs, and color transfer was assessed using a gray scale. For wet crocking, a damp white material was used, following the same procedure as dry crocking.

Colour fastness to pressing (wet and dry)

Dry and wet pressing tests are crucial for apparel fabrics. Two 2" × 4" specimens were cut from each dyed sample and attached to white cotton of the same size. For dry pressing, a hot iron was applied for 10 seconds. For wet pressing, the iron was applied to damp specimens for 10 seconds. Staining on the white fabric and color change in the dyed samples were assessed using a gray scale.

Colour fastness to artificial perspiration (acidic and alkaline)

Perspiration can facilitate bacterial attack on textile fibers and affect color fastness. Unsatisfactory perspiration fastness may result from color bleeding, migration, or change. To assess this, specimens were tested in both acidic (pH 5.6) and alkaline (pH 7.2) conditions following the AATCC method. Two 2" × 4" specimens from each dyed sample were sandwiched between undyed white cotton, stitched on three sides, and numbered. The test was conducted using a Perspirometer (Japan), with acidic and alkaline solutions prepared separately.

Chemicals	Acidic	Alkaline
Sodium chloride	2.65 gm/l	3gm/l
Urea	0.75gm/l	-
pH	**5.6**	**7.2**

Acetic acid and sodium bicarbonate were used to adjust the pH for acidic and alkaline solutions. Test samples were saturated with the respective solutions, left for 30 minutes, then squeezed and placed between plastic plates in the Perspirometer. A weight was applied, and the setup was heated in an oven at 60°C for four hours. Afterward, samples were assessed for color fastness and staining using a gray scale.

Results and Discussion

The findings of the study entitled, **"Optimization of Parameters for Dyeing of Khadi Silk Fabric with Natural Dye Extracted from *Delonix regia* Flowers"** are explained under following subheads:

1. **Hues obtained.**

   The dye extracted from *Delonix regia* flowers produced beautiful shades of brown colour on khadi silk fabric. The colour obtained were different with the changings mordant, mordanting techniques, mordant concentration and dyeing time.

2. Results of Colour measurement

Dyed samples were analyzed using a spectrophotometer to measure K/S, L*, a*, b*, c*, and h* values. K/S indicates color depth, while L* represents lightness (0 = black, 100 = white). The darkest samples (lowest L*) were selected. The a* value denotes red (+) or green (-), and b* indicates yellow (+) or blue (-). Chroma (c*) measures color intensity, and the hue angle (h*) determines color direction on the color wheel (0° = red, 90° = yellow).

Table 2: Colour Measurement of the Samples Mordanted with Aluminium Potassium Sulphate and Dyed with *Delonix regia* Dye for 30 Minutes

Mordent Concentration & Mordanting Techniques	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
5%	3.307	68.34	2.19	20.40	20.52	83.85
10%	4.675	67.92	2.58	26.67	26.79	84.44
15%	5.313	64.88	2.93	24.55	24.72	83.15
Post- Mordanting						
5%	3.203	69.16	3.25	20.29	20.55	80.86
10%	3.481	65.98	3.77	18.99	19.36	78.73
15%	4.344	63.95	4.12	22.49	22.86	79.58
Simultaneous-Mordanting						
5%	6.597	68.99	2.41	32.35	32.44	85.70
10%	7.096	67.83	2.94	34.08	34.21	85.04
15%	**7.350**	66.34	2.29	30.30	30.38	85.63

The data in the table reveals that the depth of shade (K/S) for samples dyed with *Delonix regia* increased as the concentration of Aluminium Potassium Sulphate mordant increased, irrespective of the mordanting technique employed. The darkest shade, with the highest K/S value of 7.35, was obtained using a 15% alum concentration through simultaneous mordanting. As a result, this concentration and method were identified as the most effective for achieving optimal color depth.

Table 3: Colour Measurement of the Samples Mordanted with Aluminium Potassium Sulphate and Dyed with *Delonix regia* Dye for 45 Minutes

Mordent Conc. & Mordanting Tech.	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
5%	4.136	67.20	2.87	22.53	22.71	82.71
10%	5.858	66.25	3.30	24.00	24.22	82.15
15%	6.043	66.01	3.09	24.45	24.65	82.76
Post- Mordanting						
5%	3.387	61.92	5.96	20.65	21.50	73.88
10%	3.420	65.38	4.60	20.33	20.74	77.14
15%	4.198	62.94	5.75	24.06	24.74	76.52

Simultaneous-Mordanting						
5%	5.626	68.99	2.41	32.35	32.44	85.70
10%	6.409	67.83	2.94	34.08	34.21	85.04
15%	**7.770**	66.34	2.29	30.30	30.38	85.63

The table shows that the depth of shade (K/S) for samples dyed with *Delonix regia* and mordanted with Aluminium Potassium Sulphate consistently increased with higher mordant concentrations, regardless of the mordanting technique used. The darkest shade, with the highest K/S value of 7.770, was achieved using a 15% alum concentration through simultaneous mordanting. Therefore, this concentration and method were determined to be the most effective.

Table 4: Colour Measurement of the Samples Mordanted with Aluminium Potassium Sulphate and Dyed with *Delonix regia* Dye for 60 Minutes

Mordent Concentration & Mordanting Techniques	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
5%	5.923	65.59	3.25	25.00	25.21	82.57
10%	6.048	65.87	3.31	25.14	25.36	82.44
15%	**6.137**	63.53	3.89	23.66	23.97	80.64
Post- Mordanting						
5%	3.346	62.61	5.96	20.72	21.56	73.92
10%	3.493	63.92	4.57	17.39	17.98	75.26
15%	4.434	63.34	5.10	20.82	21.43	76.19
Simultaneous-Mordanting						
5%	4.732	65.81	4.19	25.04	25.39	80.47
10%	5.030	65.31	4.09	25.35	25.68	80.80
15%	5.361	64.75	3.83	22.86	23.18	80.47

The data in the table demonstrates a clear trend: the depth of shade (K/S) for samples dyed with *Delonix regia* and mordanted with Aluminium Potassium Sulphate increased proportionally with higher mordant concentrations, irrespective of the mordanting technique used. The darkest shade, with the highest K/S value of 6.137, was achieved using a 15% alum concentration during pre-mordanting. Therefore, this concentration and method were identified as the most effective.

Table 5: Colour Measurement of the Samples Mordanted with Ferrous Sulphate and Dyed with *Delonix regia* Dye for 30 Minutes

Mordant Concentrations & Mordanting Techniques	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
1%	3.394	67.93	4.50	1928	19.80	76.83
3%	3.675	60.56	3.24	15.10	15.44	77.85

5%	**5.971**	56.20	2.58	18.75	18.92	82.14
Post- Mordanting						
1%	3.797	60.16	6.29	14.25	15.58	66.16
3%	5.329	61.18	5.10	21.51	22.11	76.62
5%	5.961	49.47	1.12	12.62	12.67	84.89
Simultaneous-Mordanting						
1%	2.894	62.57	-2.13	8.61	8.87	103.91
3%	3.088	59.48	-2.56	7.75	8.16	108.34
5%	3.596	61.03	-3.68	9.26	9.96	111.71

The table indicates a clear pattern: the depth of shade (K/S) for samples dyed with *Delonix regia* and mordanted with Ferrous Sulphate consistently rose with higher concentrations of mordant, regardless of the mordanting techniques applied. Notably, the darkest shade, yielding the highest K/S value of 5.971, was achieved with a 5% concentration of FeSO4 during pre-mordanting. Consequently, this concentration and method were chosen as optimal.

Table6: Colour Measurement of the Samples Mordanted with Ferrous Sulphate and Dyed with *Delonix regia* Dye for 45 Minutes

Mordant Concentrations & Mordanting Techniques	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
1%	3.509	65.23	6.30	19.74	20.72	72.27
3%	3.832	64.23	4.39	20.60	21.07	77.94
5%	4.644	63.27	5.51	22.68	23.34	76.32
Post- Mordanting						
1%	2.871	63.66	5.80	13.88	15.05	67.28
3%	5.337	68.99	2.41	32.35	32.44	85.70
5%	**5.634**	56.32	8.01	20.45	21.97	68.58
Simultaneous-Mordanting						
1%	3.505	57.73	-1.84	8.11	8.32	102.78
3%	3.783	57.77	-1.96	9.12	9.33	102.17
5%	3.805	57.40	-2.21	8.76	9.04	104.21

The table clearly demonstrates that the depth of shade (K/S) for Delonix regia-dyed samples mordanted nm Ferrous Sulphate consistently intensified with higher concentrations of the mordant, regardless of the mordanting techniques employed. Notably, the darkest shade, yielding the highest K/S value of 5.634, was achieved with a 5% concentration of FeSO4 during post-mordanting. Consequently, this concentration and method were deemed optimal.

Table 7: Colour Measurement of the Samples Mordanted with Ferrous Sulphate and Dyed with *Delonix regia* Dye for 60 Minutes

Mordent Concentrations & Mordanting Techniques	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
1%	3.350	59.79	5.07	14.78	15.63	71.04
3%	3.810	61.36	6.19	17.45	18.51	70.45
5%	**4.552**	59.76	5.34	19.65	20.36	74.76
Post- Mordanting						
1%	3.617	56.06	6.70	12.30	14.00	61.39
3%	3.658	56.94	7.12	13.42	15.19	62.05
5%	4.510	50.64	5.43	11.69	12.89	65.06
Simultaneous-Mordanting						
1%	3.739	58.39	-2.07	9.46	9.68	102.39
3%	3.958	58.47	-1.04	11.43	11.48	95.22
5%	4.011	61.02	0.78	15.26	15.28	87.06

The table illustrates a consistent trend: as the concentration of Ferrous Sulphate used for mordanting increases, so does the depth of shade (K/S) of the samples dyed with Delonix regia. This pattern holds true regardless of the mordanting technique employed.

Furthermore, it was noted that among the various concentrations tested, the highest K/S value of 4.552, indicating the darkest shade, was achieved with a 5% concentration of FeSO4 when applied through pre-mordanting. Consequently, this concentration was deemed optimal for the process.

Table 8: Colour Measurement of the Samples Mordanted with Amla and Dyed with *Delonix regia* Dye for 30 Minutes

Mordent Concentration & Mordanting Techniques	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
10%	7.62	63.03	1.6	25.12	25.18	86.31
20%	7.893	62.34	2.52	25.64	25.77	84.35
30%	10.898	60.07	2.72	28.26	28.4	84.47
Post- Mordanting						
10%	9.822	66.08	4.42	29.11	29.44	81.34
20%	10.490	66.29	4.20	30.11	30.4	82.02
30%	11.157	66.01	3.99	32.08	32.33	82.88
Simultaneous-Mordanting						
10%	10.676	66.58	3.05	31.39	31.54	84.41
20%	12.830	62.72	4.80	33.5	33.84	81.82
30%	**13.142**	61.64	5.02	32.43	32.81	81.18

The table demonstrates a consistent trend: the depth of shade (K/S) of Delonix regia-dyed samples, mordanted with Amla, escalates with the ascending concentration of the mordant, regardless of the mordanting techniques employed.

Moreover, it was noted that among the tested concentrations, the highest K/S value of 13.142, indicating the darkest shade, was achieved with a 30% concentration of Amla when applied through Simultaneous-mordanting. Consequently, this concentration was identified as the optimum choice.

Table 9: Colour Measurement of the Samples Mordanted with Amla and Dyed with *Delonix regia* Dye for 45 Minutes

Mordent Concentration & Mordanting Techniques	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
10%	8.408	60.1	1.86	24.26	24.33	85.59
20%	10.233	60.03	1.72	26.84	26.9	86.29
30%	10.36	57.72	2.01	25.98	26.06	85.54
Post- Mordanting						
10%	8.907	67.74	3.67	28.33	28.57	82.58
20%	9.334	66.6	3.92	28.48	28.75	82.13
30%	9.594	67.91	3.8	29.01	29.26	82.51
Simultaneous-Mordanting						
10%	9.376	67.95	2.79	30.24	30.37	84.69
20%	10.676	67.6	2.78	32.03	32.15	85.00
30%	**12.142**	63.87	4.04	31.9	32.15	82.75

The table reveals a consistent trend: regardless of the mordanting techniques used, the depth of shade (K/S) for Delonix regia-dyed samples mordanted with Amla increases with higher concentrations of the mordant.

Moreover, it was noted that among the tested concentrations, the darkest shade, with the highest K/S value of 12.142, was obtained using a 30% concentration of Amla with Simultaneous-mordanting. Therefore, this concentration was deemed the optimal condition.

Table 10: Colour Measurement of the Samples Mordanted with Amla and Dyed with *Delonix regia* Dye for 60 Minutes

Mordent Conc. & Mordanting Tech.	K/S Value	L*	a*	b*	c*	h*
Pre- Mordanting						
10%	8.021	63.02	1.66	25.51	25.56	86.24
20%	10.309	59.54	2.16	26.77	26.86	85.35
30%	10.622	58.84	1.77	25.85	25.91	86.06
Post- Mordanting						

10%	9.167	69.64	3.13	28.82	28.99	83.76
20%	9.528	67.26	4.01	27.32	27.61	81.61
30%	10.983	64.76	4.82	29.51	29.9	80.7
Simultaneous-Mordanting						
10%	11.646	65.4	3.38	32.28	32.46	83.99
20%	11.939	66.57	2.48	33.8	33.89	85.77
30%	**12.830**	63.34	4.36	32.98	33.26	82.44

The table illustrates that the depth of shade (K/S) for Delonix regia-dyed samples, when mordanted with Amla, consistently increases with higher concentrations of the mordant, regardless of the mordanting techniques applied.

Additionally, it was noted that among the tested concentrations, the darkest shade, with the highest K/S value of 12.830, was achieved using a 30% concentration of Amla with Simultaneous-mordanting. Consequently, this concentration was identified as the optimal choice.

1) **Optimized parameters for mordanting and dyeing**

The optimized parameters for mordanting and dyeing based on colour measurement are given in table-

Table 11: optimize parameter for dyeing and mordanting

S. No	Mordants	Mordant Conc. (in % owf)	Mordanting Technique	Mordanting Time (in minute)	Dyeing Time (in minute)	M: L Ratio (Gm:ml)	Dyeing Temperature (In ^{O}C)
1	$AlK(SO_4)_2$	15%	SIM	30	45	1:50	100
2	$FeSo_4$	5%	PRM	30	30	1:50	100
3	Amla	30%	SIM	30	30	1:50	100

According to the findings from the table, the optimal conditions varied for different mordants and dyeing times. For aluminium potassium sulphate, the ideal concentration was determined to be 15% when employing simultaneous mordanting for a 45-minute dyeing duration. Meanwhile, a 5% concentration of ferrous sulphate with pre-mordanting and a 30-minute dyeing time yielded optimal results. Similarly, simultaneous mordanting with a 30% concentration of amla was found to be the best approach.

In terms of dyeing time, it was concluded that 30 minutes was optimal for both amla and ferrous sulphate mordants, while 45 minutes was deemed optimal for alum. These decisions were based on the K/S values measured using a spectrophotometer. Throughout the experiments, the M:L ratio was maintained at 1:50, and the dyeing temperature was kept constant at 100°C.

Results of colour fastness test

a. **Colour fastness to washing**

Color fastness to washing measures a fabric's ability to retain its color after laundering. It is an important aspect of textile performance, particularly for garments and fabrics that are frequently laundered. It is influenced by dye type, dyeing technique, fabric composition, and washing conditions such as temperature, detergent, and agitation. Standardized tests like AATCC Test Method 61 or ISO 105-C06 evaluate color retention by subjecting dyed samples to controlled washing, followed by assessment using a colorimeter or visual comparison. Results are graded from 1 (severe fading) to 5 (no change). The summary of color fastness results for samples dyed using optimized parameters is presented in Table (No.12).

Table 12: Results of Colour Fastness to Washing

S. No	Mordants	Mordent Conc.	Mordanting Tech.	Colour fastness to washing	
				Change in colour	Staining
1	$AlK(SO_4)_2$	15%	SIM	4/5	5
2	$FeSo_4$	5%	PRM	4	4/5
3	Amla	30%	SIM	4/5	5

The table data clearly indicates that the khadi silk samples dyed with Delonix regia flower exhibited excellent color fastness to washing. Minimal color change was observed, along with negligible to no staining on adjacent fabric.

b. **Colour fastness to Ironing**

The result of colour fastness of the dyed samples to ironing regarding colour change and staining are given in the following table:

Table 13: Result of Colour Fastness to Ironing

S. No	Mordants	Mordent Conc.	Mordanting Tech.	Dry Ironing		Wet Ironing	
				Colour Change	Staining	Colour Change	Staining
1	$AlK(SO_4)_2$	15%	SIM	4/5	5	4	3/4
2	$FeSo_4$	5%	PRM	4/5	5	4	4
3	Amla	30%	SIM	4/5	5	4	4

Table 13 clearly shows that khadi silk samples dyed with *Delonix regia* flowers exhibited excellent color fastness to dry ironing, with minimal color change and no staining on adjacent fabric. Additionally, during wet ironing, the samples demonstrated good color fastness, with slight color change and minor to noticeable staining on the adjacent fabric.

c. Colour Fastness to rubbing

The results of colour fastness of the samples dyed with optimized parameters to rubbing is as follows (table:)

Table 14: Results of Colour Fastness to Rubbing

S. No	Mordants	Mordent Conc.	Mordanting Tech.	Dry Rubbing		Wet Rubbing	
				Colour Change	Staining	Colour Change	Staining
1	$AlK(SO_4)_2$	15%	SIM	4/5	4/5	4/5	4/5
2	$FeSo_4$	5%	PRM	4/5	5	4	4
3	Amla	30%	SIM	4/5	5	4/5	4

The data in the table indicates that khadi silk samples dyed with *Delonix regia* flowers exhibited excellent color fastness to dry rubbing, with minimal color change and little to no staining on adjacent fabric. Similarly, during wet rubbing, the samples showed very good to good color fastness, with slight to noticeable color changes and minor to moderate staining on adjacent fabric.

d. Colour fastness to perspiration

The result of colour fastness of the dyed samples to perspiration regarding colour change and staining are given in the following table:

Table 15: Result of Colour Fastness to Perspiration

S. No	Mordants	Mordent Conc.	Mordanting Tech.	Acidic perspiration		Alkaline perspiration	
				Change in colour	Staining	Change in colour	Staining
1	$AlK(SO_4)_2$	15%	SIM	3/4	4	4	4/5
2	$FeSo_4$	5%	PRM	3	4	4	4/5
3	Amla	30%	SIM	3/4	4	4/5	4/5

The data in the table reveals that khadi silk samples dyed with *Delonix regia* flowers exhibited fair color fastness to perspiration, with a fair to moderate color change and slight staining on adjacent fabric. In alkaline perspiration, the samples displayed very good to good color fastness, with slight to noticeable color changes and minor staining on adjacent fabric.

Colour fastness to sunlight

The dyed samples were exposed to sunlight for seven consecutive days and the color fastness to sunlight was evaluated over seven days. The result of colour fastness of the dyed samples to sunlight regarding colour change and staining are given in the following table:

Table16: Result of Colour Fastness to Perspiration

S. No	Mordants	Mordent Conc.	Mordanting Tech.	1 day	2day	3day	4day	5day	6day	7day
1	$AlK(SO_4)_2$	15%	SIM	5	5	4/5	4/5	4/5	4/5	4/5
2	$FeSo_4$	5%	PRM	5	5	5	4/5	4/5	4/5	4/5
3	Amla	30%	SIM	5	5	5	5	4/5	4/5	4/5

The table data indicates that khadi silk samples dyed with Delonix regia flower experienced slight color change after 2-3 days of sunlight exposure.

For samples mordanted with Aluminium Potassium Sulphate ($AlK(SO_4)_2$) at a 15% concentration and subjected to simultaneous mordanting (SIM), consistently high color fastness ratings (between 4 and 5) were observed throughout the seven-day period.

Similarly, samples mordanted with Ferrous Sulphate (FeSO4) at a 5% concentration and treated with pre-mordanting (PRM) demonstrated excellent color fastness, maintaining a rating of 5 for the entire duration and slightly decreasing to 4/5 from the fourth day onwards.

For samples mordanted with Amla at a concentration of 30% and subjected to simultaneous mordanting (SIM), the color fastness ratings were consistently high, with a rating of 5 for the majority of the period and slightly decreasing to 4/5 on the fifth day onwards.

Overall, all three sets of dyed samples demonstrated good to excellent color fastness to sunlight, with minimal color change and staining observed over the seven-day testing period.

Conclusion

This study confirms that natural dye can be successfully extracted from fallen *Delonix regia* flowers through an eco-friendly process. Optimizing dyeing conditions is essential to reduce costs and maintain fabric quality. The study highlights that these flowers serve as a rich source of natural dye, producing a variety of vibrant shades with good color fastness properties. The optimized parameters ensured even dyeing, depth of shade, and color brightness. Overall, the findings demonstrate that fallen *Delonix regia* flowers offer a sustainable and effective alternative for natural dye production, making them a valuable resource for eco-friendly textile applications.

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