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PROCESS OPTIMIZATION AND FASTNESS PERFORMANCE OF ROSE-DERIVED ANTHOCYANIN DYE ON NATURAL AND SYNTHETIC FIBRES

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ABSTRACT

Rose petal derived anthocyanin dye was applied to cotton, wool, silk, and polyester fibres using pre, meta, and postmordanting techniques with alum and potassium dichromate. Dye extraction was performed using an acidified solvent system and optimized through response surface methodology. The dyed fabrics were assessed for colour strength (K/S) and colour fastness to washing, rubbing, perspiration, light, and water according to ISO standards. The results revealed that mordant type, concentration, and mordanting technique significantly influenced dye uptake and fastness performance. Cotton exhibited superior fastness properties when postmordanted with 4.5% alum, while wool showed improved durability with potassium dichromate under premordanting conditions. Silk demonstrated the highest colour strength (K/S = 5.323) with 4.5% potassium dichromate using postmordanting. Polyester showed limited dye affinity. The findings indicate that rosederived anthocyanin dye can serve as a sustainable textile colorant when optimized mordantfibre interactions are employed.

***Key words*:** Anthocyanin dye, Rose petals, Natural dyeing, Mordanting techniques, Colour strength (K/S), Colour fastness

Introduction

Colour has been an integral part of human civilization, with dyeing traditions being practiced for centuries across cultures. Dyes, defined as substances capable of imparting colour to materials, have been used since ancient times, ranging from early cave art to modern textile applications. Archaeological evidence indicates that humans have employed colourants since 1500–900 BC, and natural dyes continue to be valued for their aesthetic and ecological significance. The dye industry represents a major global sector, contributing significantly to employment, exports, production, and gross domestic product (GDP). In India, textile exports constitute a major source of foreign exchange earnings. Recent advances, including the application of genetic engineering, are being explored to improve dye production methods by enhancing the quality and yield of dye-producing plants (Dipayan S *et al.*, 2023).

Natural dyes are known for producing harmonious, soft, and subtle shades that impart a soothing visual effect. Unlike synthetic dyes, they are non-toxic, non-polluting, and pose minimal risks of carcinogenicity or poisoning, thereby offering improved safety for both human health and the environment. Their applications extend beyond textiles to food, pharmaceutical, and cosmetic industries. Despite Indias vast biodiversity and strong potential for natural dye production, their utilization has declined due to limited technical knowledge regarding extraction and dyeing processes and difficulties in meeting industrial-scale demand (Divya *et al.*, 2013). Moreover, natural dyes are environmentally friendly and do not create disposal issues. Their extraction and application involve fewer chemical reactions, making them a simpler and safer alternative to synthetic dyes (Gulrajani M.L. 2001).

Natural dyes are predominantly used in the colouring of textiles, drugs, and cosmetics (Das *et al.*, 2016). The dislodgement of colourants constitutes the initial stage of organic dyeing (Habib *et al.*, 2022). The extraction of natural dyes involves the separation of colouring compounds from plant matrices through the disruption of cell walls using physical or chemical methods, followed by dissolution of the pigments in suitable solvents under controlled conditions (Ghurde *et al.*, 2023). Common flower-derived pigments include anthocyanins (Fig. 1), which produce red, purple, and blue colours and are water-soluble; flavones, responsible for pale-yellow hues and also water-soluble; and carotenes, which yield yellow, orange, and red colours and are oil-soluble (Saha and Dutta, 2007; Siva R. 2007).

Natural dyes generally require the use of mordants to achieve effective fixation on textile fibers. A mordant function as a chemical bridge between the dye molecule and the fabric fiber, ensuring strong and durable bonding. Mordants may be metallic salts such as chromium, iron, aluminium, copper, and tin; oil mordants such as Turkey red oil; or natural mordants including tea leaves, myrobalan, vinegar, and pomegranate rind. The application of mordants improves colour fastness by enhancing resistance to fading caused by washing and exposure to sunlight (Singh and Srivastava, 2015). The type of mordant employed also influences the final shade obtained, and mordanting may be carried out either before or after dyeing, depending on the desired outcome.

The term “mordant” originated from the inability of certain dyes to adhere to fibers without assistance. Natural dyes are highly dependent on mordants, which form strong ionic or coordination bonds with both the dye molecules and textile fibers, thereby enhancing resistance to fading due to washing, rubbing, and light exposure (Ammayapan and Jose, 2015) (Fig. 2).

Roses, widely admired for their ornamental and aromatic properties, also possess significant potential as sources of natural dyes. Rose petals contain anthocyanins, pigments responsible for red, pink, and purple hues (Najem *et al.*, 2013). These pigments not only impart colour but also exhibit antibacterial activity (Kumar, 2017; Saati *et al.*, 2018). Roses are easily cultivated and can be selectively grown for dye extraction, making them a renewable and sustainable alternative to synthetic dyes. Depending on the cultivar, a wide range of shades can be obtained, offering a diverse natural colour palette. Dyes derived from rose petals often demonstrate good colour fastness, resulting in prolonged colour retention.

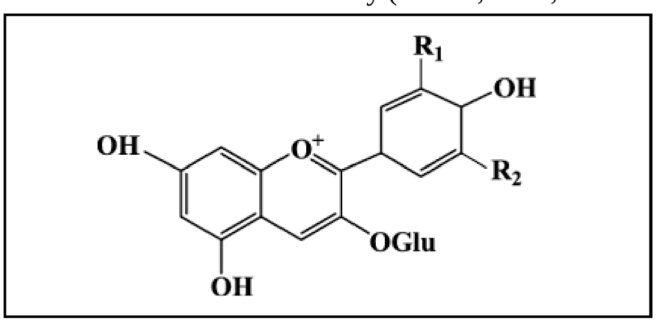

Fig. 1: Chemical structure of anthocyanin.

Natural rose dyes have promising applications in cosmetics, providing safer and eco-friendly alternatives for colouring formulations. They are also suitable for dyeing yarns, wool, and other textile materials, supporting sustainable craft and textile practices. Considering the growing demand for eco-friendly dyes, concerns regarding human health and environmental safety, and the need to promote sustainable textile technologies, the present study was undertaken with the following objectives:

- Screening of mordants and mordanting processes for achieving maximum stability of natural dyes on fabrics
- Evaluation of the stability of natural dyes on fabrics

Materials and Methods

Experimental Procedure

Natural dye was extracted from rose flower petals using a solvent extraction method with 0.015% HCl as the solvent. The rose flower petals used in the natural dye extraction process were procured from the Ghazipur market, New Delhi, and the extraction itself was conducted within the Division of Floriculture and Landscaping at ICAR-IARI, New Delhi in 2023-24. Rose petal anthocyanin, a natural dye, was isolated through a 90-minute hot-air oven solvent extraction. This process

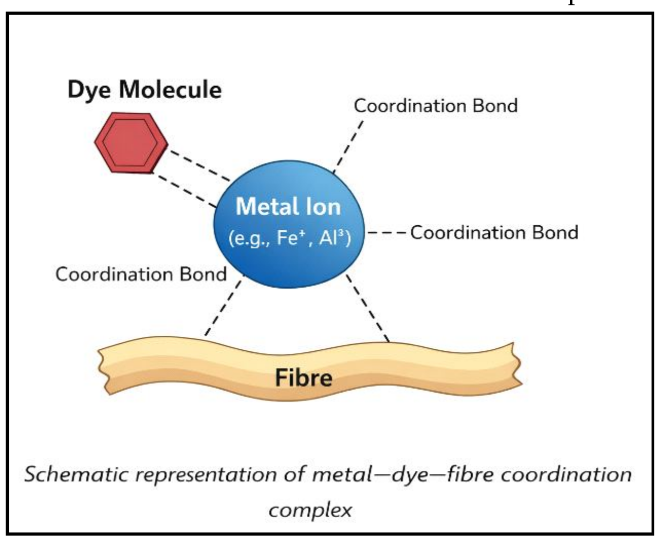

Fig. 2: Schematic representation of metal–dye–fiber coordination complex.

Table 1: List of mordant combinations used to dye different fabrics with pre, meta and postmordanting techniques.

	Cotton	Wool	Silk	Polyester
Premordanting	Alum (1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum (1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum (1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum (1.5%,3%,4.5%) PD (1.5%,3%,4.5%)
Metamordanting	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)
Postmordanting	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)	Alum(1.5%,3%,4.5%) PD (1.5%,3%,4.5%)

PD: Potassium dichromate

utilized a specific ratio of rose petals to a solvent (water and HCl). To optimize the anthocyanin extraction process, researchers used a statistical tool called Response Surface Methodology (RSM) (Sinha *et al.*, 2012). Yield of the natural dye was determined using anthocyanin content and redness index.

The extracted natural dye was applied on cotton, wool, silk and polyester fabrics using alum and potassium dichromate as mordants as shown in Table 1. Three different methods of applying the mordant were used: applying it before dyeing, after dyeing, or simultaneously with dyeing. Concentrations of both mordants i.e., alum (K Al (SO„) , .12H_2O) and potassium dichromate (K, Cr, O‡) were taken as 1.5%, 3% and 4.5% owf (on the weight of fabric) respectively. Mordanting temperature was kept at 60! for all the techniques.

Selection of fabric

Cotton, wool, silk, and polyester fabrics were chosen to be dyed with a natural dye extracted from rose petals. Smaller, 8×8 cm pieces of each fabric were used for initial dyeing experiments involving various mordants. For colour fastness testing, one-meter lengths of respective, fabric were dyed.

Preparation of fabric

The fabrics (polyester, wool, silk, and cotton) were cleaned before dyeing to remove impurities. Each fabric type required a specific washing or cleaning method. The following section outlines the specific cleaning or washing procedures used for each type of fabric.

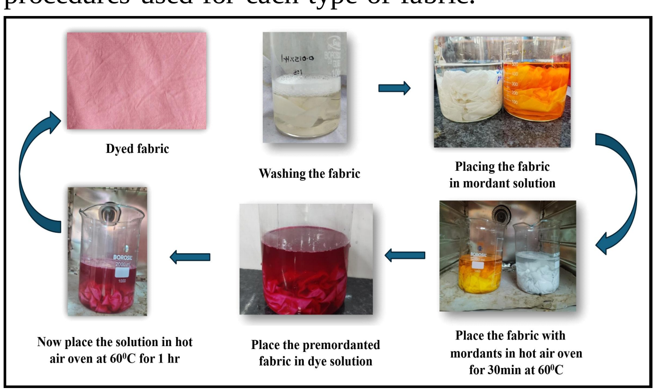

Fig. 3: Process of Premordanting using different mordants.

Cotton fabric was boiled in a sodium hydroxide solution to remove starch. Wool and polyester fabrics were both washed with detergent to eliminate impurities. Silk fabric underwent a different cleaning process. It was treated with a blend of detergent and sodium bicarbonate to remove wax, gum, and other contaminants (Gulrajani M.L., 1992).

The dyeing process with mordants employed a material-to-liquor ratio of 1:50. However, a different ratio of 1:15 was used when conducting fastness tests.

Mordanting Techniques

Mordants are essential for natural dyeing. They are substances used to bind dyes to fabric fibers. The choice of mordant can influence the final colour produced. Mordanting can be done either before or after the dyeing process, depending on the desired outcome.

Mordanting can be done in three different methods: pre-mordanting, simultaneous mordanting, and post-mordanting (Samanta and Agarwal, 2009).

Premordanting

The mordant was applied to the fabric before the dyeing process. Each mordant was initially dissolved in a little amount of boiling water, then distilled water was used to dilute in separate containers to make them into different concentrations. The pre-soaked fabric was treated with the mordant in the hot air oven for about 30

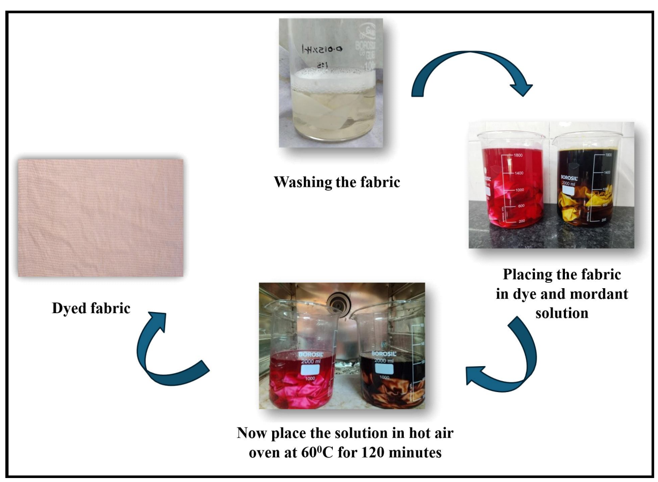

Fig. 4: Process of Metamordanting using different mordants.

Table 2: Ratings for light fastness tests with scores.

Scores	Ratings
8	Outstanding
7	Excellent
6	Very good
5	Good
4	Fairly good
3	Fair
2	Poor
1	Very poor

minutes at 60°C. Afterwards, the fabric was dyed with the natural rose dye in the same oven for an hour. Once the dyeing process was complete, the fabric samples were taken out, rinsed thoroughly with water, and air-dried in a shaded area. The process of premordanting was shown in Fig. 3.

Metamordanting

The mordant and dye were applied to the fabric at a time. The mordants were taken in a small amount of dye extract before being placed in the main dye solution. The pre-soaked fabric was dyed in hot air oven for 120 minutes at 60°C. The samples were rinsed thoroughly with water and kept in a shaded area for drying after dyeing. The process was depicted in Fig. 4.

Postmordanting

The fabric was dyed first, and then the mordant was applied. The pre-soaked fabric was dyed in hot air oven for 120 minutes at 60°C. The dyed fabrics were immersed in the mordant solution for a time of 30 minutes at same temperature as of dyeing. The samples of fabric were taken out of mordant solution, cooled down, rinsed with tap water, gently squeezed, and dried in a shaded area. The process was shown in Fig. 5.

Colour fastness is the ability to maintain its colour over time without fading or transferring to other surfaces and its crucial quality is assessed in textile industry. The Society of Dyers and Colourists has established standardized tests to measure colour fastness. Importantly, a fabric colour fastness can vary on the conditions it is exposed to, so testing should be tailored to the intended use of fabric (Kulkarni *et al.*, 2014).

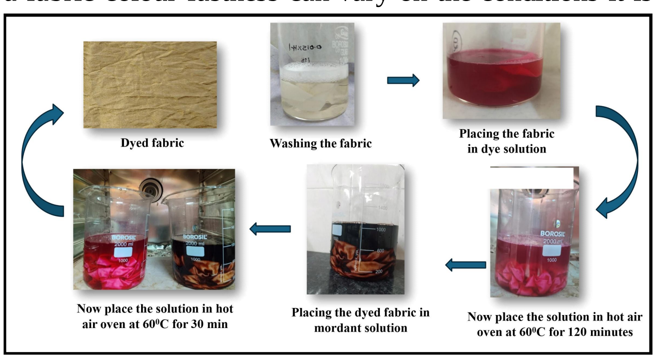

Fig. 5: Process of Postmordanting using different mordants.

Table 3: Ratings for change in colour of colour fastness tests to washing, drycleaning, perspiration and water with scores.

Scores	Ratings
5	Negligible or no change
4	Slightly changed
3	Noticeably changed
2	Considerably changed
1	Much changed

To evaluate the stability of natural dye colour strength and colour fastness tests (washing, dry cleaning, crocking/ rubbing, perspiration, light and water) were conducted. Twenty dyed fabric samples, made from various fabrics with different mordant concentrations and mordanting techniques, were chosen for colour fastness testing. These samples were taken based on their visual appearance, including colour quality and uniformity. Different dyed fabric samples used for the fastness tests are listed in the below Table 5 and Fig. 6. Each sample had a unique fabric type, mordant concentration, and mordanting technique. Two gray scales were used to assess colour fastness: ISO 105 A02:1993 for colour change and ISO 105 A02:2019 for staining. Colour fastness was graded according to Table 2, 3 and 4. The fastness tests of the dyed fabric will be carried out at NITRA (North Indian Textile Research Association), NITRA Technical Campus, Ghaziabad (U.P.) India.

Washing fastness (ISO C10:2006):

Natural dyes often fade when exposed to water, such as during washing or dry cleaning. This poor colour fastness is due to several factors. The bond between dye and fabric is often weak, causing the dye to release. Additionally, the dye structure can be altered during washing, especially in alkaline conditions, leading to colour

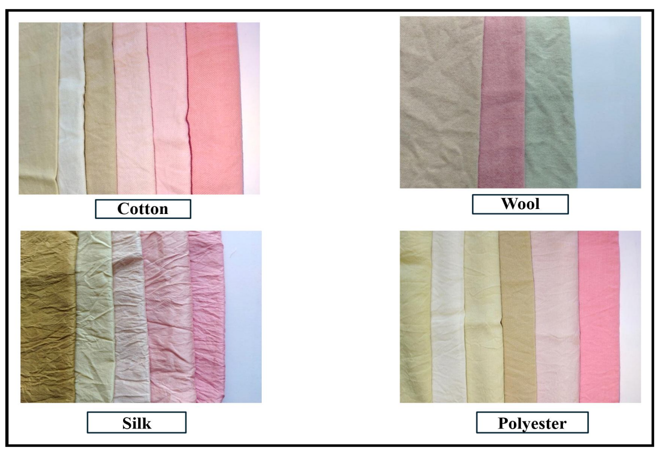

Fig. 6: Fabrics used for colour fastness test and colour strength.

Table 4: Ratings for staining of colour fastness tests to washing, drycleaning, crocking/rubbing, perspiration and water with scores.

Scores	Ratings
5	Negligible or no staining
4	Slightly stained
3	Noticeably stained
2	Considerably stained
1	Much stained

change. Many natural dyes contain hydroxyl compounds that are sensitive to alkaline environments, further contributing to colour loss. It was observed, natural dyed fabrics frequently experience colour fading when washed with detergents or soaps (Teli *et al.*, 2001).

To evaluate colour fastness, a composite sample was made by sewing together 5×5 cm pieces of cotton and wool. This sample was then machine-washed in a soap solution at 40°C for 45 minutes. After washing and drying, the colour change in the dyed sample and any staining on the wool were assessed using a standardized colour scale.

Dry cleaning fastness (ISO 105 D01:2010)

To assess dry-cleaning fastness, a 10×10 cm composite sample of cotton and silk was created. This sample was immersed in perchloroethylene solvent for 30 minutes at 30±2°C. After agitation, the sample was air-dried at a temperature not exceeding 65°C. The degree of staining on the cotton and silk, as well as the colour change in the dyed sample, were evaluated using a gray scale, similar to the washing fastness tests.

Crocking/Rubbing fastness (ISO 105 X 12:2016)

Colour fastness to rubbing measures how well a fabric resists colour transfer when rubbed against another surface. It is a crucial test for consumers to assess fabric quality and a significant concern for textile manufacturers (Nimkar and Bhalekar, 2007b).

To assess colourfastness to rubbing, a crockmeter was used. A 14×5 cm dyed sample was placed on the crockmeter, and a small white cloth was clamped onto the rubbing finger. The finger, with the cloth attached, was rubbed against the sample 10 times in a downward motion. This process was repeated for both dry and wet conditions, with the cloth being moistened with distilled water for the wet rub test. The degree of staining on the white cloth and the colour change on the sample were evaluated using a gray scale.

Perspiration fastness (IS 105 E04:2013)

To evaluate perspiration fastness, a fabric sample was sandwiched between wool and linen and sewn together. Separate tests were conducted for acidic and alkaline perspiration. For acidic perspiration, a test solution containing sodium dihydrogen orthophosphate, sodium chloride, and histidine was prepared and adjusted to pH 5.5. For alkaline perspiration, a solution containing sodium chloride, disodium hydrogen orthophosphate, and histidine was prepared and adjusted to pH 8. The fabric sample was soaked in the appropriate test solution, placed under

Table 5: List of samples used for the fastness tests.

Sample no.	Fabric	Mordanting Techniques	Type of Mordant	Concentration of Mordant
1	Silk	Postmordanting	Potassium Dichromate	4.5%
2		Metamordanting	Potassium Dichromate	3.0%
3		Premordanting	Potassium Dichromate	4.5%
4		Metamordanting	Alum	1.5%
5		Premordanting	Alum	4.5%
6	Wool	Premordanting	Alum	1.5%
7		Metamordanting	Potassium Dichromate	1.5%
8		Premordanting	Potassium Dichromate	4.5%
9	Polyester	Postmordanting	Alum	4.5%
10		Metamordanting	Potassium Dichromate	3.0%
11		Postmordanting	Alum	1.5%
12		Postmordanting	Potassium Dichromate	3.0%
13		Premordanting	Potassium Dichromate	4.5%
14		Premordanting	Alum	1.5%
15	Cotton	Metamordanting	Potassium Dichromate	1.5%
16		Postmordanting	Alum	4.5%
17		Postmordanting	Potassium Dichromate	1.5%
18		Premordanting	Potassium Dichromate	1.5%
19		Metamordanting	Alum	3.0%
20		Premordanting	Alum	3.0%

Table 6: Results of colour fastness tests of cotton fabric samples with different combinations.

Fastness		Premordanting		Metamordanting		Postmordanting	
		Alum (3%)	PD (1.5%)	Alum (3%)	PD (1.5%)	Alum (4.5%)	PD (1.5%)
Light fastness		2	2	2	2	4-5	2
Washing fastness	CC	1	1	1	1	4-5	1-2
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Crocking fastness	Dry	4-5	4-5	4-5	4-5	4-5	4-5
	Wet	4	4	4	4-5	4-5	4-5
Perspiration (acidic)	CC	1	1	1	1	4-5	3
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Perspiration (alkaline)	CC	1	1	1	1	4-5	4-5
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Water fastness	CC	1	1	1	4	4-5	1-2
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Cotton fabric with 4.5% Alum mordant using Postmordanting technique gave better response i.e., 4-5 grade to all the fastness tests respectively.							

pressure, and dried in an oven. The degree of staining on the wool and linen, as well as the colour change in the dyed sample, were assessed using a gray scale, following the same criteria as for washing fastness tests.

Light fastness (ISO 105-B02:2014):

A dye molecule consists of two main parts, chromophores and auxochromes. The chromophore primarily determines a dye ability to resist fading from light, while the auxochrome has a smaller impact on light fastness. The purpose of testing a fabric colour fastness to light is to measure how much the colour fades when exposed to a specific light source (Cristea and Vilarem, 2006).

To check the light fastness, dyed samples were exposed to light in a xenon tester alongside blue wool standards with known lightfastness ratings (1 to 8). Half of each sample was shielded from light. The xenon tester was set to color temperatures of 5500 K and 6500 K. The degree of fading in the exposed portions of the dyed samples was compared to the fading of the blue wool standards to determine their lightfastness.

Water fastness (ISO 105-E01:2013)

To assess water fastness, a fabric sample was soaked in water, drained, and placed between two plates under pressure (12.5 kPa). After drying the sample and any adjacent fabrics separately, any colour changes or staining were evaluated using gray scales.

Colour strength (k/s)

Dye strength is directly related to its ability to absorb light. Colour analysis involves measuring the amount of light reflected from a sample when illuminated by a specific light source. This is typically done using an instrument with an optical sensor and a signal processor. The sensor measures light reflectance at different wavelengths, converting it into an electrical signal. The signal processor then determines the colour values.

The Kubelka-Munk equation describes the relationship between reflectance, absorbance, and scattering within a dyed sample:

$$k/s = [(1-R)^2)/2R]$$

where,

K represents light absorption and

S represents light scattering.

The colour strength of dyed fabric samples was measured as K/S values using an "SS 5100H Spectrophotometer" with a "10° Standard CIE lab Observer" and D65 illuminant at the maximum

Table 7: Results of colour fastness tests of wool fabric samples with different combinations.

Fastness		Premordanting		
		Alum (1.5%)	PD (4.5%)	PD (1.5%)
Light fastness		3	4-5	4-5
Washing fastness	CC	1	4-5	4-5
	CS	4-5	4-5	4-5
Drycleaning fastness	CC	4-5	4-5	4-5
	CS	4-5	4-5	4-5
Crocking fastness	Dry	4	4-5	4-5
	Wet	3-4	4	4
Perspiration (acidic)	CC	1	4-5	4-5
	CS	4-5	4-5	4-5
Perspiration (alkaline)	CC	1	4-5	4-5
	CS	4-5	4-5	4-5
Water fastness	CC	1	4-5	2
	CS	4-5	4-5	4-5
Wool fabric with 4.5% Potassium dichromate using premordanting technique gave better response i.e., 4-5 grade to all the fastness tests respectively.				

Table 8: Results of colour fastness tests of silk fabric samples with different combinations.

Fastness		Premordanting		Metamordanting		Postmordanting
		Alum (4.5%)	PD (4.5%)	Alum (1.5%)	PD (3%)	PD (4.5%)
Light fastness		3	3	3-4	4	1-2
Washing fastness	CC	1	1	1	4-5	4-5
	CS	4-5	4-5	4-5	4-5	4-5
Drycleaning fastness	CC	4-5	4-5	3-4	4-5	4-5
	CS	4-5	4-5	4-5	4-5	4-5
Crocking fastness	Dry	4-5	4-5	4-5	4-5	4-5
	Wet	4-5	4-5	4-5	4-5	4-5
Perspiration (acidic)	CC	1	1	1	2-3	2-3
	CS	4-5	4-5	4-5	4-5	4-5
Perspiration (alkaline)	CC	1	1	1	2-3	2-3
	CS	4-5	4-5	4-5	4-5	4-5
Water fastness	CC	1	1	1	1	4-5
	CS	4-5	4-5	4-5	4-5	4-5
Silk fabric with 3% Potassium dichromate using Metamordanting technique gave better response to fastness tests i.e., 4-5 (grade) for washing, crocking, drycleaning and water fastness tests; 4 (grade) for light fastness and 2-3 (grade) for perspiration test in both acidic and alkaline medium respectively.						

wavelength. Samples were placed in the instrument and illuminated with light. The computer displayed reflectance values. For each sample, readings were taken with three different orientations.

Result and Discussion

Different mordants can produce different colour hues from the same dye extract (Panda *et al.*, 2022). Evidence suggested that using the premordanting technique with alum serving as a fixative produced the original colour of the rose natural dye in all fabrics because in premordanting, the mordant is applied to the fabric before the dye which allows a direct interaction between the mordant and the dye molecules, forming a stronger bond (Iqbal, M. 2023) and the mordant-dye complex formed in premordanting is typically more consistent than those formed in metamordanting or postmordanting. This leads to improved colour fastness to factors like washing, light, and perspiration (Panda *et al.*, 2022). A concentration of 1.5% alum produced better colour shades compared to higher concentrations of 3% and 4.5%. Various shades, including light purplish pink, pale purplish pink, and strong purplish pink were observed in samples dyed using the premordanting technique with different concentrations of mordant in all fabrics. In contrast, pale orange yellow to pale green yellow and purplish pink to very pale purple shades were observed using the metamordanting and postmordanting techniques. light yellowish brown to moderate olive brown and greyish yellow green colour shades were observed in silk fabric samples dyed using the postmordanting technique at different concentrations.

The results indicate that cotton fabric treated with a

Table 9: Results of colour fastness tests of polyester fabric samples with different combinations.

Fastness		Premordanting		Metamordanting		Postmordanting	
		Alum (1.5%)	PD (4.5%)	Alum (3%)	PD (1.5%)	Alum (4.5%)	PD (3%)
Light fastness		2-3	2-3	4-5	3	2-3	2-3
Washing fastness	CC	1	1	3-4	1	3	3
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Crocking fastness	Dry	4-5	4-5	4-5	4-5	4-5	4-5
	Wet	4	4-5	4-5	4-5	4-5	4-5
Perspiration (acidic)	CC	1	1	3-4	2-3	1	3
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Perspiration (alkaline)	CC	1	1	3-4	2-3	1	3
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Water fastness	CC	3-4	1	4-5	2-3	4-5	2-3
	CS	4-5	4-5	4-5	4-5	4-5	4-5
Polyester fabric with 3% Potassium dichromate using Metamordanting technique gave better response to fastness tests i.e., 4-5 (grade) for light, crocking and water fastness tests; 3-4 (grade) for washing and perspiration respectively.							

Table 10: List of fabric samples with different combinations used for colour strength test.

Sample no.	Fabric	Mordanting Techniques	Type of Mordant	Concentration of Mordant	Colour strength (k/s value)
1	Silk	Postmordanting	Potassium Dichromate	4.5%	5.323
2		Metamordanting	Potassium Dichromate	3%	0.754
3		Premordanting	Potassium Dichromate	4.5%	0.333
4		Metamordanting	Alum	1.5%	0.423
5		Premordanting	Alum	4.5%	0.527
6	Wool	Premordanting	Alum	1.5%	0.596
7		Metamordanting	Potassium Dichromate	1.5%	0.218
8		Premordanting	Potassium Dichromate	4.5%	0.536
9	Polyester	Postmordanting	Alum	4.5%	2.172
10		Metamordanting	Potassium Dichromate	3%	0.254
11		Postmordanting	Alum	1.5%	1.795
12		Postmordanting	Potassium Dichromate	3%	1.795
13		Premordanting	Potassium Dichromate	4.5%	0.362
14		Premordanting	Alum	1.5%	0.838
15	Cotton	Metamordanting	Potassium Dichromate	1.5%	1.832
16		Postmordanting	Alum	4.5%	0.398
17		Postmordanting	Potassium Dichromate	1.5%	1.420
18		Premordanting	Potassium Dichromate	1.5%	0.378
19		Metamordanting	Alum	3%	0.628
20		Premordanting	Alum	3%	1.205

4.5% alum mordant through the post-mordanting method achieved the best overall colour fastness, with ratings of 4–5 across all assessments (Table 6). This observation aligns with findings that post-mordanting cotton with alum (potassium aluminium sulphate) generally enhances colourfastness, often producing good to excellent ratings (3–5/5) compared with unmordanted samples (Hanumantha *et al.*, 2020). Similarly, wool fabric processed with a 4.5% potassium dichromate mordant using the pre-mordanting technique also showed excellent colour fastness (Table 7). This is consistent with the work that demonstrated the wool treated with chromium-based mordants such as potassium dichromate typically exhibits very good to excellent fastness properties, including improved resistance to washing, light, and rubbing (Aminoddin, 2012).

Silk fabric treated with a 3% potassium dichromate mordant through the metamordanting method displayed good colour fastness to washing, crocking, dry cleaning, and water, although its perspiration fastness was only moderate, as presented in Table 8. These findings agree with the report that stated potassium dichromate (as well as alum) can substantially enhance fastness properties in silk dyeing. The study further notes that metamordanting generally produces good fastness to washing, crocking, and water, while perspiration fastness may be moderate or variable depending on the mordant concentration and dyeing conditions.

For polyester fabric, treatment with a 3% potassium dichromate mordant through the metamordanting technique resulted in good colour fastness to light, crocking, and water, while washing and perspiration fastness remained moderate, as shown in Table 9. This outcome corresponds with the findings that although polyester, being a hydrophobic synthetic fibre, generally responds less effectively to metallic mordants, the use of chromium salts or surface-modified polyester can enhance fastness to light, crocking, and water. However, their study also indicates that washing and perspiration fastness often remain moderate due to variations in dye structure and fibre pretreatment.

Mordants, such as alum, potassium dichromate, and iron salts, can improve light fastness and colour absorption,

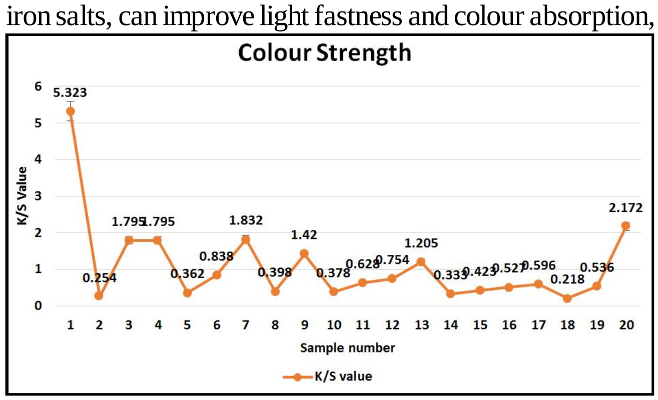

Fig. 7: Colour strength of the fabric samples dyed with various concentrations of mordants and mordanting techniques.

especially for cotton (Zarkogianni *et al*., 2011). Alum, at a concentration of 4.5%, has been found to produce excellent colour fastness for cotton when used in a post-mordanting process (Janani *et al*., 2014). For wool, premordanting with potassium dichromate has shown good result (Zarkogianni *et al*., 2011).

Metallic mordants generally enhance colour fastness properties, with many treatments achieving very good (4/5) ratings for wash, water, perspiration, and rubbing fastness (Repon *et al*., 2017). However, lightfastness can vary depending on the specific mordant used (Zarkogianni *et al*., 2011; Repon *et al*., 2017).

The highest colour strength (K/S value) was observed in silk fabric treated with a 4.5% potassium dichromate mordant using the postmordanting technique, followed by polyester fabric treated with a 4.5% alum mordant using the postmordanting technique as depicted in Table 10 and Fig. 7.

The observed differences in colour fastness and colour strength among the various fabric types and mordant treatments different fibers have varying affinities for dyes and mordants. For example, wool and silk, being protein fibers, have a greater affinity for dyes compared to synthetic fibers like polyester (Panda *et al.*, 2022). The chemical composition of the dye can affect how well it bonds with the fiber and interacts with the mordant (Zarkogianni *et al*., 2011). Mordants like alum, ferrous sulphate, and tannin can significantly increase colour intensity (K/S values) and create various colour hues (Panda *et al.*, 2022; Viet Nam Luong Nguyen *et al*., 2024). The fabric type also influences dyeing results, with silk often exhibiting better colour fastness than cotton (Viet Nam Luong Nguyen *et al*., 2024). Natural dyes offer advantages beyond colouration, including UV protection and antimicrobial properties (Gawish S. *et al*., 2017).

Conclusion

Rose-derived anthocyanin dye demonstrated satisfactory colour strength and fastness properties on both natural and synthetic fibres when appropriate mordanting techniques were employed. Postmordanting with 4.5% alum was most effective for cotton, while potassium dichromate premordanting yielded superior results for wool. Silk fabric exhibited the highest colour strength when postmordanted with potassium dichromate. The study highlights the importance of mordant–fibre interactions and confirms the feasibility of rose anthocyanin dye as an eco-friendly alternative for textile coloration.

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