Sustainable Dyeing of Wool by Natural Dyes in Conjunction with Natural Mordants

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1 Introduction

Natural colourants have been used in textile, leather as well as food since prehistoric times. These colourants are obtained from natural substances such as animal and vegetable matter with no or very little chemical processing. Synthetic dyes were introduced in 1856 and being cheaper and easily available resulted in a drastic decline in the usage of natural colourants. However, in the present era there has been a revival of interest in natural colourants due to their sustainable behaviour [1, 2]. Environmentalists are always concerned about the use of synthetic colourants in textile industry as they cause waste disposal and water pollution problems [3]. Synthetic dyes and finishes have great environmental concern and thus needs sustainable alternatives [4]. Application of enzymes [5, 6], biopolymers [7–10], herbal finishes [11, 12], natural dyes, and suitable alternatives play a pivotal role in sustainable textile wet processing. Natural dyes do not cause any health hazards being biodegradable hence they can be easily used without much environment concerns. Despite this, use of natural dyes for dyeing textiles has been restricted mainly to cottage industries or at artisan level printers due to associated problem with natural dyes such as lack in reproducibility, poor fastness and cumbersome extraction and application methods [13, 14]. Recently, many commercial printers have started using natural dyes to overcome the environmental damage caused by synthetic dyes. Despite several limitations, there has been a trend to revive the art of natural colouring in recent years due to their distinct

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V. Midha and A. Mukhopadhyay (eds.), *Recent Trends in Traditional and Technical Textiles*, https://doi.org/10.1007/978-981-15-9995-8_12

soothing aesthetic appeal. India being rich in biodiversity has more than 450 plants yielding dyes and pigments for food, textiles and allied industries [15, 16]. However, many of these plant colourants are not yet fully explored for their potential in dyeing textiles. Majority of these plants extracts are being used for medicinal purposes being having good antibacterial properties [16, 17]. Natural dyes along with biopolymers also shown good dyeing and finishing properties [18–20]. The chemical constituents such as quinine, tannin, phenol, etc., present in plant extract provide colour as well as medicinal properties which can be also harvested for producing functional properties to textiles [21]. Thus, dyeing potential of different natural colourants extracted from varied plants, i.e. banyan bark, peepal bark, papaya leaf and Kalanchoe-pinnata leaf were evaluated on wool fabric. Although, only dyeing studies of wool are discussed in this present research paper.

Natural dyes have poor fastness properties hence need mordanting. Pre, meta and post mordanting with heavy metal salts such as aluminium potassium sulphate, ferrous sulphate, copper sulphate, potassium dichromate, etc., is being used traditionally. Although, natural dyes are ecofriendly in nature but owing to use of associated heavy metallic salts in mordanting step makes the dyeing process toxic. Thus, it is required to find out alternatives to heavy metallic salts. Natural mordants can be explored as ecofriendly alternative in dyeing of textiles with natural dyes [22, 23]. Hence, natural biomordants are also used in investigation to compare their behaviour in dyeing with metallic mordants.

2 Materials and Methods

2.1 Materials

2.1.1 Textile Materials

Wool fabric was chosen for this study.

2.1.2 Plant Materials

Four types of plant sources, i.e. banyan bark, peepal bark, papaya leaf and Kalanchoe-pinnata leaf were explored for their dyeing potential.

2.1.3 Mordants

Three chemical mordants such as aluminium potassium sulphate, ferrous sulphate, copper sulphate and four natural mordants such as amla, harda, pomegranate rind and orange peel were taken for this study.

2.2 Preparation of Dye Solution and Dyeing

Using optimised conditions of extraction, i.e. MLR 1:30, pH 5 and time 90 min at 100 °C, the dye was extracted from Kalanchoe-pinnata and papaya leaves, peepal and banyan barks [24–26]. It is pertinent to mention that in case of Kalanchoe-pinnata and papaya leaves shade % and mordant % was kept at 20% owing weight of the fabric. Whereas in case of peepal and banyan bark shade % and mordant % was kept at 10% owing to the weight of the fabric based on some preliminary experiments. All fabrics were cut into 20 × 20 cm size samples and dyed for optimising dyeing parameters, i.e. MLR, pH and temperature of the dye bath as well as time of dyeing for obtaining maximum *K*/*S* value. Further, the dyed fabrics were mordanted with four natural mordants such as amla, harda, orange peel and pomegranate to improve fastness properties. Similarly, dyed fabrics with optimised dye recipes were also mordanted with three chemical mordants, i.e. alum, copper sulphate and ferrous sulphate to compare their fastness behaviour with natural mordants.

2.3 Characterisation of Dye Extract and Dyed Fabrics

2.3.1 Antioxidant Property

Anti-oxidant property is a measure of the capacity of extracts to scavenge the stable free radicals of DPPH. Samples of 0.20 ml volumes of extracts were added to 3.8 ml of 0.1 mM DPPH solution in ethanol [17]. Samples were put in dark for 30 min to complete the reaction at room temperature for decolourising the solution. Further, decolourisation was assessed on spectrophotometer at 517 nm wavelength and RSA percentage was calculated using Formula (1):

$$\text{Radical Scavenging Activity (\%)} = 1 - \frac{\text{Absorbance (sample)}}{\text{Absorbance (control)}} \times 100 \qquad (1)$$

where $\text{Absorbance}_{\text{sample}}$ refers to the absorbance of the solution having dye extract and $\text{Absorbance}_{\text{control}}$ refers to the absorbance of the solution having the de-ionised water.

2.4 Anti-microbial Behaviour Evaluation of Dye and Dyed Fabrics

Extracted dye and dyed fabrics were evaluated for anti-microbial behaviour using AATCC-100 method using gram-positive (*S. aurous*) and gram-negative (*E. coli*) bacteria at IIT, Delhi using quantitative assessment of anti-microbial behaviour.

Equation (2) was used to calculate bacterial reduction percentage.

$$\text{Bacterium Reduction } (\%) = \frac{A - B}{A} \times 100 \tag{2}$$

where, A represents bacterial colonies for the control after 24 h incubation time
B represents bacterial colonies for sample after 24 h incubation time.

2.5 Analysis of Colour Co-ordinates of Dyed Fabrics

All the dyed samples were assessed for measuring colour co-ordinates (L, a, b and K/S) using Premier Colour scan computer colour matching system at D65 illuminant/10° observer.

2.6 Evaluation of Fastness Properties of Dyed Fabrics

The light fastness, rubbing fastness (wet and dry) and washing fastness of the dyed fabric samples were evaluated as per ISO 105-BO2:2002, ISO-105-X12 and IS: 3361:79, methods respectively.

3 Results and Discussion

Highest K/S value was taken as the optimisation criteria for different dyeing variables and the results are shown in Table 1.

It is clear from Table 1 that all four-extract dyed protein fabric show maximum K/S values in acidic medium.

Table 1 Optimised dyeing conditions for wool fabric four all extracts

Extracts	Variables			
	Time (min)	pH	Temperature (°C)	MLR
Banyan bark	90	3	90	1:30
Peepal bark	90	3	90	1:30
Papaya leaf	90	3	90	1:30
Kalanchoe-pinnata leaf	90	5	90	1:30

3.1 Anti-oxidant Activity of the Extracts

All-natural species of plants have rich phenolics, carotenoids, flavonoids and secondary metabolites in their chemical structure which contribute towards anti-oxidant behaviour. All four extracts were tested for anti-oxidant activity against the free radicals by DPPH because its chemical reaction is very easy to perform [21, 27]. The findings of the study are as follows:

Ascorbic acid calibration curve Eq. (3).

$$y = -0.4892x + 0.7801 \tag{3}$$

where y is absorbance value and x is the amount of Ascorbic Acid.

Resultant value of antioxidant for all extracts is as shown in Table 2.

It can be seen that among all four extracts Kalanchoe-pinnata leaf has maximum Anti-oxidant property so it can be used in cosmetics and finishing of facial wipes etc. for textile application [28].

3.2 Anti-microbial Property

All four extracts and the dyed protein fabric showed very good anti-microbial property against *E. coli* (gram−) and *S. aurous* (gram+) bacteria as mentioned in Table 3. Whereas, papaya leaf extract has maximum bacterial reduction %.

Table 2 Anti-oxidant characteristics of all extracts

Extracts	Antioxidant property	
	Absorbance of extract	Anti-oxidant assay equivalent to ascorbic acid
Banyan bark	0.629	0.308
Peepal bark	0.526	0.519
Papaya leaf	0.523	0.525
Kalanchoe-pinnata leaf	0.445	0.685

Table 3 Bacterial reduction % of all extracts and dyed fabric

Bacteria	Bacterial reduction %							
	Banyan bark		Peepal bark		Papaya leaf		Kalanchoe-pinnata leaf	
	Extract	Fabric	Extract	Fabric	Extract	Fabric	Extract	Fabric
S. aurous	96.06	92.16	96.16	92.79	96.92	94.58	96.82	93.49
E. coli	95.50	90.89	95.63	91.52	96.93	94.19	95.76	92.62

Thus, all these four natural extracts can be used efficiently in medical textiles being excellent antibacterial properties.

3.3 Colour Measurement Using Computer Colour Matching System

The colour co-ordinate values and shades of wool fabric dyed with Banyan and Peepal bark extract in conjunction with various mordants and mordanting techniques are shown in Table 4. Whereas, the colour co-ordinate values and shades of wool fabric dyed with Papaya and Kalanchoe-pinnata leaf extracts in conjunction with various mordants and mordanting techniques are indicated in Table 5.

It can be seen from Tables 4 and 5 that all the dyed samples with different mordants and mordanting techniques exhibit different shades. It can be observed that alum does not have much effect on colour, ferrous sulphate gives tones of grey and copper sulphate changes shades into greenish tone. Pomegranate peel has large amount of tannins hence highlights its own shades in combination with extracts. Harda powder along with extracts modifies the shades of dyed fabrics up to a little extent while Orange peel and Amla powder don’t affect the actual shade obtained with true extract. Wool fabric being coarse absorbs large quantity of dye resulting in dark shades. Although, it can be observed that no specific particular trend was observed for any mordant and mordanting technique.

3.4 Colour Fastness Analysis

Tables 6, 7, 8 and 9 show results of colour fastness ratings of the wool dyed fabric with banyan bark, peepal bark, papaya leaf and Kalanchoe-pinnata leaf, respectively. It can be observed from these tables that all the dyed fabrics show satisfactory to good wash fastness. Chemical mordants form H-bond or coordinate bonds with dye and fabric resulting in satisfactory to good wash fastness properties. Although, it can be observed from these tables that rubbing fastness was in generally poor to satisfactory except the Kalanchoe-pinnata dyed wool fabric. Poor rubbing fastness may be occurred due to deposition of natural dyes molecules more on fabric surface instead of penetration inside the interiors of the fabric. Use of appropriate levelling agents may reduce this problem and can improve the rubbing fastness properties.

The results of the study show that all the dyed samples give good light fastness rating or there is increase in darkness of the dyed wool samples instead of fading. The increase in colour depth of some wool dyed sample is due to oxidation of aromatic constituents of natural colourants [29]. It can be also analysed that natural mordants are also comparable to heavy metal-based mordants. Thus, all the four plants extract

Table 4 Colour co-ordinates of wool dyed with banyan and peepal bark extracts

S. No	Name	Wool dyed fabric with banyan bark extract					Wool dyed fabric with peepal bark extract				
		*L**	*a**	*b**	*K/S*	Shade	*L**	*a**	*b**	*K/S*	Shade
Undyed wool		87.8	−1.2	11.7	0.3		87.8	−1.2	11.7	0.3	
W/O mordant		58.1	11.0	19.6	2.5		89.9	21.3	23.19	2.7	
1	Al pre	54.6	13.8	22.6	3.6		55.1	9.7	21.5	3.9	
2	Al meta	62.9	9.4	21.7	2.2		61.8	6.7	21.1	3.6	
3	Al post	59.8	11.4	20.3	2.4		57.8	9.1	20.4	3.1	
4	Cu pre	44.7	10.9	17.3	6.0		48.6	6.0	19.8	5.7	
5	Cu meta	47.2	6.2	18.4	5.7		51.2	3.9	21.8	6.0	
6	Cu post	45.6	8.4	18.2	6.2		47.2	4.6	18.8	6.1	
7	Fe pre	44.3	6.1	10.6	4.6		42.9	3.0	10.0	5.3	

(continued)

Table 4 (continued)

S. No	Name	Wool dyed fabric with banyan bark extract					Wool dyed fabric with peepal bark extract				
		*L**	*a**	*b**	*K/S*	Shade	*L**	*a**	*b**	*K/S*	Shade
8	Fe meta	42.8	1.3	7.0	4.4		45.8	1.8	10.4	4.9	
9	Fe post	44.0	3.1	9.5	4.5		44.4	2.6	13.1	5.6	
10	H pre	52.3	9.9	25.0	6.2		50.1	8.5	23.2	6.9	
11	H meta	54.6	8.7	26.0	5.8		53.7	7.3	25.7	6.6	
12	H post	57.1	9.0	29.5	5.8		54.9	7.6	26.1	6.0	
13	P pre	50.3	10	23.0	6.0		51.8	8.1	22.6	6.0	
14	P meta	51.3	7.1	23.2	6.4		52.7	7.3	23.8	6.2	
15	P post	54.9	9.8	27.5	6.0		53.5	7.8	24.5	6.0	
16	O pre	51.1	11.1	20.3	4.2		56.1	9.0	19.6	3.5	
17	O meta	53.7	9.2	20.8	4.0		56.4	7.9	20.1	3.4	

(continued)

Table 4 (continued)

S. No	Name	Wool dyed fabric with banyan bark extract					Wool dyed fabric with peepal bark extract				
		*L**	*a**	*b**	*K/S*	Shade	*L**	*a**	*b**	*K/S*	Shade
18	O post	55.7	9.8	22.0	3.7		56.4	8.4	19.9	3.3	
19	A pre	52.8	13.2	19.6	3.5		50.7	8.4	19.4	4.8	
20	A meta	53.9	9.7	18.3	3.3		54.1	7.7	21.0	4.3	
21	A post	57.5	10.6	18.8	2.6		53.6	7.5	20.5	4.3	

Abbreviations Al: alum, Fe: ferrous sulphate, Cu: copper sulphate, H: harda, A: amla, O: orange peel, P: pomegranate peel, Pre: pre-mordanting, Meta: meta-mordanting, Post: post-mordanting

Table 5 Colour co-ordinates of wool dyed with papaya and Kalanchoe-pinnata leaf extracts

S. No	Name	Wool dyed fabric with papaya leaf extract					Wool dyed fabric with Kalanchoe-pinnata leaf extract				
		*L**	*a**	*b**	*K/S*	Shade	*L**	*a**	*b**	*K/S*	Shade
Undyed wool		87.8	−1.2	11.7	0.3		87.8	−1.2	11.7	0.3	
W/O mordant		67.0	2.7	23.9	2.5		66.5	2.8	16.0	1.9	
1	Al pre	62.2	2.7	24.5	3.6		83.8	−1.6	12.2	0.4	
2	Al meta	68.6	1.2	28.2	2.8		72.2	−0.5	19.7	1.6	
3	Al post	68.4	0.3	20.8	1.9		66.7	−1.3	19.2	2.0	
4	Cu pre	49.3	2.5	21.9	6.6		66.4	−5.9	19.4	2.0	
5	Cu meta	50.8	−0.1	24.1	7.0		52.0	−0.4	25.3	6.7	
6	Cu post	52.9	−1.7	22.6	5.7		48.9	1.1	20.1	6.2	
7	Fe pre	52.8	3.6	21.1	5.1		68.2	3.6	16.7	1.4	

(continued)

Table 5 (continued)

S. No	Name	Wool dyed fabric with papaya leaf extract					Wool dyed fabric with Kalanchoe-pinnata leaf extract				
		*L**	*a**	*b**	*K/S*	Shade	*L**	*a**	*b**	*K/S*	Shade
8	Fe meta	43.2	−0.1	12.9	6.4		44.4	−0.9	8.5	4.9	
9	Fe post	47.8	2.6	18.1	6.0		43.3	0.2	7.3	4.6	
10	H pre	54.1	3.5	26.3	8.0		59.6	4.8	29.2	5.9	
11	H meta	58.7	3.6	27.9	6.5		58.9	4.8	27.6	5.9	
12	H post	57.8	3.5	29.6	7.1		57.9	5.6	30.0	6.9	
13	P pre	51.7	5.0	24.1	7.7		57.1	1.2	25.1	5.9	
14	P meta	56.4	5.7	28.0	7.0		57.7	3.8	28.7	6.4	
15	P post	56.0	6.7	29.3	7.2		59.5	4.1	32.2	7.3	
16	O pre	60.9	1.7	20.8	3.1		79.1	0.5	20.0	0.9	
17	O meta	64.7	2.6	21.5	2.5		67.8	2.6	18.2	1.8	

(continued)

Table 5 (continued)

S. No	Name	Wool dyed fabric with papaya leaf extract					Wool dyed fabric with Kalanchoe-pinnata leaf extract				
		L^*	a^*	b^*	K/S	Shade	L^*	a^*	b^*	K/S	Shade
18	O post	66.5	2.7	20.0	2.1		68.2	1.8	18.6	1.8	
19	A pre	54.3	3.8	20.0	4.8		60.3	5.2	22.6	3.3	
20	A meta	58.7	4.0	20.6	3.7		62.3	2.9	19.6	3.0	
21	A post	56.4	4.1	18.8	3.7		60.3	3.9	21.9	3.8	

Abbreviations Al: alum, Fe: ferrous sulphate, Cu: copper sulphate, H: harda, A: amla, O: orange peel, P: pomegranate peel, Pre: pre-mordanting, Meta: meta-mordanting, Post: post-mordanting

Table 6 Fastness ratings for dyed wool fabric with banyan bark extract

Applied mordant	Mordanting technique	Wash fastness			Rubbing fastness		Light fastness
		Fading	Staining		Dry	Wet	
			Cotton	Wool			
Without mordant		3/4	4	3/4	3	3	7
Harda	Pre	3/4	4	3/4	1–2	1–2	Darker
	Meta	3/4	3/4	3/4	1–2	1–2	Darker
	Post	3/4	3/4	3/4	1–2	1–2	Darker
Orange peel	Pre	3/4	3/4	3/4	3	2–3	Darker
	Meta	4	4	4	2–3	2	Darker
	Post	4	4	4	3	2–3	Darker
Pomegranate peel	Pre	3/4	3/4	3/4	3	2–3	Darker
	Meta	3/4	3/4	3/4	2–3	2	Darker
	Post	4	4	4	3	2–3	Darker
Amla	Pre	3/4	3/4	3/4	2–3	3	7
	Meta	4	4	4	2–3	2	6
	Post	3/4	3/4	3/4	4	3–4	7
Alum	Pre	4	4	3/4	1–2	1–2	7
	Meta	4/5	4	4	1–2	1–2	7
	Post	4	4	3/4	2	2	7
$CuSO_4$	Pre	3/4	4	3/4	1–2	1–2	7/8
	Meta	4	4	4	1–2	1–2	7/8
	Post	4	4	4	2	2	7/8
$FeSO_4$	Pre	3/4	4	3/4	2	1–2	Darker
	Meta	3/4	3/4	3/4	1–2	1–2	Darker
	Post	3/4	3/4	3/4	1–2	1–2	Darker

Table 7 Fastness ratings for dyed wool fabric with peepal bark extract

Applied mordant	Mordanting technique	Wash fastness			Rubbing fastness		Light fastness
		Fading	Staining		Dry	Wet	
			Cotton	Wool			
Without mordant		4	4	3/4	2–3	2	6
Harda	Pre	4	4	3/4	2–3	2–3	Darker
	Meta	3/4	3/4	3/4	2	2	Darker
	Post	4	4/5	4	2–3	2	Darker
Orange peel	Pre	4	4/5	4	2–3	2–3	7
	Meta	3/4	4	3/4	1–2	1–2	7
	Post	3/4	4	3/4	2	2	7

(continued)

Table 7 (continued)

Applied mordant	Mordanting technique	Wash fastness			Rubbing fastness		Light fastness
		Fading	Staining		Dry	Wet	
			Cotton	Wool			
Pomegranate peel	Pre	3/4	4	3/4	1–2	1–2	Darker
	Meta	4	4/5	4	1–2	1–2	Darker
	Post	4	4/5	4	2	2	Darker
Amla	Pre	4	4/5	4	1–2	1–2	7
	Meta	3/4	4	3/4	1–2	1–2	7
	Post	4	4/5	4	2–3	2–3	7
Alum	Pre	3/4	3/4	3/4	1–2	1–2	6
	Meta	4	4	4	2	2	6
	Post	3/4	3/4	3/4	2–3	2–3	6
$CuSO_4$	Pre	4	4	4	1–2	1–2	6
	Meta	3/4	3/4	3/4	2	2	6
	Post	3/4	3/4	3/4	1–2	1–2	6
$FeSO_4$	Pre	3/4	3/4	3/4	1–2	1–2	6
	Meta	4	4	4	2	2	6
	Post	3/4	3/4	3/4	2–3	2–3	6

Table 8 Fastness ratings for dyed wool fabric with papaya leaf extract

Applied mordant	Mordanting technique	Wash fastness			Rubbing fastness		Light fastness
		Fading	Staining		Dry	Wet	
			Cotton	Wool			
Without mordant		4	4/5	4/5	3	3	7
Harda	Pre	3/4	3/4	3/4	1–2	1–2	Darker
	Meta	3/4	3/4	3/4	1–2	1–2	Darker
	Post	4	4	4	-2	1–2	Darker
Orange peel	Pre	4	4/5	4/5	3	2–3	7/8
	Meta	4/5	4/5	4/5	2–3	2	7/8
	Post	4	4/5	4/5	3	2–3	7/8
Pomegranate peel	Pre	3/4	3/4	3/4	3	2–3	Darker
	Meta	4	4	4	2–3	2	Darker
	Post	3/4	3/4	3/4	3	2–3	Darker
Amla	Pre	3/4	4	3/4	2–3	3	Darker
	Meta	4	4/5	4	2–3	2	Darker
	Post	4	4/5	4	4	3–4	Darker

(continued)

Table 8 (continued)

Applied mordant	Mordanting technique	Wash fastness			Rubbing fastness		Light fastness
		Fading	Staining		Dry	Wet	
			Cotton	Wool			
Alum	Pre	4/5	4/5	4/5	1–2	1–2	7/8
	Meta	4	4	4	1–2	1–2	7/8
	Post	4	4	4	2	2	7/8
$CuSO_4$	Pre	4/5	4/5	4/5	1–2	1–2	7/8
	Meta	4/5	4	4	1–2	1–2	7/8
	Post	4/5	4	4	2	2	7/8
$FeSO_4$	Pre	3/4	3/4	3/4	2	1–2	Darker
	Meta	3	3/4	3/4	1–2	1–2	Darker
	Post	3	3/4	3/4	1–2	1–2	Darker

Table 9 Fastness ratings for dyed wool fabric with Kalanchoe-pinnata leaf extract

Applied mordant	Mordanting technique	Wash fastness			Rubbing fastness		Light fastness
		Fading	Staining		Dry	Wet	
			Cotton	Wool			
Without mordant		4	4/5	4/5	4/5	4	Darker
Harda	Pre	4	4/5	4/5	4/5	3	Darker
	Meta	4/5	4/5	4/5	4/5	3/4	Darker
	Post	4/5	4/5	4/5	4/5	4	Darker
Orange peel	Pre	4	4/5	4/5	4	3/4	No change
	Meta	4	4/5	4/5	4	3/4	Darker
	Post	3/4	4/5	4/5	4/5	4	Darker
Pomegranate peel	Pre	3/4	4/5	4/5	3	2/3	Darker
	Meta	3/4	4/5	3/4	4/5	3/4	Darker
	Post	4	4/5	4	4	3/4	Darker
Amla	Pre	4	4/5	4	4/5	4	No change
	Meta	4	4/5	4/5	4/5	3/4	No change
	Post	3/4	4/5	4	4/5	4	Shade change
Alum	Pre	4	4/5	4/5	4/5	4	No change
	Meta	4	4/5	4/5	4/5	4	Darker
	Post	4	4/5	4/5	4/5	4	Darker

(continued)

Table 9 (continued)

Applied mordant	Mordanting technique	Wash fastness			Rubbing fastness		Light fastness
		Fading	Staining		Dry	Wet	
			Cotton	Wool			
$CuSO_4$	Pre	4	4/5	4/5	4/5	3/4	No change
	Meta	3/4	4/5	4	3/4	3	No change
	Post	4	4/5	4	3	2/3	No change
$FeSO_4$	Pre	3/4	4/5	4/5	4/5	4	Darker
	Meta	3/4	4	4	2/3	1/2	Darker
	Post	3/4	4	3/4	2/3	2	Shade change

as well as natural mordants have very good potential in dyeing and finishing of textiles in an ecofriendly way.

4 Conclusion

All the studied four plant extracts such as banyan bark, peepal bark, papaya leaf and Kalanchoe-pinnata have a very good amount of anti-oxidant contents which make them effective colouring and finishing agents for textiles. Finding of the study shows that all the plant extracts have good affinity towards wool. These plants extracts in conjunction with different natural and chemical mordants give beautiful and wide colour spectrum to wool fabric. It is pertinent to mention that natural mordants showed comparable results of dying and colour fastness to chemical mordants. Hence, natural mordants provide an ecofriendly alternative to toxic heavy metal-based chemical mordants. Besides these, dyed wool fabrics with these four natural extracts possess very high bacterial reduction % leading their application in medical and functional textiles.

In summary, all the four natural extracts in conjunction with natural mordants have good potential in sustainable dyeing of wool fabric with additional antibacterial properties.

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