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Effect of Mordant on UV Protection and Antimicrobial Activity of Cotton, Wool, Silk and Nylon Fabrics Dyed with Some Natural Dyes

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Abstract

In this study, eco-friendly natural coloring matter such as pomegranate, curcumin, cutch, red onion peel and a mixture of red onion peel/curcumin (40 g/L, 50%) are used. They are extracted in water at 80°C (red onion at boiling). Cotton, wool, silk and nylon fabrics are dyed using conventional method at pH 4 (except cotton at pH 8), liquor ratio 1:40 and 25 g/L dye concentration for a specific time in presence or absence of FeSO4 using simultaneous mordanting method. Colour strength (K/S) and colorimetric data (L*, a* and b*) are measured at specific λ_{max}. Also, fastness properties (light, washing, rubbing) are determined. Also, ultraviolet protection and antibacterial activity of fabrics against micro-organisms strains of *Staphylococcus aureus, Klebsiella Pneumoniae* and *Candida albicans* are measured. Results of the dyed fabrics are highly UV protective and have effective antibacterial activity. All the above dyed fabrics are suggested to use in the medical cloths.

Keywords: Pomegranate; Curcumin; Cutch; Mordants; UV protection; Antimicrobial activity

Introduction

Nowadays, there is a great interest in the application of natural dyes in textile coloration all over the world. This is due to the imposed environmental standards in several countries for the toxic and allergic reactions of synthetic dyes. Natural dyes are biodegradable, non-harmful, eco-friendly in nature, producing highly, attractive and smooth shades. Fabrics dyed with natural dyes usually have weak fastness properties and can be improved by applying metal salts as mordants [1]. The metal ions form a complex with the dye molecule; which is insoluble in water and give a higher color fastness [2]. It is not clear if mordants enhance the antibacterial activity of fabrics or it may decrease it [3]. Furthermore, bioactivity of fabrics dyed with natural dyes is very important [4,5]. There are about 6% is in the UV-B region and 94% in the UV-A region of the total solar UV radiation reaching the earth's surface. UV-A causes little noticeable reaction on the skin but it reduces the immunological response of skin cells. UV-B is the most responsible for the growth of skin cancers [6-13]. In addition to the importance of avoiding exposure of human-skin to solar UV radiation, the dyed clothes are more UV protected than undyed ones [14-17].

The following are some natural dyes which are studied in this article and their chemical structure:

Pomegranate

Ancient Egyptians have used pomegranate for treatment of tapeworm and other infections. Compared to the pulp, the inedible pomegranate peel contains as much as three times the total amount of polyphenols, including condensed tannins, catechins, gallocatechins and prodelphinidins. Due to the higher phenolic content of the peel extracts yields, they are used in dietary supplements and food preservatives [14,15,18,19]. Also, pomegranate is used for antibacterial finishing of cotton fabric (Table 1) [20-26].

Curcumin

It has been used since ancient times to dye textiles with yellow, orange and brown colours [18]. The antimicrobial activity of wool, cotton fabric treated with curcumin was reported (Table 2) [27-30].

Cutch

It is composed of catechol and catechin. It is a vegetable dye used for tanning and dyeing of wool, silk and cotton to give a yellow brown colour. It has a gray brown color with iron salt and olive brown with copper salt. Fabrics dyed with cutch have excellent light and washing fastness properties [31,32].

Cutch is a brown natural dye obtained from the heart wood of Acacia cutch, found in most of the Indian sub-himalayas [33]. The content of catechin in cutch varies from 4 to 7% [34]. The extracted material from cutch is used for textile dyeing widely. Pharmacological researches have verified that cutch is utilized in traditional medicines, clarify anti-inflammatory and anticancer activities. The extract is prepared by steeping the wood in boiling water until a syrupy liquid is formed, then evaporating, drying and ground into powder. Cutch is usually used in India, Indonesia and Peru. Antimicrobial activity of non-mordanted and mordanted dyed woolen yarns using cutch is investigated against some bacterial species and shows that cutch is a promising antimicrobial agent for bioactive textile fabrics [35,36].

To extend the interest of using natural dyes as a good alternative not only to synthetic dyes but also to synthetic functional finishes on different fabric types, which give natural dyes a merit of achieving simultaneous dyeing and finishing. In the present research, three natural dyes are chosen of polyphenolic composition, such as dry pomegranate peel which is a waste of the fruit industry, curcumin, cutch and a mixture of red onion peel/curcumin extracts (50% wt) are used to dye cotton, wool, silk and nylon fabrics with/without $FeSO_4$ as

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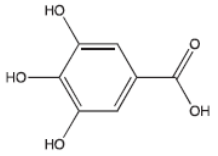
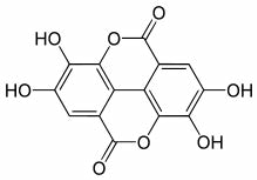
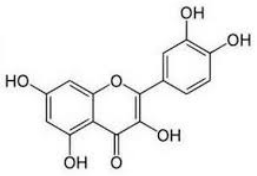
Plant name	Name	Chemical structure
Important phenolic compounds of pomegranate	a: Gallic Acid	
	b: ellagic acid	
Red Onion	Alium cepa peel	

Table 1: Chemical structure of the important phenolic compounds of pomegranate and Red Onion peel.

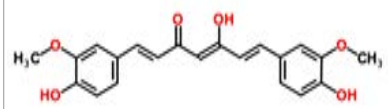
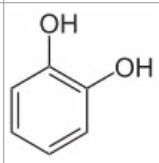
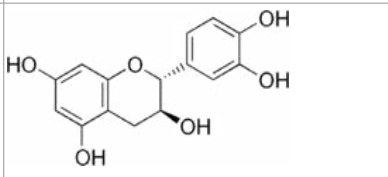
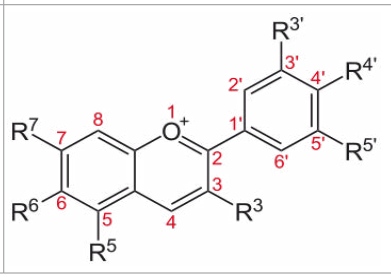
Plant name	Type	Chemical structure
a: Curcumin	($C_{21}H_{20}O_6$)	
b: Cutch	I: Catechol [$C_6H_4(OH)_2$]	
	II: Catechin anthocyanin ($C_{15}H_{14}O_6$)	
	III: Epi catechin	

Table 2: Chemical structure of cutch and curcumin.

a mordant. Colour strength (K/S) and colour data are measured. Also, light, washing, rubbing fastness properties are determined. The UPF protection factor of the dyed fabrics with pomegranate, curcumin, cutch and the mixture of red onion peel/curcumin (50%) were measured. The antimicrobial activity was measured by assessed the percentage reduction against *Staphylococcus aureus*, *Klebsiella pneumoniae* and *Candida albicans* using optical density method at 660 nm (Table 3).

Materials and Methods

Materials

Chemical reagents: Chemical reagents used for adjusting the pH were glacial acetic acid and anhydrous sodium carbonates. Ferrous sulphate used as a mordant. In addition to a nonionic detergent (Triton X-100) and sodium sulphate were used in soaping and washing.

Fabrics: Different fabrics were used such as cotton (weight 133.78 g/m^2, thickness 0.37 mm), wool (308.8 g/m^2, 0.55 mm), silk (58.08 g/m^2, 0.18 mm) and nylon fabric (89.14 g/m^2, 0.31 mm). All the fabrics were produced by The Misr Spinning and Weaving Company, El-Mahalla El-Kubra, except silk which was imported from abroad.

Methods

Extraction method: Pomegranate, curcumin, cutch and red onion peel were crushed and extracted by heating at 80°C or at boiling in case of red onion for one hour at a concentration of (25 or 40 g/L), cooling to room temperature, then they were filtered using nylon fabric [37].

Scouring of fabrics: Scouring was done for every fabric as follows:

- Silk fabric: 2 g/L nonionic detergent (Triton X-100), heating at 60°C for 1 hour using liquor ratio 1:50 with stirring.
- Wool and nylon fabrics: 2 g/l nonionic detergent and 5 g/l sodium sulfate, heating at 45°C for 30 min. using liquor ratio 1:50 with stirring. Then silk and wool fabrics were rinsed and washed with warm water.

Cotton fabric: 2 g/L Na_2CO_3, 5 g/L nonionic detergent using L:R 1:50 and boiling for one hour, then rinsing and air drying [38].

Mordanting method: In this study the simultaneous mordanting method was used during dyeing, at liquor ratio 1:40 [2]. Ferrous sulphate ($FeSO_4.7H_2O$) (1.5 g/L) was used as a mordant for proteinic and cotton fabrics.

Dyeing method: For cotton, simultaneous mordanting method was done with dye extract (40 g/L) and $FeSO_4$ (1.5 g/L). Dyeing was carried out at 100°C in an infrared dyeing machine (Roaches Co., England). After extraction of the natural dye, a known concentration dyeing bath (25/40 g/L) was prepared at pH 8 for cotton and pH 4 for all other fabrics using liquor ratio1:40 at 100°C for cotton fabric and 80°C for other fabrics. The dyeing process was started at 40°C then raised gradually to 80/100°C and continued for one hour. Finally, fabrics were soaped using 2 g/L non-ionic detergent (Triton X-100) at 50°C for 30 min., then rinsed with warm water and air dried.

Plant	Botanic name	Components of colors	Family	$\lambda_{max,nm}$
1: Pomegranate	*Pumica granatum* L	Red colour gallotanin	Punicaceae	380
2: Rhizone of tumeria	*Curcuma longa*	Curcuminoids (yellow)	Zingiberacecas	435
3: Acaci catechu or dark catechu	Catechu	Tannins and dyes (Brown)	Catechol and catechin	385

Table 3: Characteristics of natural dyes (pomegranate, curcumin and cutch).

Fastness testing

Washing fastness: The colour fastness to washing was determined according to ISO 105-C01:1989 (E) test method [39]. The washing fastness test was conducted in a launderometer (ATLAS–Germany) using 5 g/L nonionic detergent at 50°C for 45 min. using liquor ratio 1:50. The composite specimen was removed, rinsed with running tap water, squeezed, then opened and dried in air. It included the test specimen and the two adjacent fabrics in contact of the main sample. Gray scale was used to assess the colour change of the dyed sample and the staining of the two adjacent undyed fabrics (cotton and wool).

Light fastness: This test was evaluated according to ISO 105-B02: 1988 test method using a xenon lamp [40]. Samples were exposed to a continuous light for 35 hours in order to determine the degree of colour resistance to light photo-degradation.

Rubbing fastness: Rubbing fastness was determined according to test method ISO 105-X12: 1987 using a crock-meter under conditions for determination of dry and wet fastness [41].

Colorimetric measurements

Color strength (K/S): The color strength (K/S) in visible region of the spectrum (400-700) nm was calculated based on Kubelkae – Munk equation:

$$K/S = \frac{(1-R)}{2R} - \frac{(1-R_0)}{2R_0}$$

R: Decimal fraction of the reflectance of the dyed fabric.

R_0: Decimal fraction of the reflectance of the undyed fabric.

K: Absorption coefficient.

S: Scattering coefficient.

The colorimetric properties of dyed fabrics were obtained with Hunter Lab DP-9000 Color-Spectrophotometer

Color data CIE LAB space: *Colour-difference formula CIE (L*, a*, b*):* The total difference CIE (L*, a*, b*) was measured using the Hunter-Lab spectrophotometer (model: Hunter Lab DP-9000).

CIE (L*, a*, b*) between two colours each given in terms of L*, a*, b* is calculated from:

L* value: indicates lightness, (+) if sample is lighter than standard, (-) if darker.

a* and b* values: indicate the relative positions in CIE Lab space of the sample and the standard, from which some indication of the nature of the difference can be seen.

UPF measurement: The ability of the dyed fabric to block UV light is given by the ultraviolet protection factor (UPF) value [16]. The measurement of UPF values was performed in UV/Visible Spectrophotometer 3101 PC with a software version, using an integrating sphere loaded with the fabric from 290 nm at an interval of 10 nm to 400 nm.

The measurements of the UV-penetration characteristics of the fabrics were carried out in the range of 290-400 nm by using the UV penetration and protection measurements system. Before measurements the fabrics were conditioned at NTP for 24 hours. During the measurements, four scans were obtained by rotating the sample 90° each time and the spectral data were recorded as the average of these four scans.

Equation (1) is used by the software to calculate the UPF value for a flat, tensionless dry fabric.

$$UPF = \frac{\sum_{290}^{400} E(\lambda)\times\varepsilon(\lambda)\times\Delta(\lambda)}{\sum_{290}^{400} E(\lambda)\times T(\lambda)\times\varepsilon(\lambda)\times\Delta(\lambda)}$$

Equation for calculating the UPF value (1).

Where E(λ) is the solar irradiance (Wm^{-2} nm^{-1}) measured; ε(λ) is the arythematic action spectrum; Δ(λ) is the wavelength interval of the measurements ; and $T(\lambda)$ is the spectral transmittance at wavelength λ^{290}. The percentage blocking of UVA (315-400 nm) and UVB (315-290 nm) was calculated from the transmittance data.

Antimicrobial measurement

The antibacterial and antifungal studies of dyed fabrics were accomplished using standard methods (AATCC TM 100 and AATCC TM 30) [42,43]. The dyed fabric was introduced into 20 ml nutrient broth and inoculated with the respective bacterial strains followed by overnight (24 h) incubation at 37°C. growth of the bacterial strains were determined by a spectrophotometer at optical density 660 nm (OD_{660}) in presence of the dyed fabric against a blank of un-inoculated sterile medium. Similarly, the fungal strains inoculated into potato dextrose broth and incubated for 48 h at 28°C in a shaker incubator followed by measurement at optical density 450 nm (OD_{450}) against a blank of un-inoculated sterile medium. Before recording the optical density of the respective media after incubation, the culture tubes were shaken thoroughly in order to bring micro-organisms into suspension. Optical density is directly proportional to the number of micro-organisms (bacteria or fungi) in the medium. The percentage of reduction of the micro-organisms was expressed as follows:

R=(B – A)/Bx100

Where; R: Percentage of reduction of microbial population; B: Absorbance of the media inoculated with microbes and A: Absorbance of the media inoculated with microbes and dyed fabric.

Results and Discussions

Effect of $FeSO_4$ on fabrics dyed with pomegranate extract

Table 4 and Figure 1 show the colour data of pomegranate extract, for dyeing cotton, wool silk and nylon. For cotton dyed with pomegranate, the color strength increases to 2.9 after using $FeSO_4$ compared to the control (1.58). Also $FeSO_4$ increases color strength of wool from 28.05 to 29.63 and silk to 17.00 compared to the control 10.08 and decreases in case of nylon to 15.76 compared to 20.18 for the control. Thus cotton increases 83% in color strength, wool 5.6%, silk 68% but nylon decreases 21%. These results indicate that the color

Type of fabric	Type of mordant	λmax	K/S	L*	a*	b*
Control Cotton	-	380	1.58	76.64	2.14	20.30
Cotton	$FeSO_4$	375	2.9	55.75	1.70	5.11
Control Wool	-	380	28.05	55.53	6.34	37.18
Wool	$FeSO_4$	375	29.63	24.05	5.68	6.44
Control Silk	_	380	10.08	66.68	4.58	28.93
Silk	$FeSO_4$	395	17.0	29.01	3.78	4.61
Control Nylon	-	380	20.18	68.20	2.46	34.18
Nylon	$FeSO_4$	370	15.76	48.98	3.5	11.78

Table 4: Effect of $FeSO_4$ on K/S, colour data and UPF of cotton, wool, silk and nylon fabrics dyed with pomegranate extract using simultaneous dyeing and mordanting method.

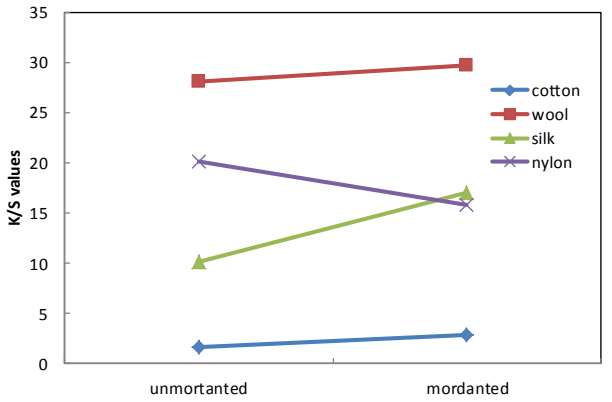


Figure 1: Effect of $FeSO_4$ on K/S values of fabrics dyed with pomegranate.

Type of fabric	Type of mordant	λmax	K/S	L*	a*	b*
Control Cotton	-	435	3.63	78.21	6.13	59.77
Cotton	$FeSO_4$	435	1.07	74.75	4.15	25.98
Control Wool	-	425	25.53	56.17	15.87	63.49
Wool	$FeSO_4$	410	19.66	37.23	9.98	28.85
Control Silk	-	430	16.96	73.07	7.48	81.16
Silk	$FeSO_4$	425	8.48	57.89	9.79	44.26
Control Nylon	-	425	28.11	64.67	17.74	80.99
Nylon	$FeSO_4$	420	26.65	39.25	18.70	41.70

Table 5: Effect of $FeSO_4$ on K/S, colour data and UPF of cotton, wool, silk and nylon fabrics dyed with curcumin extract using simultaneous dyeing and mordanting method.

of mordanted fabric was significantly changed, as a function of metal complex formation of the dye with $FeSO_4$.

Application of mordants showed significant variations in colorimetric data, depending upon the extent of interaction developed between fabrics, metal, and dye components. All mordanted dyed fabrics displayed higher color strength values as compared to non-mordanted ones. This may be due to the fact that mordanting process increases interaction between dye and fabrics through coordination complex formation, which eventually results in higher dye uptake.

Table 4 reveals the colorimetric data of the dyed fabrics, as a* and b* values decrease, that means a little shifted towards green co-ordinate in red yellow zone of CIE Lab color space, except nylon fabric (the colour is shifted towards red co-ordinate due to increase of a* values), also the mordanted fabrics become darker due to the decrease in L* value.

Effect of $FeSO_4$ on fabrics dyed with curcumin extract

It is clear from Table 5 and Figure 2 that fabrics dyed with curcumin only (without any mordant) gives the best results of K/S for all fabrics; cotton 3.63, silk 16.96, wool 25.53, and nylon 28.11 with bright colours respectively. These values are decreased when using $FeSO_4$, indicating that there is no need for using $FeSO_4$ in case of dyeing with curcumin. The decrease of color strength by mordanting is as follows: 70% cotton, 50% silk, 23% wool, and 5% nylon.

In general, the dyeing affinity of fibres depends on the content of functional polar groups in fibres. It is well known that the number of functional group in wool is larger than that of silk, and polarity of protein fibres is higher than that of cellulose fibre. The K/S value was in the order of cotton<silk<wool<nylon fabrics for all natural colorants. It was found that this order of dyeing affinity matched the order of polarity/functional group content of fabrics very well.

Table 5 shows that mordanting with $FeSO_4$ decreased L* values indicating a darker shade, also, a* and b* values decrease, that means a little shifted towards green co-ordinate in red yellow zone of CIE Lab color space, except silk and nylon which shifted towards red co-ordinate.

The wavelength for the control and the mordanted fabrics are changed as follows: cotton changed from 435 to 430 nm, wool changed from 425 to 410 nm, silk changed from 430 to 425 nm and nylon changed from 425 to 420 nm. These little change of wavelength means that there is a small shift in color for the dyed mordanted fabrics with curcumin extract using $FeSO_4$ comparing to the blank.

Effect of $FeSO_4$ on fabrics dyed with cutch extract

In case of cutch (Table 6 and Figure 3) using $FeSO_4$ as a mordant, K/S increases for all fabrics. Thus color strength increases from 1.23 to 2.84 for cotton, from 6.64 to 14.74 for silk, from 15.48 to 15.58 for nylon and from 12.81 to 18.40 for wool. The wave length of the dyed controls and mordanted fabrics are changed from 385 to 355 nm (in case of wool), and from 386 to 355 nm (in case of silk). This is due to the oxidation of ferrous to ferric form by reacting with atmospheric oxygen and 1:2 metal-dye complex forming ability of iron salts within dyed substrate produced dark shades. The ferrous and ferric forms co-exist on the fiber and their spectra overlap, which shifts λmax and results in color change to a darker shade.

Also, Table 6 clarifies the mordanting with ferrous sulphate leads to decrease in L* values which means a darker shade and a decrease of

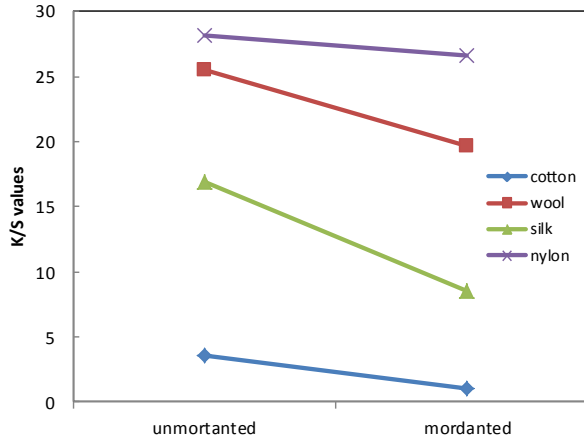


Figure 2: Effect of $FeSO_4$ on K/S values of fabrics dyed with curcumin.

Type of fabric	Type of mordant	λmax	K/S	L*	a*	b*
Control Cotton	_	385	1.23	68.36	7.47	10.81
Cotton	$FeSO_4$	385	2.84	51.08	4.84	7.85
control Wool	_	385	12.81	42.98	20.29	32.68
Wool	$FeSO_4$	355	18.40	29.21	6.53	10.86
Control Silk	--	385	6.64	57.15	16.74	28.64
Silk	$FeSO_4$	355	14.74	29.72	7.15	8.42
Control nylon	---	365	15.48	52.08	15.92	34.33
nylon	$FeSO_4$	365	15.58	37.3	10.25	14.76

Table 6: Effect of $FeSO_4$ on K/S, colour data and UPF of cotton, wool, silk and nylon fabrics dyed with cutch extract using simultaneous dyeing and mordanting method.

a* and b* values, that means a little shifted towards green co-ordinate in red yellow zone of CIE Lab color space.

Effect of $FeSO_4$ on fabrics dyed with mixture of red onion peel/curcumin extract

Table 7 and Figure 4 demonstrate the effect of $FeSO_4$ on a mixture of red onion peel/curcumin extract (50%, 40 g/l) for dyeing different kinds of fabrics. It is clear that using mordant increases K/S from 2.67 to 3.46 in case of cotton fabrics. Contrary, the presence of mordant decreases K/S values for wool fabrics. But using mordant increases the values of K/S from 15.29 to 17.94 for silk fabrics. In case of nylon fabrics, K/S decreases from 28.22 to 27.22. So, mordanting process is effective for cotton and silk and not effective in case of wool and nylon.

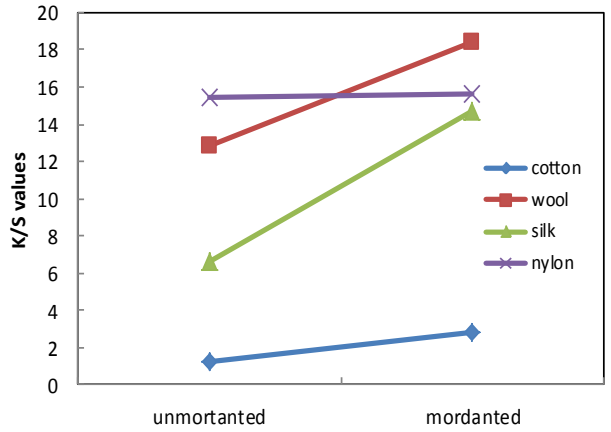


Figure 3: Effect of $FeSO_4$ on K/S values of fabrics dyed with cutch.

Type of fabric	Type of mordant	λ_{max}	K/S	L*	a*	b*
Control Cotton	-	395	2.67	67.40	5.35	33.96
Cotton	$FeSO_4$	430	3.46	52.66	2.46	17.93
Control Wool	-	365	33.75	37.17	21.36	33
Wool	$FeSO_4$	395	30.10	19.47	2.68	8.33
Control Silk	-	380	15.29	53.72	13.27	44.74
Silk	$FeSO_4$	400	17.94	27.99	3.15	13.81
Control Nylon	-	395	28.55	48.68	16.70	51.57
Nylon	$FeSO_4$	365	27.22	22.92	5.67	12.64

Table 7: Effect of $FeSO_4$ on K/S, colour data and UPF of cotton, wool, silk and nylon fabrics dyed with mixture of red onion peel/curcumin extract using simultaneous dyeing and mordanting method.

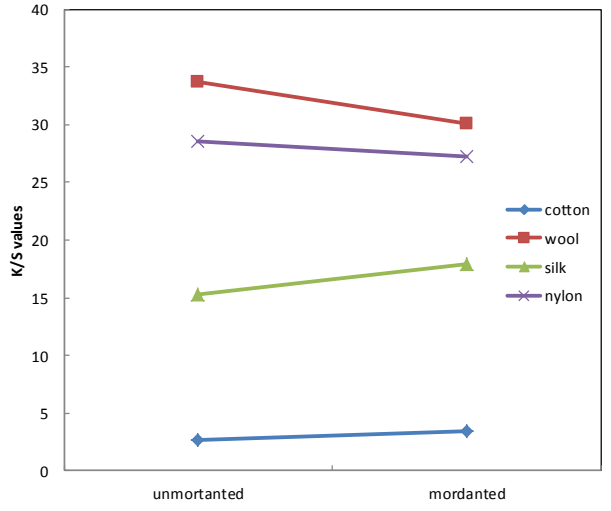


Figure 4: Effect of $FeSO_4$ on K/S values of fabrics dyed with mixture of red onion peel/curcumin extract.

Also, mordanting with ferrous sulphate (Table 7), leads to a decrease in L* values (darker shade), a decrease of a* and b* values, that means a little shifted towards green co-ordinate in red yellow zone of CIE Lab color space.

Fastness properties

Fastness properties of dyed fabrics with pomegranate: Table 8a indicates that dyed fabrics with pomegranate extract only (control) give better results than the mordanted fabrics in case of rubbing fastness, except cotton, which has the same results. The washing fastness of the non-mordanted fabrics (control) and the dyed mordanted fabrics has no significant change and they have shown good to excellent results, except dyed nylon fabric with pomegranate extract (control) [6]. The light fastness data of dyed mordanted fabrics with pomegranate extract give very good results which is better than the dyed fabrics with pomegranate only (control).

Fastness properties of dyed fabrics with curcumin: Table 8b shows that the light fastness results of the dyed mordanted fabrics with curcumin are better than the dyed fabrics with curcumin only (control). The rubbing fastness is poor to good except for dyed mordanted cotton fabric and dyed nylon fabric with curcumin only (control) which have better results. The washing fastness of the dyed mordanted fabrics with curcumin give good to excellent results compared to the dyed fabrics with curcumin only (control).

Fastness properties of dyed fabrics with cutch: Table 9a explains that rubbing fastness results of dyed fabrics with cutch extract only (control) are slightly better than the dyed mordanted fabrics with cutch extract. The light fastness results are good to very good especially for the dyed mordanted samples. The washing fastness results of all mordanted and non-mordanted dyed fabrics with cutch show very good to excellent results.

Plant	Fabric	Mordant $FeSO_4$	Rubbing fastness		Washing fastness			Light fastness
			Dry	Wet	Alt	SC	SW	
a. pomegranate	Wool	Control	4	3	4-5	4-5	3-4	2-3
		$FeSO_4$	3	1	4	4-5	4-5	5-6
	Silk	Control	4	4	4-5	4-5	4	3
		$FeSO_4$	3	2-3	4-5	4-5	4	5-6
	Cotton	Control	3	3	4-5	4-5	4-5	5-6
		$FeSO_4$	3	3	4	4-5	4-5	5-6
	Nylon	Control	4-5	4	3-4	2-3	3-4	2-3
		$FeSO_4$	2	2	4-5	4-5	5	5
b. curcumin	Wool	Control	3	2	3	2	3	4
		$FeSO_4$	3	1	4	4-5	4-5	5-6
	Silk	Control	3	3	3	2-3	3-4	3
		$FeSO_4$	3-4	3-4	4-5	3-4	4-5	3-4
	Cotton	Control	4	2-3	2	3	4-5	3
		$FeSO_4$	4-5	4	4	3-4	4-5	3-4
	Nylon	Control	4-5	4	3-4	2-3	3-4	2-3
		$FeSO_4$	4	3-4	4-5	3-4	4-5	6

SC: staining on cotton
SW: staining on wool
Alt. Alteration.

Table 8: Color fastness of simultaneous dyed mordanted cotton, wool, silk and nylon fabrics with $FeSO_4$ using pomegranate or curcumin extract.

Fastness properties of dyed fabrics with red onion peel/curcumin extract (50% wt.): Table 9b illustrates the mixture of red onion peel and curcumin extract (50% wt.) has better light fastness than dyed fabrics with curcumin extract alone. Addition of $FeSO_4$ increases the light fastness of all dyed fabrics with mixture of red onion peel and curcumin extract. Mordanted and non-mordanted dyed fabrics with curcumin have shown better washing fastness results than with the mixture of red onion peel and curcumin extract.

UPF properties of natural colorants

UV blocking property of mordanted and non-mordanted dyed fabrics is investigated by measuring the diffuse transmittance in the UV radiation range through different kinds of fabrics (cotton, wool, silk and nylon) which are characterized by low transmittance values that ranged between 0.02 and 9.63% at 296 nm and between 0.04 and 8.60% at 396 nm and the results are shown in Tables 4-7.

These results indicate that, for cotton, wool, silk and nylon dyed with pomegranate without or with the addition of ferrous sulphate (Table 10), most fabrics have acquired excellent UPF values, except dyed nylon fabric which has bad UPF values. Finally, the addition of ferrous sulphate highly increases the UPF values protection of the fabrics as a result of high iron content, with exception of cotton, where UPF decreases from 80.2 (control) to 52 in presence of $FeSO_4$.

In case of cotton, wool, silk and nylon fabrics dyed with curcumin with/without ferrous sulphate (Table 10), wool fabric acquires excellent transmission blocking, and dyed silk fabrics give very good UPF results but the dyed nylon and cotton fabrics have bad transmission blocking. Dyeing using curcumin in the presence of ferrous sulphate highly increased the UPF protection of the fabrics compared to the unmordanted fabrics except dyed nylon and cotton fabrics.

For cotton, wool, silk and nylon fabrics dyed with cutch (Table 10), most fabrics have excellent UPF protection values (50+) except dyed nylon fabric which acquires bad UPF results. Addition of $FeSO_4$ greatly increases the UPF except dyed nylon fabrics [6].

From Table 10, it is noticed that cotton, wool, silk and nylon fabrics dyed with a mixture of red onion peel/curcumin extract (50%) have excellent UPF protection values (50+), except dyed nylon fabric. Addition of $FeSO_4$ increases UPF from 38.80 to 52.42 for cotton fabric and from 144 to 377 for silk fabric, but for wool fabric UPF is decreased from 2738 for the non-mordanted fabric (control) to 2471 for the dyed mordanted fabric using $FeSO_4$, but dyed nylon fabric acquires bad UPF results.

From the previous results it is concluded that for all natural dyes studied in the present work, the mordanted dyed fabrics using $FeSO_4$ give higher UV protection than the non-mordanted dyed fabrics (control) with few exceptions. Another observation is that nylon fabric with all the natural dyes used have high K/S but gives lower UPF than other fabrics dyed with the same kind of natural dyes, this may be attributed to the fact that the UV blocking properties of the textiles are affected by different factors such as structure and physiochemical nature of the fabric [44], for example in a previous study, it is concluded that the thread count has a negative correlation with their UPF value [45].

The distribution of transmittance spectra in Table 10 in the UV-B band (290-315 nm) and UV-A band (315-400 nm), moving from the lowest to the highest (wool<silk<cotton<nylon fabrics) as the range of UV-A and UV-B Transmittance values for wool is (0.02-0.11), for silk is (0.25-2.48), for cotton is (1.13-6.55) and for nylon is (5.54-9.63), seemed to be inversely correlated to fabric cover factor and UPF and independent of fabric type [46-51].

Antimicrobial activity of natural colorants

Some natural colorants possess significant antimicrobial activity especially those containing natural tannins, curcuminoids, quinines etc. and which persist after application on textile fabric [21]. Antimicrobial

Plant	Fabric	Mordant $FeSO_4$	Rubbing fastness		Washing fastness			Light fastness
			Dry	Wet	Alt	SC	SW	
a. catechu	Wool	Control	3-4	2	4-5	4	4	4
		$FeSO_4$	1-2	1-2	4-5	4-5	4	5-6
	Silk	Control	3	3-4	4	4	3-4	5-6
		$FeSO_4$	1-2	1-2	4-5	4-5	4-5	5-6
	Cotton	Control	3	2-3	4	4	4-5	5
		$FeSO_4$	1-2	1-2	4-5	4-5	4-5	6
	Nylon	Control	3-4	3	4-5	3-4	3-4	4-5
		$FeSO_4$	2-3	1	4-5	3-4	3-4	6
b. mixture of onion/curcumin (50%).	Wool	Control	3-4	2-3	4	2	2	5
		$FeSO_4$	2	2	4-5	3-4	4-5	5-6
	Silk	Control	2-3	2-3	3	2-3	2-3	3-4
		$FeSO_4$	2-3	2	4-5	3	3-4	5-6
	Cotton	Control	4	3-4	3	2-3	3	3-4
		$FeSO_4$	3	2-3	3-4	3-4	4-5	6
	Nylon	Control	4	3-4	4-5	2-3	2-3	3
		$FeSO_4$	3	2-3	4	3	3-4	6

SC staining on cotton
SW staining on wool
Alt. Alteration.

Table 9: Color fastness of simultaneous dyed mordanted cotton, wool, silk and nylon fabrics with $FeSO_4$ using cutch or mixture of red onion peel/curcumin extract.

Type of fabric	Pomegranate			Curcumin			Cutch			Red onion peel/curcumin		
	UPF range	Transmittance (%)		UPF range	Transmittance (%)		UPF range	Transmittance (%)		UPF range	Transmittance (%)	
		UV-A 315-400 nm	UV-A 315-400 nm		UV-A 315-400 nm	UV-B 290-315 nm		UV-A 315-400 nm	UV-B 290-315 nm		UV-A 315-400 nm	UV-B 290-315 nm
Cotton	80.2 (50+)	1.7	1.13	17.37	5.39	5.75	43.24	2.65	43.24	38.80	2.80	2.53
Cotton+$FeSO_4$	52 (50+)	2.36	1.8	17.70	6.55	5.51	69.89 (50+)	1.73	69.89 (50+)	52.42 (50+)	2.14	1.85
Wool	1808 (50+)	0.06	0.06	1032 (50+)	0.11	0.09	1594 (50+)	0.08	1593.7 (50+)	2738 (50+)	0.04	0.04
Wool+$FeSO_4$	1884 (50+)	0.06	0.05	3918 (50+)	0.04	0.02	4065 (5+)	0.04	4065 (50+)	2471 (50+)	0.04	0.04
Silk	189 (50+)	0.88	0.47	40.28	2.10	2.48	89.39 (50+)	1.48	89.39 (50+)	144 (50+)	0.69	0.67
Silk+$FeSO_4$	228 (50+)	0.52	0.43	62.60 (50+)	1.69	1.39	338 (50+)	0.43	337.57 (50+)	377 (50+)	0.30	0.25
nylon	21.16	5.54	4.61	10.65	8.60	9.63	17.01	6.37	17.01	26.37	3.74	3.80
Nylon+$FeSO_4$	19.88	5.83	4.89	14.90	6.22	6.73	17.97	6.04	17.97	19.38	5.21	5.14

Table 10: Effect of $FeSO_4$ on UPF of cotton, wool, silk and nylon fabrics dyed with pomegranate, curcumin, cutch and red onion peel/curcumin extracts using simultaneous dyeing and mordanting method.

activity of colorant is dependent on chemical structure and functional groups present in the colorant.

From Figures 5-8, it is clear that curcumin alone possess the best antimicrobial activity against bacteria and fungi as a result of methoxy and hydroxyl groups existence, which is believed to improve the antimicrobial activity of curcumin extract [28]. The results of antimicrobial activity of curcumin with different fabrics are as follow; firstly, dyed cotton with curcumin extract reveals 87% reduction of *Staphylococcus aureus*. Secondly, dyed wool with curcumin extract attains 100% reduction of *Candida albicans*. Thirdly, dyed silk with curcumin extract attains 85% reduction of *Klebsiella pneumonia* and 100% reduction of *Candida albicans*. Finally, dyed nylon with curcumin extract reveals 85% reduction of *Staphylococcus aureus* and *69%* reduction of *Klebsiella pneumoniae*. Then come pomegranate extract as a second plant against bacteria and fungi, as it attains; firstly, 69% reduction of *Klebsiella pneumonia* with cotton. Secondly; pomegranate extract has 75.2% reduction of *Klebsiella pneumoniae* with silk fabric. Thirdly; the dyed nylon with pomegranate extract, resulted in 77% reduction of *Klebsiella pneumoniae* and 73% reduction of *Candida albicans* [27]. The percentage reduction of bacteria and fungi is dependent on the type of natural colorant and the fabric used.

Mordanting of different dyed fabrics with some colorants improves the antimicrobial activity, for example; the dyed cotton fabric with pomegranate using $FeSO_4$ attains 100% reduction of *Staphylococcus aureus*. Also, mordanted dyed wool fabric with curcumin extract using $FeSO_4$ attains 100% reduction of *Staphylococcus Aureus* and 73% for *Candida albicans*. In case of dyed wool with mixture of red onion peel/curcumin extract (50% wt.) using $FeSO_4$, the reduction is 100% for *Candida albicans*. Mordanting of dyed silk fabric with cutch using $FeSO_4$ makes the reduction rate of the three microbes used high and this is clear from the reduction results; *Staphylococcus aureus* (99.9%), *Klebsiella pneumonia* (89%) and *Candida albicans* 70.8%. Also dyed silk fabric with mixture of red onion peel/curcumin extract (50% wt.) using $FeSO_4$ has 80% reduction of *Staphylococcus aureus*. Moreover, the dyed nylon with pomegranate extract/$FeSO_4$ attains a reduction percentage of 87% of *Staphylococcus aureus* and 65% of *Klebsiella pneumonia* [52]. In some cases, presence of $FeSO_4$ decreases the antimicrobial activity compared to its absence due to the involvement of some hydroxyl groups in coordinate bond with metal mordant which becomes inactive against bacteria and fungi. For example mordanting of dyed cotton, silk

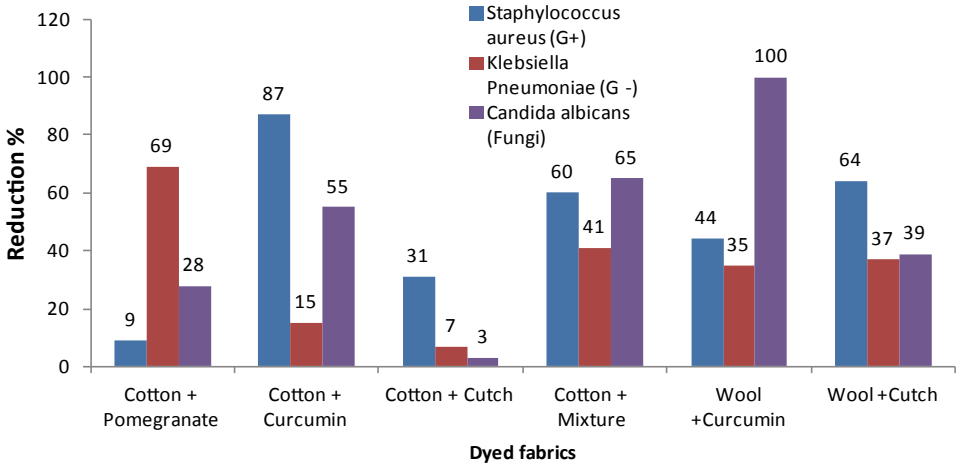


Figure 5: Antimicrobial activity of dyed cotton and wool fabrics with Pomegranate, Curcumin, Cutch and mixture extracts.

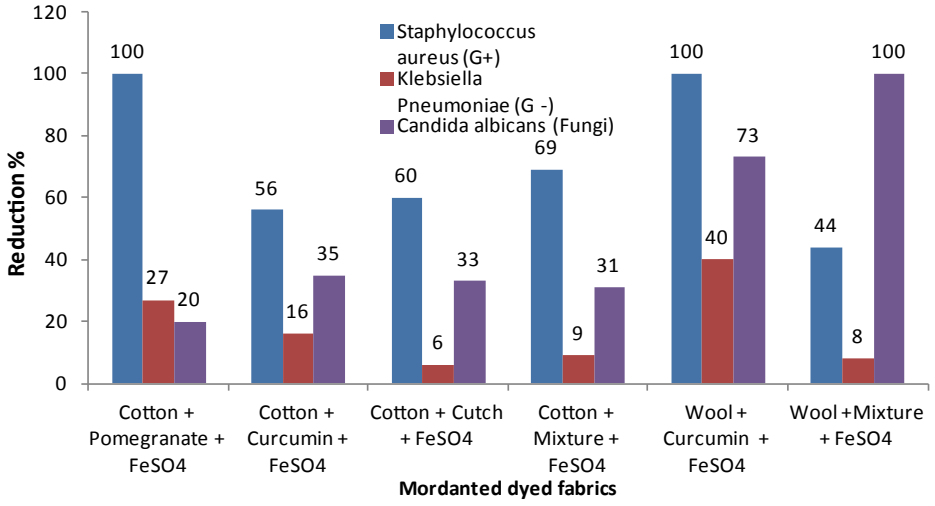


Figure 6: Antimicrobial activity of mordanted dyed cotton and wool fabrics with Pomegranate, Curcumin, Cutch and mixture extracts using $FeSO_4$.

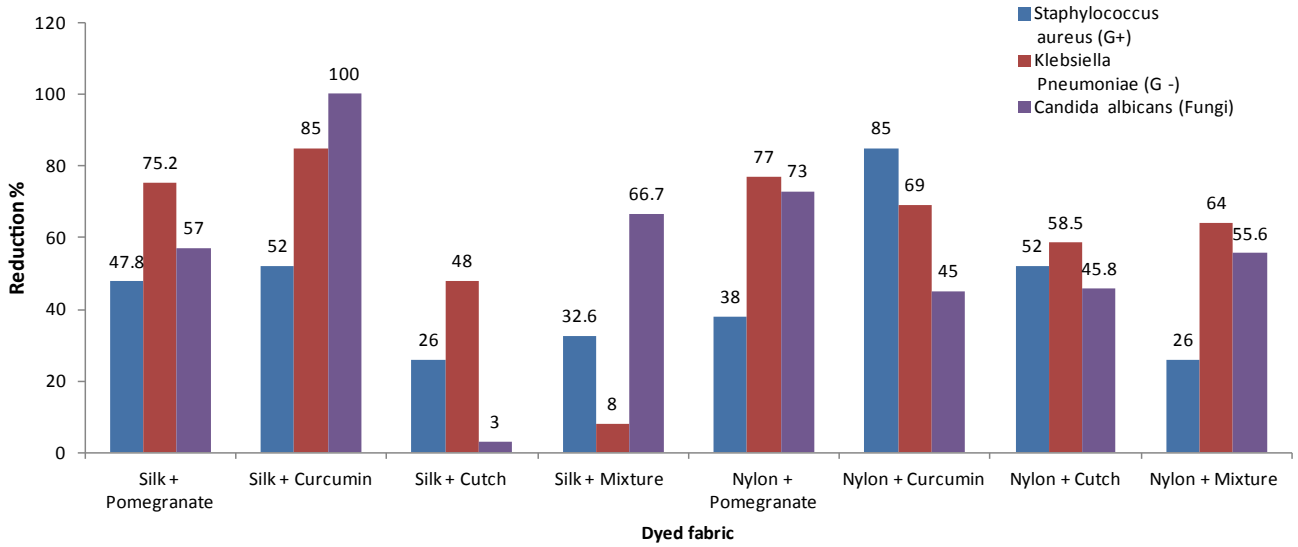


Figure 7: Antimicrobial activity of dyed silk and nylon fabrics with Pomegranate, Curcumin, Cutch and mixture extracts.

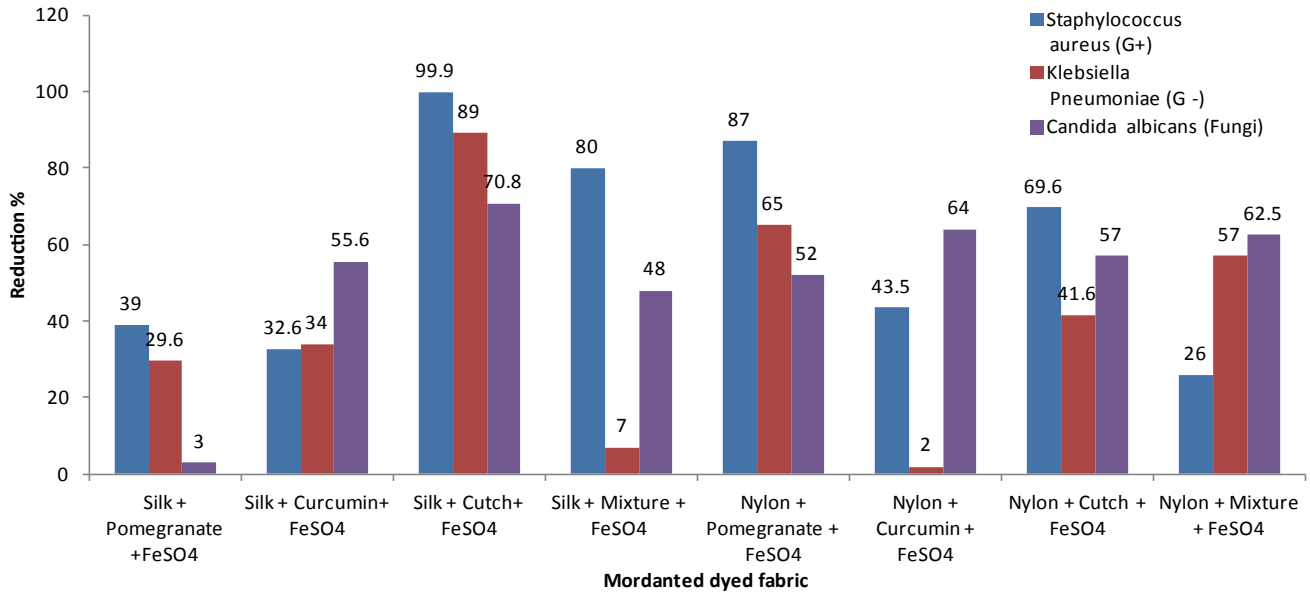


Figure 8: Antimicrobial activity of mordanted dyed silk and nylon fabrics with Pomegranate, Curcumin, Cutch and mixture extracts using $FeSO_4$.

and nylon fabrics with curcumin extracts using $FeSO_4$ and in case of mordanting of dyed silk fabric with pomegranate extract using $FeSO_4$.

Conclusions

Dyeing of cotton, wool, silk and nylon fabrics with some natural dyes such as; pomegranate, curcumin, cutch and a mixture of red onion peel/curcumin extracts without or with ferrous sulfate as mordant reveals an excellent UV protection properties (50+) except nylon fabrics. Mordanting of dyed fabrics with $FeSO_4$ does not affect the color fastness to rubbing, but improves the color fastness to washing and light giving results ranged from good to excellent. The dyed fabrics with curcumin extract possess the best antimicrobial activity against (G+) and (G-) bacteria and fungi. Using ferrous sulphate as a mordant with different dyed fabrics with some colorants improves the antimicrobial activity except nylon fabrics.

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